Ansøgning om Stibofondens IT-rejsestipendie til ph.d.-studerende

Projekt plan for eksternt forskningsophold ved University of Cambridge

Beskrivelse af studieopholdets relevans og udbytte for ph.d.-afhandlingen

Det forventede udbytte er et 4 måneders eksternt forskningsophold på University of Cambridge fra September 2019 til start Januar 2020, som faciliterer et samarbejde på tværs af forskningsgrupper (CogSys på DTU Compute og MLG på Cambridge) og udgivelse af 2 artikler med Assistant Professor, José Miguel Hernandez-Lobato. Idéen der ligger til grund for opholdet er, at bruge deep learning til data drevet modellering af Raman spektre og den bagvedliggende proces givet den molekylære struktur til automatisk design, detektering og screening af medicin i micro-containers. Dette er i tråd med mit PhD projekt i "Active Deep Learning for Nano-Sensor Systems", som omhandler machine-learning assisteret forskning til nano-sensor og udvikling af medicin. Projektet er et led i forskningsmålet for hele grundforskningscenteret, IDUN Center of Excellence (http://www.idun.dtu.dk/research), og forventes, at bringe stor værdi til både forskere i nano-teknologi og Dansk farmaceutisk industri. Dette opnåes ved, at bruge de dybe prædiktive modeller til effektiv automatisk screening og bestemmelse af egenskaber for ny medicin. Dette kan anvendes til en strømlining af designprocessen af både medicin og de micro-containers der skal indeholde det, således at vi kan levere medicinen mere målspecifikt, effektivt og med større sikkerhed for patienten.
Da værts-vejleder og forskningsgruppen i Cambridge har en stærk international profil indenfor de metoder jeg anvender i mit projekt, såsom usikkerhedsestimering, Bayesianske neural netværk, aktiv læring og automatisk design af eksperimenter, vil dette ophold være den perfekte mulighed for, at udvikle min forskning, viden og idéer i machine-learning assisteret eksperimentering i et anerkendt og aktivt forskningsmiljø. Da University of Cambridge kræver et bench fee på 500 GBP/mdr (i alt 17.300kr), bliver denne udgift dækket af mit projekt. Med højere leveomkostningerne i Cambridge og udgifter til udstyr og udgivelser, anmoder jeg derfor om støtte af jer til, at dække merudgifterne på 34.000 kr. forbundet med opholdet. Jeg ansøger hermed om et rejsestipendie på 35.000 kr. Tak for jeres tid.

4 June 2019
MFV

De bedste hilsner,

Maximillian Fornitz Vording
PhD Student
Section for Cognitive Systems

DTU Compute
Department of Applied Mathematics
Computer Science
www.compute.dtu.dk

Building 321, Room 106
Richard Petersens Pl,
2800 Kgs. Lyngby, Denmark

Dir. +45 61603013
Tel.. +45 45 25 30 31 and
maxvo@dtu.dk

Detailed plan for external stay

For my external research stay I have ideas for combining deep generative models (DGM), uncertainty estimation, multi-task learning and active learning (AL) for molecular exploration and detection through Raman spectra as a molecular fingerprint. This is mainly inspired by the work of my host-supervisor, Assistant Professor, José Miguel Hernández-Lobato, on ChemVAE, GVAE, BNN-LV, PBP, the recent work on Deep Learning Spectroscopy by my supervisor, Associate Prof. Mikkel N. Schmidt and my own work w. Prof. Ole Winther developing a Gaussian-mixture-VAE for gene expressions and exploration of cell types in latent space. These ideas lead to Miguel, my supervisors and me agreeing on and planning a 4 months research project in the Machine Learning Group, University of Cambridge, which now needs additional external funding from you.

The project for this 4 months external stay is a part of my PhD project in Active Deep Learning for Nano-Sensor Systems, which is described in detail below, and will therefore be focused on developing deep learning models for Raman spectroscopy, which is the most commonly used technique for detection of molecules. Therefore I will here motivate Raman spectroscopy and explain why a data-driven approach will benefit the research and industry in pharmaceutical engineering.

The first research question is: Can we determine and detect the fingerprint of the building blocks of nature itself in a smarter more data efficient way? The hypothesis is: We can use deep neural networks for learning the underlying process behind how light is scattered by linking the Raman spectra and various representations of molecular structure. Learning how to generate the fingerprint of molecules, will make it possible to detect the molecules, their concentrations and properties as medicine contained in micro-containers by non-invasive methods, e.g. lasers.

Raman scattering stems from driven molecular vibration coming from symmetric and asymmetric stretching of bonds between atoms in molecules, when the incident laser hits the molecule. The intensity is below 0.01% of the direct Raleigh scattered light, so it needs filtering and the signal-to-noise-ratio is low, which also argues for using Surface-Enhanced Raman Spectroscopy (SERS) or Coherent anti-Stokes Raman scattering spectroscopy (CARS). SERS leads to a very complex behaviour and makes it hard to simulate with DFT. The frequency of the Raman scattered light (Raman bands) will depend on the strength of the atomic bonds and atomic masses and can be modelled in the time domain with an ordinary differential equation like Hooke's law and Newton's 2nd law of motion. Through quantum mechanical equations the differential functional theory (DFT) can be used to simulate Raman spectra, but for complicated molecular compounds and environment like SERS, the simulation rarely fits with real world measurements

and will often be re-adjusted manually to fit this. This suggests using a data-driven approach by generating spectra through deep graph neural networks, which are commonly used for linking molecular properties to the molecular structure.
Here is the representations of molecules and what we need for predicting molecular properties and Raman spectra. We need both molecular structure, atomic mass and band strength to determine vibrational modes and differential equations.

A list of these commonly used representations of molecular structure:
- SMILES (Text representation of molecules)
- Coulomb matrix (Energy interaction based on distances between all atoms)
- Bag of bonds
- Histograms
- Radial distribution functions
- Chemical environment
- ACSF

We can find these resources in the following datasets:
- https://www.researchgate.net/post/Free_Database_with_Raman_spectra
- https://www.ccdc.cam.ac.uk/solutions/csd-system/components/csd/
- https://serc.carleton.edu/research_education/crystallography/xldatabases.html
- http://oqmd.org/
- http://quantum-machine.org/datasets/

At the IDUN Center of Excellence, researchers can as well provide huge amounts of data for our project through their ongoing experiments with Raman spectroscopy on micro-container drug-delivery. With computational resources at both University of Cambridge and DTU Compute, we can scale up to big data and thereby the representational strength of our deep learning models tremendously.

The plan for the project during the external stay is:
For this project the goal is for me to be the main author on two publications in high-impact conferences or journals and will be conducted in collaboration with the following researchers:

Host-supervisor: *José Miguel Hernández-Lobato - Assistant Professor (CAM)*
Principal supervisor: *Mikkel N. Schmidt - Associate Professor (DTU)*
Co-supervisor: *Tommy Sonne Alstrøm - Senior Researcher (DTU)*

We will have a weekly 30 min. Meeting with Host-supervisor and additional 30 min. Meeting with supervisors at DTU Compute, so we synchronise ideas and work.
The work will follow the following study plan roughly dependent on results along the way.

Study plan for external stay:

1. **September:**
    1. Test deep generative models, Grammar variational autoencoder (Work by host J. M. Hernández-Lobato) and Graph neural networks for spectra (work by supervisor, M.N. Schmidt), for various representations of molecules, to choose best candidate.
    2. Based on this screening, collect datasets with Raman spectra and chosen molecular structure and additional molecular properties.
2. **October:**
    1. Create a combined model linking the latent representation of molecules with a generative neural network for Raman spectra.
    2. Test different likelihood distributions and peak shape functions (Pseudo-Voigt or Lorentz).
    3. Write paper on results and submit to either journal IEEE Transactions on Pattern Analysis and Machine Intelligence or given it's state wait to January and submit to ICML.
3. **November**:
    1. Use the deep generative model for active learning and estimating uncertainties on Raman spectra and predicted properties.
    2. Design and test an automated experimental design process out of this with actual humans-in-the-loop interacting with the model.
4. **December**:
    1. Write paper based on using the model for active learning and experimental design and efficient screening of molecules.
5. **January:**
    1. Submit one or two papers to Thirty-seventh International Conference on Machine Learning (ICML) in the end of January, 2020.

Budget for PhD external stay at MLG, University of Cambridge

PhD Student:	Maximillian Fornitz Vording

Time for external stay	Set date/time
Start date	02/09/2019
End date	03/01/2020
Days	123
Work days	90
Weeks	18
Months	4

Expenses	Net Cost (DKK)	Monthly Cost (DKK)	Weekly Cost (DKK)	Daily Cost (DKK)
Insurance (Covered by Europæiske ERV)				
Travel (flight + train CPH-CBD 2-ways)	4,400.00			
Bench fee (500GBP) for visiting students at University of Cambridge	17,300.72	4,325.18		
Living cost, food, UK internet and phone connection	6,788.00	1,697.00		
Daily travel by train or bus in Cambridge	7,534.98			61.26
Extra cost for accomodation in Cambridge compared to Copenhagen	3,800.00	950.00		
Equipment for Cambridge office (2 screens+keyboard+mouse)	1500			
IEEE Journal publication charges	10,230.00			
ICML 2020 Conference attendance early-bird student fee	3,000.00			
Total (DKK)	54,553.70			

Own Coverage	Net Coverage (DKK)	Monthly Coverage (DKK)	Weekly Coverage (DKK)	Daily Coverage (DKK)
Project 01 NAMEC II Kogsys: 10566 - Travels - X.11.1	20,000.00	5,000.00		
Total (DKK)	20,000.00			
Balance without external funding	-34,553.70			

External Funding	Funding applied for (DKK)	Realised funding (DKK)
STIBOFONDENs IT-rejsestipendie til ph.d. studerende	35,000.00	0
Total (DKK)	35,000.00	0
Balance with external funding (DKK)	446.30	-34,553.70

DTU Compute

Copenhagen, 4 June 2019

Letter of support for Maximillian Fornitz Vording external research stay

To Whom it May Concern,

After completing his master's degree, Maximilian Fornitz Vording started his work as a Ph.D. student at the Department of Applied Mathematics and Computer Science at the Technical University of Denmark, where I have the pleasure to be his main supervisor. Maximilian has a strong educational record, and received the top grade for his master's thesis. His work has lead to a research article that has been submitted for publication in the journal Bioinformatics.

Through his own work, Maximilian has established a contact to researchers at Cambridge University. I believe Maximilian would benefit strongly from going on an external research stay at the University of Cambridge and achieving his goals on applying deep generative models to molecular design and detection through Raman spectroscopy. This can lead to a stronger collaboration between us at DTU Compute, Section for Cognitive Systems, researchers in nano-physics at the IDUN Center of Excellence and most important of all the group hosting Maximillian under the supervision of Assistant Professor, José Miguel Hernández-Lobato.

Since the Machine Learning Group at the University of Cambridge and his host supervisor, have a strong profile in Bayesian neural networks and active learning, this external stay will be the perfect chance for leveraging his knowledge to the state-of-the-art methods in these topics and will create a rich foundation for his ideas and contribution in the more or less unexplored field of active deep learning.

I wholeheartedly support Maximilians effort to reaslise his research plans. On request, I would be delighted to provide further information.

Respectfully yours,

Mikkel Schmidt,
Associate Professor, DTU Compute

Technical University of Denmark
Department of Applied Mathematics and Computer Science
Building 303B
2800 Kgs. Lyngby
Denmark
Tel +45 45 25 30 31
Fax +45 45 88 13 99
www. compute.dtu.dk

CV: Maximillian Vording

LinkedIn:// https://dk.linkedin.com/in/maximillian-vording-2791bbb6
Github:// maximillian91 | maxvo@dtu.dk | +45 6160 3013

EDUCATION

TECHN. UNIV. OF DENMARK
MSc in Mathematical Modelling and Computation
Focus area: Cognitive Science // Machine Learning and Signal Processing
Feb 2015-Jun 2017 | Lyngby, DK
Cum. GPA: 3.94 (US), 10.76 (DK) // Thesis: 12 (DK), A+ (US)

UNIVERSITY OF COPENHAGEN
BSc in Physics
Focus area: Biophysics // Complex Systems
Aug 2011-Dec 2014 | Copenhagen, DK
Grade Avg.: 9.35 (DK) // Thesis: 12 (DK), A+ (US)

SKILLS

PROGRAMMING
`Matlab` • LaTeX • `Python` (`NumPy`, `SciPy`, `Lasagne`, `TensorFlow`, `PyTorch`) • `Java` • `R` • `C` and `C++` (`OpenMP`, `CUDA`) • `MySQL`

EXPERIENCE

TEACHING ASSISTANT | NFYA06018U: Intro to Programming
Sep 2014 - Dec 2014 | UCPH, Copenhagen, DK
- `Matlab` programming - visualize data and simulations through GUI.
- Planning and implementation of exam project in Active Matter simulation

TEACHING ASSISTANT | 02456: Deep Learning
Aug-Dec 2017 | DTU Lyngby, DK
- Guide through and develop exercises on VAE. Supervised 3 projects on SegNet.

PRIVATE TEACHING | Mathematics, Physics and Programming
2012-2017 | Copenhagen, DK
- Teaching students individually on all educational levels

COURSEWORK

(`Matlab` and/or `Python` was used in most courses.)

PHD
Bayesian Data Analysis [DK]
Adv. Topics in Machine Learning [DK]
Summer School on Graphical Models [DK]
MLSS 2019 [ZA]
Bayesian Reading Group [DK]

MASTER
Advanced Machine Learning (`Python`)
High Performance Computing (`C++`)
Cognitive Science and Modelling
Computational Tools for Big Data (`Python`)
Auditory Signal Processing and Perception
Audio Information Processing Systems
Non-Linear Signal Processing
Constrained Optimization
Time Series Analysis (`R`)
Innovation and Product Development
Deep Learning (`Python`, `TensorFlow`)

BACHELOR
Dynamical and Complex systems
Molecular biology (`Python`)
Object oriented programming (`JAVA`)
Quantum Mechanics
Mathematical Methods in Physics, Calculus and Linear Algebra
Electrodynamics and -magnetism
Thermodynamics
Statistical and Experimental Methods
Intro to Programming for Physicists

RESEARCH

DTU COMPUTE: SECTION FOR COGNITIVE SYSTEMS

Advanced Machine Learning Exam Project
Mar 2016 - May 2016 | DTU Lyngby, DK
Super-resolution using Variational Auto-encoders
Supervisor: Ole Winther (PhD. Professor)
- Using Neural Networks in `Python` with `Theano`, `Lasagne` and `Parmesan`
- Creating and presenting a scientific poster and article

Deep Learning Exam Project
Sep 2016 - Dec 2016 | DTU Lyngby, DK
Music generation using recurrent neural networks
Supervisor: Ole Winther (PhD. Professor)
- Using Recurrent Neural Networks (GRU) in `Python` with `Theano` and `Lasagne`.

Master's thesis: Deep learning for single-cell transcript counts
Sep 2016 - Jun 2017 | DTU Lyngby, DK
Gaussian mixture variational auto-encoder
Supervisor: Ole Winther (PhD. Professor), Tune Pers (PhD. Professor)
- Developed variational inference library in `TensorFlow`.
- Handle over-dispersion and sparsity w. zero-inflated count distributions in deep generative model.

PAPERS

Jan 2019 | bioRxiv 318295
scVAE: Variational auto-encoders for single-cell gene expression data
CH Grønbech, MF Vording, PN Timshel, CK Sønderby, TH Pers, O Winther

RESEARCH PROFILE

Here I present you with the research activities I have been running during my Masters and onward in my PhD.
The reports and repositories from my last 3 research projects can be found here:

1. Super-resolution Using Variational Auto-encoding - GitHub
2. Music Generation Using Recurrent Neural Networks - GitHub

- In a course on Deep Learning with Prof. Ole Winther we implemented a GRU-network for music generation by next-step prediction. To enhance the generalization performance of the model and enable generation of new notes from the initial sequence, we were feeding the previous output as the next input.

3. Master's thesis - GitHub

, where we developed a Gaussian mixture variational auto-encoder for modeling single-cell gene expression counts with supervisor, Ole Winther, at The Technical University of Denmark and the biological research group, Pers Lab, at Novo Nordisk Foundation Center for Basic Metabolic Research. During my MSc I've been developing unsupervised and semi-supervised generative models for learning the complex inter-dependencies between distributions of high-dimensional sparse gene expression counts through the low-dimensional representation in auto-encoders. I am expanding the VAE framework from [1] Kingma and Welling to include Gaussian Mixture priors [2, 3, 4], time-dependence in latent space like Chung et al. [7] and likelihood distributions for counts like zero-inflated Poisson and Negative binomial. We can model single-cell transcripts from the Drop-Seq experiment in [9] Macosko et al. and **10x-Genomics**.
By modeling the data generating process in a latent representation, we can acquire clustering of data points and thereby use density and uncertainty sampling for to query for labels on the most representative cluster members and thereby save time in screening of new cell types. We have implemented our scVAE model **Github**
In August 2017 I started my PhD project in Active Deep Learning for Nano-sensor systems at DTU Compute, Section for Cognitive Systems and IDUN center of excellence. Together with my supervisors Professor Jan Larsen, Associate Professor Mikkel N. Schmidt and Senior Researcher Tommy Sonne Alstrøm, I have planned the research in two parts. The first part of research is methodological and will be leveraging the state-of-the-art active learning techniques build in frameworks of Bayesian neural networks and generative models, where model prediction uncertainties and distances in latent space are decision criteria. The second part of the research will be applying the achieved methods and my knowledge in data processing, physics and biology in a users-in-the-loop framework for nano-sensor, drug development and optimal experimental design in close cooperation with the projects at IDUN.
I see no boundaries between the different academic topics of research, when it comes to reaching new scientific findings and technological achievements, which is why I studied a bachelor in Biophysics at the University of Copenhagen to understand the nature of networks behind intelligent behavior. During my Master's program at DTU, applied machine learning various contexts, like cognitive science, musical genre recognition, melody generation and identification of new cell types from single cell transcriptomes.
This multidisciplinary profile will help me in communicating results and ideas beyond my own field of study with analogies and concepts from a broad range of research areas. Complex machine learning models and our hypothesis generation are data driven, so how and what data is collected is crucial for the generalisation performance due to experimental bias and the balance in different classes of data points. Therefore it is important for me to be a part of the data collection from beginning to end, using my broad knowledge of the different fields of research involved in it.
I will be using my broad educational background and cognitive science in developing users-in-the-loop machine learning applications. Here gathering domain knowledge in an efficient way, also means considering the human perception, attention and range of knowledge, so the quality and density of information in the data can be kept high and effort and cost spend by the user low.

Maximillian Fornitz Vording
PhD student on project "Active Deep Learning for Nano-sensor systems" at The Technical University of Denmark
2100 Copenhagen E - Silkeborggade 18, st.
maxvo@dtu.dk || +45 6160 3013
LinkedIn:// https://dk.linkedin.com/in/maximillian-vording-2791bbb6 || Github:// **maximillian91**

References

1. D. Kingma and M. Welling (2014), Auto-Encoding Variational Bayes, ICLR 2014 [pdf]
2. Dilokthanakul - Deep Unsupervised Clustering With Gaussian Mixture Variational Autoencoders, arXiv e-prints, Nov 2016
3. Ranganath et al. "Hierachical Variational Auto-encoders"
4. Nalisnick (2016 NIPS) - Approximate Inference for Deep Latent Gaussian Mixtures
7. Chung et al., "A Recurrent Latent Variable Model for Sequential Data", ArXiv e-prints, June 2015
8. Fraccaro et al, "Sequential Neural Models with Stochastic Layers"
9. Macosko et al., "Highly Parallel Genome-wide Expression Profiling of Individual Cells Using Nanoliter Droplets", Cell, May 2014

Diploma

Maximillian Fornitz Vording

has been awarded the degree Master of Science in Engineering by

Technical University of Denmark

Degree awarded: 30 June 2017

Anders O. Bjarklev
President

Philip J. Binning
Dean

Technical University of Denmark

List of grades for Maximillian Fornitz Vording (147246)

Education: Master of Science in Engineering (Master of Science in Mathematical Modelling and Computation)

Results extracted 4/6-2019 15:51

Number	Title	Grade	ECTS	Date
E01	Deep Learning for Modelling Single-Cell Transcript Counts	12 (A)	30.0	s17
01415	Computational Discrete Mathematics	BE (P)	5.0	v16
02456	Deep learning	12 (A)	5.0	v16
S01	Deep Learning for Genomics	12 (A)	5.0	v16
02417	Time Series Analysis	12 (A)	5.0	s16
02460	Advanced Machine Learning	12 (A)	5.0	s16
02612	Constrained optimisation	10 (B)	5.0	s16
41633	Innovation and Product Development	10 (B)	10.0	s16
02454	Introduction to Cognitive Science	7 (C)	5.0	v15
02457	Non-Linear Signal Processing	10 (B)	10.0	v15
02458	Cognitive Modelling	12 (A)	5.0	v15
02614	High-Performance Computing	12 (A)	5.0	v15
02807	Computational tools for data science	12 (A)	5.0	v15
02452	Audio Information Processing Systems	10 (B)	5.0	s15
02582	Computational Data Analysis	12 (A)	5.0	s15
31236	Auditory Signal Processing and Perception	10 (B)	10.0	s15

Total points for this education:

Exams	120
Credit	0
Total	**120**

Danmarks Tekniske Universitet

Vording, Maximillian Fornitz
Silkeborggade 18,st
2100 København Ø

Cpr-nummer 230791-2123
Studienummer 147246

All study activities

4. juni 2019

Credits in ECTS-point

		Norm	mangler	Period	marked	Mark	Total
RAM	Enrolled from 01.08.2017 at open programme PhD, commenced 01.02.2008 for (18) ph.d.-uddannelsen ministerial order 18 by 14.01.2008 in Ph. d.-retning	180	159,5				20,5
UDD	(18) ph.d.-uddannelsen i Ph. d.-retning	180	159,5				20,5
STU	Curriculum (18) ph.d.-uddannelsen in Ph. d.-retning, commenced 01.02.2008	0	0				20,5
GRP	Optional Courses in Ph.D-studies after 2002	0	0			passed	15,5
EKA	02901 Advanced topics in machine learning	2,5	0	S17	27.11.2017	PA	2,5
EKA	02936 Bayesian data analysis	5	0	S18	15.06.2018	PA	5
EKA	02943 Image analysis and computer graphics summer school on graphical models	3	0	S17	18.08.2017	PA	3
EKA	02943 Image analysis and computer graphics summer school on semi-supervised learning	3	3				0
EKA	02949 DTU compute phd seminar	2,5	0	W18-19	03.12.2018	PA	2,5
EKA	88553 Teaching and Learning	2,5	0	W18-19	26.11.2018	PA	2,5
GRP	Focus Ph.D-courses						0
EKA	PhD Course at Department of Applied Mathematics and Computer Science Title: Bayesian reading group	2,5	2,5	S19		Exam regist	0
GRP	Advanced courses	0	0			passed	5
GRP	Videregående kurser ved COMPUT	0	0			passed	5
EKA	02809 UX design prototyping	5	0	W18-19	16.01.2019	12(A)	5
EKA	PH.D-Afhandling	0	0				0
GRP	Valgfrie grundlæg. kurser,	0	0				0

Cpr-nummer **230791-2123**
Studienummer **147246**

	Norm	mangler	Period	marked	Mark	Total
Sum of credit transfer						0
Hereby marked before study start						0
External grading						5
Internal grading						15,5
Internal grading						0
Marked by only one examiner						0
7-point grading scale						5
Marked Pass/not pass						15,5

Extra curricular

EKA	Project course at Depart	5	W16-17	20.12.2016	12(A)
EKA	Department of Applied Mathemat	30	S17	30.06.2017	12(A)
EKA	01415 Computational discrete m	5	W16-17	29.11.2016	PA
EKA	02417 Time series analysis	5	S16	20.06.2016	12(A)
EKA	02452 Audio information proces	5	S15	02.06.2015	10(B)
EKA	02454 Introduction to cognitiv	5	W15-16	17.12.2015	7(C)
EKA	02456 Deep learning	5	W16-17	27.12.2016	12(A)
EKA	02457 Non-linear signal proces	10	W15-16	18.01.2016	10(B)
EKA	02458 Cognitive modelling	5	W15-16	16.12.2015	12(A)
EKA	02460 Advanced machine learnin	5	S16	22.06.2016	12(A)
EKA	02582 Computational data analy	5	S15	28.05.2015	12(A)
EKA	02612 Constrained optimisation	5	S16	27.05.2016	10(B)
EKA	02614 High-performance computi	5	W15-16	19.02.2016	12(A)
EKA	02807 Computational tools for	5	W15-16	08.01.2016	12(A)
EKA	31236 Auditory signal processi	10	S15	19.05.2015	10(B)
EKA	41633 Innovation and product d	10	S16	25.05.2016	10(B)

Forklaring på kolonner og forkortelser i udskriften:
I den første kolonne angives uddannelseselementets type ved hjælp af følgende forkortelser:
RAM uddannelsesramme
UDD uddannelsesdel
STU studieordning
GRP gruppe
EKA eksamensaktivitet
UVA undervisningsaktivitet
I kolonnen "norm/min" vises for aktiviteter den registrerede belastning, for uddannelsesdele den registrerede normerede studietid og for grupper summen af de obligatoriske aktiviteters belastning eller den belastning, der er minimum for beståelse af gruppen.
I kolonnen "mangler" vises for ikke beståede aktiviteter, grupper og uddannelsesdele forskellen mellem belastning i "norm/min" og summen af beståede aktiviteters belastning.
I kolonnen "termin" vises hvilken termin, resultatet hører til i. S94 betyder sommereksamen 1994, og V94-95 betyder vintereksamen 1994-95. "r" efter termin angiver, at resultatet er opnået ved en reeksamen.
I kolonnen "bestået(sum)" vises belastning for de aktiviteter, der er bestået. For grupper og uddannelsesdele vises summen af de beståede aktiviteters belastning.

KØBENHAVNS UNIVERSITET
UNIVERSITY OF COPENHAGEN

MAXIMILLIAN FORNITZ VORDING

cpr. 230791-2123

har den 6. november 2014	*has on 6 November 2014*
opnået	*been awarded the degree of*
bachelorgraden i	*Bachelor of Science in*
Fysik	*Physics*
og titlen	*and the title*

BSc i Fysik
Bachelor of Science in Physics

John Renner Hansen
Dekan/*Dean*

Karen Rønnow
Studiechef/*Director of Studies*

DET NATUR- OG BIOVIDENSKABELIGE FAKULTET
FACULTY OF SCIENCE

DET NATUR- OG BIOVIDENSKABELIGE FAKULTET
KØBENHAVNS UNIVERSITET

Maximillian Fornitz Vording

Cpr.: 230791-2123

har gennemført bacheloruddannelsen i
Fysik
6. november 2014

Oversigt over prøver og bedømmelser side 1 af 2

Følgende resultater er opnået	**Resultat 7-trinsskala**	**Resultat ECTS-skala**	**ECTS point**
Bachelorprojekt			
Bachelorprojekt i de fysiske fag	12	A	15,0
Modeling Temprate Bacteriophage Plaque Formation			
Bachelorfagpakke			
Indledende mekanik og relativitetsteori	4	D	7,5
Introduktion til matematik i naturvidenskab	7	C	7,5
Lineær algebra i naturvidenskab	10	B	7,5
Videregående klassisk mekanik	4	D	7,5
Matematik F	7	C	7,5
Termodynamik og projekt	7	C	7,5
Elektromagnetisme	4	D	7,5
Biofysik: Introduktion til biofysik	12	A	7,5
Elektrodynamik og bølger	02	E	7,5
Kvantemekanik 1	10	B	7,5
Videnskabsteori og etik for fysikere	12	A	7,5
Kvantemekanik 2	10	B	7,5

11. december 2014

Charlotte Louise Friis Rundsten
SCIENCE Uddannelse

DET NATUR- OG BIOVIDENSKABELIGE FAKULTET
KØBENHAVNS UNIVERSITET

Maximillian Fornitz Vording

Cpr.: 230791-2123

har gennemført bacheloruddannelsen i
Fysik
6. november 2014

Oversigt over prøver og bedømmelser side 2 af 2

Følgende resultater er opnået	**Resultat 7-trinsskala**	**Resultat ECTS-skala**	**ECTS point**
Statistisk fysik	10	B	7,5
Eksperimental fysik	12	A	7,5
Tilvalg			
Almen molekylærbiologi	12	A	7,5
Dynamiske systemer og kaos	12	A	7,5
Biological Sequence Analysis	12	A	7,5
Biologiske netværk (Bionet)	10	B	7,5
Valgfrit			
Objektorienteret programmering og design	10	B	7,5
Datalogi for fysikere	Bestået		7,5
Topics in Physics of Complex Systems	12	A	7,5
Computational Methods in Simulation	12	A	7,5

11. december 2014

Charlotte Louise Friis Rundsten
SCIENCE Uddannelse

FACULTY OF SCIENCE
UNIVERSITY OF COPENHAGEN

Maximilian Fornitz Vording
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has completed the Bachelor's programme in
Physics
6 November 2014

Summary of examinations and grades page 1 of 2

The following grades were awarded	Grade 7-point scale	Grade ECTS scale	ECTS credits
Bachelor Project			
Bachelor Project in Physics ..... *Modeling Temprate Bacteriophage Plaque Formation*	12	A	15,0
Computational Courses			
Introduction to Mechanics and Relativity Theory	4	D	7,5
Introduction to Mathematics for Science	7	C	7,5
Linear Algebra in Science	10	B	7,5
Classical Mechanics	4	D	7,5
Mathematics for Physicists	7	C	7,5
Thermodynamics and Project	7	C	7,5
Electromagnetism	4	D	7,5
Introduction to Biophysics	12	A	7,5
Electrodynamics and Waves	02	E	7,5
Quantum Mechanics 1	10	B	7,5
Scientific Theory and Ethics	12	A	7,5
Quantum Mechanics 2	10	B	7,5

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Summary of examinations and grades page 2 of 2

The following grades were awarded	Grade 7-point scale	Grade ECTS scale	ECTS credits
Statistical Physics	10	B	7,5
Experimental Physics	12	A	7,5
Elective Courses			
General Molecular Biology	12	A	7,5
Dynamical Systems and Chaos	12	A	7,5
Biological Sequence Analysis	12	A	7,5
Biological Networks	10	B	7,5
Optional Courses			
Object-oriented Programming and Design	10	B	7,5
Introduction to Computing for Physicists	Passed		7,5
Topics in Physics of Complex Systems	12	A	7,5
Computational Methods in Simulation	12	A	7,5

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Kompetenceprofil for uddannelsen

Uddannelsen giver den studerende et grundlæggende kendskab til og indsigt i teoretiske og eksperimentale facetter af de fysiske fags metoder og videnskabelige grundlag herunder brugen af it. Uddanneisens obligatoriske fag præsenterer fysikkens væsentligste fagområder inden for klassisk fysik, relativistisk fysik og kvantefysik. Bacheloren skal desuden foretage en selvvalgt profilering af sin uddannelse. Sammen med bachelorprojektet skal uddannelsen kvalificere til videreuddannelse på kandidatniveau samt varetagelse af erhvervsfunktioner.

1. Kompetencer
En bachelor i de fysiske fag har kompetencer til at:
- analysere en naturvidenskabelig problemstilling ud fra en fysisk synsvinkel
- formulere spørgsmål, der kan løses eller belyses ved hjælp af fysik
- udvikle og anvende kvalitative og kvantitative modeller for fysiske systemer
- analysere et problem ud fra forskellige data og kritisk diskutere løsningsmetoder
- vurdere kvaliteten af videnskabelige resultater
- identificere egne læringsbehov og strukturere egen læring
- indgå selvstændigt i fagligt og tværfagligt samarbejde med en professionel fysisk tilgang

2. Færdigheder
En bachelor i de fysiske fag har færdigheder i at:
- tilrettelægge målinger til undersøgelser af systemer, herunder mekaniske, elektriske, elektromagnetiske, optiske, og termodynamiske størrelser
- løse matematiske problemstillinger både med analytiske og numeriske metoder
- anvende modelløsning og målemetoder inden for de fysiske fag og tæt beslægtede områder
- forklare og formidle sin viden om fysikkens generelle sammenhænge på dansk og på engelsk i både mundtlig og skriftlig form
- beskrive anvendelsen af fagets resultater i en industriel og samfundsmæssig sammenhæng
- anvende computerbaserede værktøjer (IKT) som både kommunikations-, modellerings- og databehandlingsværktøj

3. Viden
En bachelor i de fysiske fag har viden om:
- de grundlæggende fysiske love inden for klassisk mekanik, termodynamik, elektromagnetisme, kvantemekanik
- de fundamentale principper for de forskellige kræfter, der virker på hver længdeskala
- målemetoder til måling af forskellige fysiske størrelser
- hvordan man vurderer kvalitet af forskellige resultater
- matematiske metoder til løsning af en lang række forskellige problemer
- numeriske metoder til databehandling og løsning af matematiske modeller
- etiske problemstillinger, overvejelser og argumenter forbundet med de fysiske fag

11. december 2014

Charlotte Louise Friis Rundsten
SCIENCE Uddannelse

FACULTY OF SCIENCE
UNIVERSITY OF COPENHAGEN

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has completed the Bachelor's programme in
Physics
6 November 2014

Skills profile for the programme

The objective of the programme is to provide students with a basic knowledge of and insight into theoretical and experimental aspects of physics' methods and scientific basis, including the use of IT. The compulsory subjects cover the major physics disciplines, i.e. classical physics, relativistic physics and quantum physics. Students are also required to develop a custom profile. Along with the Bachelor Project, the programme qualifies graduates for employment and to continue their studies at MSc level.

1. Competences
Bachelors in Physics possess the competences to:
- analyse a scientific problem from a physics perspective
- formulate questions that can be resolved or clarified by physics
- develop and apply qualitative and quantitative models for physical systems
- analyse a problem using a variety of data and critically discuss the possible methods of solving it
- evaluate the quality of scientific results
- identify their own learning needs and structure their own learning accordingly
- work independently and in academic and interdisciplinary groups with a professional physics approach

2. Skills
Bachelors in Physics possess the skills to:
- develop measurements for studies of systems, including mechanical, electrical, electromagnetic, optical and thermodynamic systems
- solve complex mathematical problems using both analytical and numerical methods
- use modelling and quantification methods in physics and adjacent subject areas
- explain and disseminate their knowledge of physics in general contexts, in Danish and in English, both orally and in writing
- discussing the use of the subject's results in an industrial and social context
- use computer-based tools (ICT) for communications, modelling and data-processing purposes

3. Knowledge
Bachelors in Physics have acquired knowledge of:
- the basic laws of physics in classical mechanics, thermodynamics, electromagnetism and quantum mechanics
- the fundamental principles of the various forces acting at each scale of longitude
- quantification methodology for various physical entities
- how to evaluate the quality of different results
- mathematical methods for solving a wide variety of problems
- numerical methods for data processing and solving mathematical models
- ethical issues, considerations and arguments associated with the physics disciplines

11 December 2014

Charlotte Louise Friis Rundsten
SCIENCE Study Administration

FACULTY OF SCIENCE
UNIVERSITY OF COPENHAGEN

Diploma Supplement

This Diploma Supplement follows the model developed by the European Commission, Council of Europe and UNESCO/CEPES. The purpose of the supplement is to provide sufficient independent data to improve the international 'transparency' and fair academic and professional recognition of qualifications (diplomas, degrees, certificates etc.). It is designed to provide a description of the nature, level, context, content and status of the studies that were pursued and successfully completed by the individual named on the original qualification to which this supplement is appended. It should be free from any value judgements, equivalence statements or suggestions about recognition. Information in all eight sections should be provided. Where information is not provided, an explanation should give the reason why.

1. INFORMATION IDENTIFYING THE HOLDER OF THE QUALIFICATION

1.1. Family name(s): Vording

1.2. Given name(s): Maximillian Fornitz

1.3. Date of birth: 23 July 1991

1.4. Danish civil registration number: 230791-2123

2. INFORMATION IDENTIFYING THE QUALIFICATION

2.1. Name of qualification and title conferred *(in Danish)*: B.Sc. i fysik

Name of qualification and title conferred *(in English)*: B.Sc. in Physics

2.2. Main fields of study: Physics

2.3. Name and status of awarding institution: Københavns Universitet, University of Copenhagen (officially abbreviated KU) is a state-financed higher education institution, regulated according to the Ministry of Higher Education and Science University Act no. 960 of 14 August, 2014.

2.4. Name and status of institution administering the studies (See 2.3.): enter if different

2.5. Language(s) of instruction/examination: Primarily Danish and to some extent English

3. INFORMATION ON THE LEVEL OF THE QUALIFICATION

3.1. Level of qualification: Theoretically, research based tertiary programme, Bachelor Programme

3.2. Official length of programme: 3 years = 180 ECTS credit points ECTS

3.3. Access requirements: Entrance to Bachelor's degree programmes is subject to the regulations contained in order no. 181 of 23 February 2010 issued by the Danish Ministry of Science, Technology and Innovation.

4. INFORMATION ON THE CONTENTS AND RESULTS GAINED

4.1. Mode of study: Full time study

4.2. Programme requirements: Entrance to Bachelor's degree programmes is subject to the regulations contained in order no. 154 of 5th March 2000 issued by the Danish Ministry of Education.

4.3. Programme details and individual grades/marks/credits obtained: Please refer to the enclosed grade transcript.

4.4. Grading scheme and if applicable grade distribution information: Please refer to the enclosed explanation of the Danish education system and the grading scale.

4.5 Overall classification of the qualification: Not applicable for Danish qualifications.

5. INFORMATION ON THE FUNCTION OF THE QUALIFICATION

5.1. Access to further study: A Bachelor's degree in a given subject area qualifies graduates for entrance to the Master's degree programme in this area, providing that there is a sufficient number of student places available.

5.2. Professional status:

6. ADDITIONAL INFORMATION

6.1. Additional information: Founded in 1479 by the Danish King Christian I, the University of Copenhagen is Denmark's oldest and largest institution of research and higher education. More than 37,000 students are enrolled in undergraduate and graduate programmes, plus an additional 2,500 PhD students. Staff members number 9,000. The University is divided into six faculties: Theology, Law, Social Sciences, Health and Medical Sciences, Humanities and Science; all situated in the capital of Denmark.

6.2. Further information: Faculty of Science

Bülowsvej 17
DK - 1870 Frb. C.

Phone +45 +4535332828
Fax +45 35324240
E-mail: science@science.ku.dk

General information on higher education in Denmark can be obtained from the following two homepages: Ministry of Science, Technology and Innovation: www.vtu.dk, or Danish Rectors Conference: www.rks.dk

7. CERTIFICATION OF THE SUPPLEMENT

7.1. Date: 11 December 2014

7.2 Charlotte Louise Friis Rundsten

7.3. SCIENCE Study Administration

7.4. SEAL

8. The Danish Higher Education System May 2013

Public higher education institutions in Denmark are regulated by national legislation concerning degree structures, teacher qualifications and examinations. All programmes are accredited by national, independent accreditation agencies and the Accreditation Council.

Higher education institutions

Higher education is offered by five types of higher education institutions:

1. Academies of Professional Higher Education (*Erhvervsakademi**) offering professionally oriented short cycle and first cycle degree programmes.
2. University Colleges (*Professionshøjskole**) offering professionally oriented first cycle degree programmes.
3. Maritime Education and Training Institutions offering professionally oriented short cycle and first cycle degree programmes.
4. Research universities *(Universitet)* offering first, second and third cycle degree programmes in all academic disciplines.
5. University level institutions offering first, second and third cycle degree programmes in subject fields such as architecture, design, music and fine and performing arts.

Most of the higher education institutions are regulated by the Ministry of Science, Innovation and Higher Education (type 1-5). The Ministry of Culture regulates a small number of higher education institutions offering first, second and third cycle degree programmes in fine and performing arts (type 5).

Degrees in the Danish Higher Education System:

Danish qualifications levels	Ordinary higher education degrees	Adult/Continuing higher education degrees	Qualifications Framework for the European Higher Education Area – Bologna Framework	European/National Qualifications Framework for Lifelong Learning – EQF/NQF
Academy Profession level	Academy Profession (AP) degree (90-150 ECTS)	Academy Profession (AP) degree (60 ECTS) (also known as Further Adult Education (VVU) degree)	Short cycle	Level 5
Bachelor's level	Professional Bachelor's degree (180-270 ECTS)*	Diploma degree (60 ECTS)	First cycle	Level 6
	Bachelor's degree (within the arts) (180 ECTS)			
	Bachelor's degree (180 ECTS)			
Master's level	Master's degree (within the arts) (120-180 ECTS)	Master degree (60-90 ECTS)	Second cycle	Level 7
	Master's degree (120 ECTS)**			
PhD level	PhD degree (180 ECTS)		Third cycle	Level 8

* Can be obtained through a full regular bachelor's programme (180-240 ECTS) or a top up bachelor's programme following an Academy Profession degree. ** A few Master's programmes are up to 180 ECTS.

Danish higher education institutions use ECTS credits for measuring study activities. 60 ECTS correspond to one year's full-time study.

Qualifications framework

The qualification levels form the basis for the Danish National Qualifications Framework for Higher Education, which is certified in accordance with the overarching Bologna Framework according to the principles adopted by the European Ministers of Higher Education. Danish higher education qualifications at levels 5-8 of the Danish Qualifications Framework for Lifelong Learning (NQF) are also compatible with levels 5-8 of the European Qualifications Framework (EQF).

Admission and progression

General access to higher education in Denmark requires an Upper Secondary School Leaving Certificate or comparable qualifications. Admission to some particular programmes requires entrance examination or submission of a portfolio of artistic work. Completion of a short-cycle degree qualifies students for admission to a first cycle programme. Holders of an Academy Profession degree can obtain a Professional Bachelor's degree within the same field of study through a top-up programme. Completion of a first cycle degree qualifies students for admission to the second cycle.

Ordinary Higher Education degrees

The Academy Profession degree is awarded after 90-150 ECTS and includes a period of work placement of at least 15 ECTS. The programmes are development-based and combine theoretical studies with a practical approach. Programmes are, among others, offered within Marketing Management, Computer Science and Chemical and Biotechnical Science. The Danish title is field of study followed by the abbreviation *AK* and the English title is *AP Graduate in* [field of study].

The Professional Bachelor's degree is awarded after 180-240 ECTS and includes a period of work placement of at least 30 ECTS. The programmes are applied programmes. They are development-based and combine theoretical studies with a practical approach. Examples of professional bachelor's degree holders are nurses, primary and lower secondary school teachers and certain types of engineers. The Danish title is *Professionsbachelor i* [field of study] and the English title is *Bachelor of* [field of study].

The Bachelor's degree from a university is awarded after 180 ECTS. The programmes are research-based and are offered in all scientific fields. The Danish title is *Bachelor (BA) i* [field of study] or *Bachelor (BSc) i* [field of study] and the English title is *Bachelor of Arts (BA) in* [field of study] or *Bachelor (BSc) of Science in* [field of study].

The Bachelor's degree (within the arts) is awarded after 180 ECTS. The programmes are based on research and artistic research. Programmes are offered within the fine arts. The Danish title is *Bachelor (BA) i* [field of study], *Bachelor I musik (BMus)* [field of study] or *Bachelor i billedkunst (BFA)* [field of study] and the English title is *Bachelor of Arts (BA) in* [field of study], *Bachelor of Music (BMus)* [field of study] or *Bachelor of Fine Arts (BFA) in* [field of study]. A higher education degree within theatre or filmmaking is awarded after 4 years of study (240 ECTS).

The Master's degree is awarded after 120 ECTS. The programmes are research-based and are offered in all scientific fields. The Danish title is abbreviated to *Cand.*[latin abbreviation of academic area] *i* [field of study]. The English title is *Master of Arts (MA) in* [field of study] or *Master of Science (MSc) in* [field of study].

The Master's degree (within the arts) is awarded after 120-180 ECTS. The programmes are based on research and artistic research. The Danish title is abbreviated to *Cand.*[latin abbreviation of academic area] [field of study]. The English title is *Master of Arts (MA) in* [field of study], *Master of Music (MMus)* [field of study] or *Master of Fine Arts (MFA) in* [field of study]. Music Academies offer a specialist degree of 2 to 4 years following the master's degree.

The PhD degree is awarded after 180 ECTS. PhD programmes are offered by the universities and some university level institutions offering degrees in the artistic and cultural field. Detailed descriptions of degree levels can be found in the Danish Qualifications Framework at www.nqf.dk. Please consult the relevant Diploma Supplement for information about the learning outcome of any specific degree.

Adult and continuing higher education

The programmes normally consist of 2 years of part-time study, equivalent to 1 year of full-time study (60 ECTS credits). Certain master programmes require 1½ years of full-time study (90 ECTS credits). Admission requirements are a relevant educational qualification and at least 2 years of relevant work experience. Adult education qualifications are available at levels corresponding to those of the ordinary higher education system. The Further Adult Education degree (*videregående voksenuddannelse/akademiuddannelse*) is awarded after studies at short cycle level and gives access to diploma programmes.

- The Diploma degree (*diplomuddannelse*) is awarded after studies at first cycle level and gives access to master programmes.
- The Master degree (*masteruddannelse*) is awarded after studies at second cycle level.

The 7 point grading scale

The grading system used in all state-regulated education programmes as of September 2007 is the 7 point grading scale. Apart from the 7 point grading scale, pass/fail assessment may also be used. 02 is the minimum grade for passing an exam. Description of grades: 12: For an excellent performance displaying a high level of command of all aspects of the relevant material, with no or only a few minor weaknesses; 10: For a very good performance displaying a high level of command of most aspects of the relevant material, with only minor weaknesses; 7: For a good performance displaying good command of the relevant material but also some weaknesses; 4: For a fair performance displaying some command of the relevant material but also some major weaknesses; 02 For a performance meeting only the minimum requirements for acceptance; 00: For a performance which does not meet the minimum requirements for acceptance; -3 For a performance which is unacceptable in all respects.