Deep Learning for Health

DeepHealth

Technical report for IKTPLUSS-funded Phase 1 and plans for future research (Phase 2)

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Abstract

The research project entitled *Deep learning for Health* (DeepHealth) was in March 2017 granted an allocation for 2017, Phase 1 of the project, by The Research Council of Norway. Our ambitious overall aim for Phase 2 (4 year project) is to take deep learning research to the next level for knowledge extraction from ubiquitous data in healthcare for predicting and preventing post-operative complications. As a first step towards this, we have during Phase 1 been working on verifying and modifying the ideas, impact and implementation of the project. In addition, we have established firm commitments from partners, we have mapped the competences of partners in order to plan for Phase 2, and we have identified risks and created plans for risk mitigation.

Introduction

The Main Objective of Phase 1 was to establish firm commitment from essential partners and users and to lay out clear roles and areas of scientific contribution, and to establish a joint plan for execution of the project as well as risk mitigation. Towards this end, we had the following secondary objectives

- To establish a concrete plan with user partners and to identify solutions and R and D areas for the development of end-to-end deep learning-based predictive analysis software tools based on electronic health records (EHRs) for operational use in the clinic (realizing expected impact).
- To research as a first step a new and more powerful (in terms of accuracy, performance) deep learning EHR prediction method with main focus on postoperative delirium applications. Generic at core, strategies for transferring the technology to other DeepHealth applications areas will be developed (verifying scientific merit).
- To develop a first pilot algorithm on image-based polyp detection and characterization, as well as developing strategies for integration of the result of the pilot into a joint processing pipeline for data fusion of imagery and EHR (verifying scientific merit).
- To organize project workshops in order to engage and commit collaborators both in Tromsø and at partner institutions and to establish an execution plan and risk mitigation procedures (confirm capabilities of research team).
- To start disseminating the purpose and initial results of DeepHealth to the general public in order to establish interaction and contribute knowledge exchange (realizing expected impact).

In order to achieve these objectives we planned five main activities to be done in Phase 1. In this report we summarize the results from all of these activities and in the end, conclude about whether what we aimed for in the main objective is achieved.
Main activity 1: Plan for end-to-end analysis: Roadmap for operationalization of analysis tools

Description of activity

This activity will identify challenges and concretize a plan with users, such as DIPS, by organizing a workshop for developing end-to-end deep learning-based EHR predictive analysis software tools for use in the clinic. We will also use partners such as Scyfer and IBM to exchange experience on EHR systems beyond those delivered regionally by DIPS.

What we did

On the 6th of September we organized a workshop in Tromsø. At this workshop representatives from the partners DIPS, The University Hospital of North Norway (UNN), The Norwegian Center for E-health research (NSE), and the Machine Learning Group at UiT The Arctic University of Norway participated. The main purpose of this workshop was to concretize a plan for how to use competences that DIPS possess in Phase 2 of the project. More precisely, we wanted to start to plan how to develop end-to-end software tools for use in the clinic based on the methods, systems and algorithms that will be developed in DeepHealth. Previous experience from research projects DIPS has been participating in is that taking the step of operationalizing the systems is difficult to succeed with. However, an important goal for DeepHealth is that the outcome of the project should not only be scientific articles, which also will be important, but lead to products that really make a difference for patients and healthcare providers. For this reason we started already at this workshop, and have continued after that, to plan how to implement our systems in the clinic.

Figure 1: Illustration of the interface in the next generation of DIPS, DIPS Arena.

One of the things we learned is that we are in a very fortunate position since DIPS is about to release a new journal system called DIPS Arena, which basically means that implementation
of our algorithms will be easier than in DIPS Classic which is the system used now. Figure 1 shows the current version of the user interface in DIPS Arena. Because of the introduction of DIPS Arena our opportunities when it comes to implementation are almost unlimited. Finn Harald Stokland who represented DIPS at the workshop sketched many different opportunities and possible ways of implementing our algorithms in the clinic, ranging from prototypes of non-mature systems to more advanced clinical decision support tools.

To be more concrete, we specifically discussed some prototypes that we would like to implement. The first is an example of a simple, patient centered prototype. Here we will add a user interface to DIPS Arena such that the nurse or doctor get notifications about the patient’s health status based on whatever the system we have implemented is recommending. DIPS’s contribution here will be to provide an API such that it is possible for external users (us) to add information into the system. A second system we would like to implement would be to provide clinical decision support to the surgeon before a surgery via DIPS Arena. We also have concrete plans about integrating a prototype of deep anchor method (described under main activity 2) in the DIPS EHR system in the gastrointestinal department. Figure 2 shows a flowchart that illustrates how we plan to integrate the prototypes in the clinic.

Figure 2: Flowchart illustrating how we plan to integrate the prototypes in the clinic.

All in all, DIPS seems to be very interested in a research project like this and wants to contribute to get the systems and algorithms we develop in DeepHealth implemented in the clinic. After the workshop DIPS has officially become partner of the project. DIPS’ main role in the project will be to be responsible for implementation of our systems at UNN. After what we learned from the workshop, and with DIPS on board in the project, we are convinced that we will be able to take the next step and not only write research papers but also operationalize our analysis tools at the hospital such that our solutions can have real impact for the patients. This will be achieved via a close interplay between Helse Nord IKT (access to real-time data), DIPS (provider of EHR-system) and UiT/UNN (developers of algorithms and provider of clinical knowledge).

In addition to DIPS, we also have the company health plus.ai (Bart Geerts) involved, which is in the process of operationalizing predictive wound infection systems across several hospitals in the Netherlands, and we will exchange experiences.

We have also as a part of main activity 1 actively sought to learn from the experiences of others when it comes to implementation of algorithms in hospitals and the evaluation of such methods, e.g. by participating at the conference AMIA 2017 in the session Designing and Evaluating user Interfaces in Healthcare.
Main activity 2: Deep anchor prototype

Description of activity

This activity will develop as a first step a new deep learning prediction engine for prediction of postoperative delirium. The aim is to take the current team’s unsupervised anchor framework to a higher precision level and to test the new approach compared to the current technology.

What we did

Here we give a brief background on anchor learning, the deep anchor framework we developed, and the results we got on the task of detecting postoperative delirium. The work that we did led to a conference paper and we refer to that for details [3]. For more details on anchor learning in general we refer to [14], a journal paper submitted and published during Phase 1.

Anchor learning. In anchor learning one can learn phenotypes and predict clinical state variables from EHR unlabeled data only by specifying a few key observations called anchors. An underlying assumption is that the presence of an anchor variable implies the presence of the latent label of interest. Thus, training examples for which the anchor variable is present are positive examples, while nothing can be said for the remaining examples and thus it can be thought of as a positive only noise model.

The framework has shown great potential in numerous applications, for example have we successfully been diagnosing postoperative delirium [14]. The potential impact of the method is enormous because of the simplistic and low labor intensive way of creating very large labeled datasets that can be exploited by learning algorithms. However, it is reasonable to question whether the framework as originally formulated is able to fully exploit and utilize the data available due to the simple binary or frequency features and typically a logistic regression classifier. This is something we have been exploiting in Main activity 2 of Phase 1.

Deep anchor learning

Figure 3: Deep anchor learning schematics.

Figure 3 illustrates both the original formulation of anchor learning and our contribution in the new deep anchor learning framework. Broadly speaking, one can say that there are four steps in the original anchor learning framework: 1. Selection of cohort of patients and data source; 2. Create feature representation of the data; 3. Specify anchors; 4. Use anchors as labels and train a classifier. As illustrated in Figure 3 our contribution is to add an additional step to the anchor learning framework where we propose to use stacked denoising autoencoders (Figure 4) as a mean to learn a higher level feature representation of patients. Moreover, this enables the
possibility of introducing more advanced non-linear classifiers than penalized logistic regression such as SVMs and hence can been seen as a modification of the last step as well.

Figure 4: The figure displays a typical architecture of a denoising autoencoder. It consists of one hidden layer with three hidden units and four input/output units. Masking noise is added to the input by replacing inputs with 0 at random and the dAE is trained to denoise the input and produce the original clean, noise-free, input.

Postoperative delirium. Complications after major surgery are unfortunately not uncommon. Central nervous system dysfunction, including postoperative delirium, is often seen in geriatric patients undergoing major surgery. Despite its potentially serious consequences, such as an increase in length of hospitalization, morbidity, mortality, and adverse events, it is often hard to detect postoperative delirium. Moreover, if the complication goes undiagnosed, it could have economical consequences for the care giver, as hospitals’ reimbursement rates are dependent on correct coding. For these reasons it is important to identify risk factors and being able to detect the complication as early as possible.

Results. As an application of the proposed framework we considered the problem of diagnosing patients with postoperative delirium. We explored a data set extracted from the Department of Gastrointestinal Surgery at the University Hospital of North Norway from 2004 to 2012. A clinician made a list of surgeries of interest, basically consisting of major abdominal surgeries requiring general anesthesia. Based on this, 1138 patients who potentially could suffer from postoperative delirium were selected into a cohort. The results showed that we were able to make better predictions using the proposed deep anchor method. More specifically, we increased the area under the precision-recall curve from 0.76 (when using the anchor method) to 0.86 (using the proposed deep anchor method). These results might ultimately benefit both the patients, in terms of reduced morbidity and mortality, and the caregivers, in terms of a more correct coding and reduced costs.
Main activity 3: Pilot on polyp detection

Description of activity

This activity will develop a first pilot on polyp detection and characterization using the team’s expertise on convolutional neural networks. Further, strategies will be developed for integration of the pilot results into a joint processing pipeline for data fusion of imagery and EHR.

What we did

We started already in April 2017 and the activity is still ongoing even though the pilot is developed. In what follows we give a brief explanation of colorectal cancer and polyps, and the Convolutional Neural Networks (CNNs) we have been using so far.

Colorectal cancer and polyps. Colorectal cancer is one of the highest causes of cancer-related deaths worldwide and has been estimated to be the most expensive cancer to treat in Norway. Advanced colorectal cancer have poor survival rate, but early diagnosis has shown to drastically increase the chance of survival. For these reasons the Norwegian government is considering a screening process to increase the chance of early detection. A screening for colorectal cancer is usually done through optical colonoscopy which is performed manually by a physician. Such a procedure usually has a high detection rate but is still affected by human factors such as fatigue. If a screening is introduced it would increase the amount of examinations that a physician must perform, possibly enhancing the effect of human factors. In addition, patients can currently expect a couple of weeks waiting time. Hence, the benefits of early detection are obvious but there are practical issues to tackle.

Figure 5: Examples of images containing polyps.

Colorectal cancer usually begins as a polyp. Polyps are abnormal growth of tissue which grow through rapidly dividing cells and could be precursors to colorectal cancer. Detection and removal of colorectal polyps is usually done with a colonoscopy, as mentioned previously. Polyps come in many different shapes and forms. Quality of images might differ, shading and glare might distort the view of polyps and stool, blood and water might make things even more difficult. See Figure 5 for examples of images containing polyps. Experienced physicians can usually overcome these difficulties but automatic poly detection models have had more difficulties. However, recent development in machine learning, and especially deep learning, have made great advances in fields like object recognition and segmentation. Applying deep learning models to medical images such as colonoscopy images can make automatic poly detection feasible.
Polyp detection using Convolutional Neural Networks. CNNs are propelling advances in a range of different computer vision tasks such as object detection and object segmentation. The prospect of automatic image assessment has prompted research in application of such models for medical image analysis. If CNN-based models are to be helpful they need to be precise, interpretable and the models uncertainty must be well understood. For the first time in colonoscopy image analysis, we introduced the idea of uncertainty quantification by leveraging so-called dropout. This gives the clinician a sense of how certain the system is in its polyp/no-polyp decision on the pixel level. We also analysed interpretability by guided back-propagation, to investigate which pixels of the colonoscopy images that drives (explains) the decision-making.

Figure 6: An illustration of the Fully Convolutional Network (FCN-8s). Color codes description: Blue: Dropout, Convolution(3x3), Batch Normalization and ReLU, Yellow: Upsampling, Pink: Summing, Red: Pooling(2x2), Green: Soft-max.

For our experiments we compared two different network architectures. We employed the Fully Convolutional Network (FCN-8s) architecture that learns a multi-stage upsampling to produce a pixel level classification (segmentation) by combining the output of the final convolution layer with the third and the fourth pooling layer. The architecture is depicted in Figure 6. The second architecture that we considered was a variant of the vanilla Segnet, where Dropout is added after the three central encoders and decoders. We evaluated our methods on the EndoScene1 dataset for endoluminal scene object segmentation introduced in 2. The first two columns of Figure 7 display a colonoscopy image example from the dataset and the corresponding polyp annotation.

Results. The fourth column and fifth column of Figure 7 shows the uncertainty maps and visualization of descriptive image regions in the input image for the predictions shown in column three of Figure 7.

1 http://www.cvc.uab.es/CVC-Colon/
The fifth column of Figure 7 shows visualization of descriptive image regions in the input image for the predictions shown in column three of Figure 7. Both the FCN-8 and Segnet model seem to agree that features extracted from the top left half of the polyp contains important information. However, while the FCN-8 model focuses only on the polyp, the Segnet model also concerns itself with parts of the colon itself. Even thought both models obtained successful segmentation in Figure 7, Segnet achieved worse performance overall, and this failure to isolate important features in the input might explain some of the difference in performance.

Much more details about this activity can be found in the internal report written by Kristoffer Wickstrøm and the paper [17] submitted to the conference BHI.

In parallel we have devised a strategy that will allow us to integrate image and EHR data into a joint processing pipeline. Both the autoencoder in main activity 2 and the convolutional neural network in main activity 3 can be viewed as feature extraction methods. By concatenating the autoencoder features and the last layers of activations from the convolutional neural network, we can combine the information from both image and EHR for further joint processing. One issue that can arise in these scenarios is missing modalities, as not all patients might have image data available. To handle these scenarios we have recently looked into the challenge of missing data modalities [8][9].
Main activity 4: Partners: Execution plan and risk mitigation

Description of activity

This main activity will consist of organizing at least two workshops both in Tromsø and at partner institutions. The aim is to establish a joint plan for partner roles (scientific and user) and identify areas of contribution and project plan and risk execution, as well as developing risk mitigation procedures. These sessions will aim to map special competences at partners to be included in the project, such as the exploitation of specialized methods within the context of the project, e.g. IBM’s natural language processing tools, or TUB and UA expertise on interpretable models for the medical domain. The Phase 1 project report will be conducted within this activity.

Figure 8: A short description of all our partners.

What we did

In Phase 1, we have further built the DeepHealth consortium, including now 18 partners, some which are new during Phase 1. We have for example started a new collaboration with University of Maribor, which has already led to a submission [10] (WP 1) and exchange of personnel. We
have had several workshops in order to map competences and analyze risk, both in Norway, Spain, US, and the Netherlands. A complete description of everything we did in Main activity 4 is shown in Table 2. Figure 8 and Figure 9 show a list of all the partners and this list can also be found at the webpage https://site.uit.no/deephealthresearch/partners/.

All the partners involved in DeepHealth are also illustrated in Figure 10. The inner circle of DeepHealth consists of UiT The Arctic University of Norway and UiT Machine Learning Group, and our collaborators at the University Hospital of North Norway (UNN), The Norwegian Center for E-health Research (NSE), Norwegian Computing Center (NR), and the Rey Juan Carlos University (URJC). All these partners are explicitly included in the budget of DeepHealth and will contribute to the project nearly on a daily basis. Our collaborators at Stockholm University (Hercules Dalianis), University of Exeter (L. Livi), University of Bristol (R. Santos-Rodriguez), University of Amsterdam (M. Welling), Technical University of Berlin (TU Berlin) (K. Muller) and IBM’s Center for Computational Health (J. Hu) are also important partners, and the three latter will host a DeepHealth member each during phase 2 of the project. The outer circle contains the collaborators DIPS, Helse Nord IKT, University of Maribor (G. Stilic), Healthplus.ai, University Hospital of Sureste, University Hospital of Mostoles and University Hospital of Fuen-
Figure 10: The inner circle of DeepHealth consists of UiT Machine Learning Group and our collaborators at NSE, NR, UNN and URJC. Stockholm University, University of Exeter, University of Bristol, University of Amsterdam, Technical university of Berlin and IBM are also important partners and the three latter will host a DeepHealth member each during phase 2 of the project. The outer circle contain collaborators that are important for the project, but will not be involved on a daily basis in the project.

These partners possess knowledge and competences that also are vital for the project, but will not be involved on a daily basis in the project.

Figure 11 shows an overview of the competences and planned areas of contribution for the different partners in Phase 2 of the DeepHealth project. As we can see illustrated in the figure, 6 of the partners possess expert knowledge on deep learning and machine learning in general. The remaining 12 partners possess a very complementary expertise on healthcare analytics and healthcare in general.

Partners with expertise on Deep learning. The Technical University of Berlin and University of Amsterdam have two of the worlds leading groups on foundational deep learning research. Both Muller’s group in Berlin, and Amsterdam Machine Learning Group headed by M. Welling, possess expert knowledge on interpretability in Deep learning and will therefore be vital for...
discussions and joint research projects on how to develop interpretable deep learning models specially tailored towards electronic health record research. Both groups will host a DeepHealth member for some time in Phase 2. These two groups will also be important for developing methods for calculating uncertainty in deep models. To be able to make predictions and at the same time estimate the certainty of the prediction is of major importance if the systems should be implemented in the clinic and was therefore identified as an important foundational research topic during Phase 1.

Our collaborators at the Norwegian Computing Center are experts on deep learning for image analysis and will therefore be important for deciding what deep learning methodology to apply for analysis of the surgical imagery and polyp images, in particular. The project is perfectly aligned with NR’s strategy, and will help drive forward research at the institution in this direction, leading to new opportunities for funding e.g. over the H2020 system. NR will have office space available for project team members in order to spend time in Oslo for seamless collaboration. NR will participate in project workshops and will take part in the dissemination of project results.

Moreover, the young researchers L. Livi (U Exeter) and R. Santos- Rodriguez (U Bristol) are close collaborators and are aligning their groups with DeepHealth at the intersection of deep learning and health. In addition they are experts on machine learning in general. Because of the problem of getting labelled data from the electronic health records to develop new unsuper-
vised machine learning methods will be prioritized, and the knowledge that these two partners have, will be important for developing such methods specially tailored towards healthcare data, in addition to developing new time series analysis methods that can deal with uncertain and incomplete data. Dr. Livi and his group have recently published several papers on neural networks specifically designed to process time series data. This type of expertise will be important to train and supervise students allocated on the DeepHealth project working on deep learning methods to classify time series.

**Partners with expertise on healthcare and healthcare analytics.** DeepHealth plan to leverage our long-term relation with IBM’s Center for Computational Health, headed by J. Hu (who has visited Jenssen’s group, and one researcher from Tromsø spent a year at IBM). In particular, IBM’s natural language processing tools, will be exploited for representing the free text in the electronic health records. In addition, in order to ensure that DeepHealth leverages domain specific knowledge when available in the context of NLP for free text, we have included expert Prof. Hercules, University of Stockholm, as a new partner. Moreover, we have together sent a proposal to the regional health trust fund of North Norway (Helse Nord) for a NLP project that will complement the text analysis part of DeepHealth.

DeepHealth will continue to work closely with the Rey Juan Carlos University in Madrid and in particular C. Soguero Ruiz. She has been vital to the team’s publications on machine learning and EHRs, and will have a 20% position in the project, and she will supervise a PhD candidate. Soguero-Ruiz will visit UiT several times per year (weeklong or month-long) and participate actively in research, management, and supervision during these periods. Universidad Rey Juan Carlos will also host DeepHealth members for shorter or longer periods of time. University of Maribor will also be partner. These two collaborators possess expert knowledge on analysis of electronic health records using machine learning and will therefore be important for developing methodology for use in work package 1. In addition, via Rey Juan Carlos University’s close collaboration with the University Hospital of Fuenlabrada, University Hospital of Mostoles and University Hospital of Sureste, we have a back-up if it turns out that we need more data. These three Hospitals are now also partners of DeepHealth and will be users of the project results.

Healthplus.ai is a company with expertise on healthcare and artificial intelligence and provide people, professionals and organizations with artificial intelligence tools that help solve medical and health related challenges. In more detail, the company’s interests span development of neural networks, application and clinical validation in health, and certifying and supplying these algorithms as scalable solutions to health care providers by incorporation of the algorithm in their workflow. Health plus.ai is for example working on prediction of postoperative complications together with Leiden University Medical Center (LUMC). Since DeepHealth will focus on prediction and prevention of complications, we foresee that Health plus.ai can contribute in discussions and joint research projects with their experience. Moreover, DeepHealth’s focus on the application of the research on uncertainty quantification and the development of probabilistic deep models, is especially relevant for the partnership, as Healthplus.ai has developed a model to predict infections after operations with data from Dutch hospitals. Currently, Healthplus.ai is in the process of improving, re-validating, testing, publishing and implementing the post-operative infection predictor algorithm with three major hospitals in Western Europe. They will share details on the results and will therefore provide us with vital experience on operationalization.

The company has a broader health and health care focus and is currently expanding the number of solutions it is developing. It is thus also possible to co-operate in other clinical and health challenges. Within the DeepHealth focus and because of the common interests, they will also
collaborate with us on novel and interpretable methodology development, research methodology, exchanging knowledge, and potentially exchange data, and host one of the project’s postdoctoral fellows.

The University Hospital of North Norway will be the main user of the project results. Prototypes of systems and algorithms developed by DeepHealth will be implemented there. They will participate actively in most of the activities in the DeepHealth project and will in particular be responsible for planning how to evaluate the outcome of the project. The Norwegian Center for E-health Research (NSE) also has competence on monitoring impact of e-health solutions, and will be important in that respect together with DeepHealth’s clinicians. Moreover, NSE has extensive experience in retrieving and analyzing data from EHRs, which will be utilized in Phase 2. NSE is in the process of employing a researcher to lead NSE’s health data analysis research activities, who will collaborate with this project.

DIPS has participated in the pre-project phase. As described under main activity 1, this includes participation in a workshop in Tromsø 6. Sept 2017 by Product Line Manager F. Stokland, and the UiT team behind the proposal “Deep Learning for Health”, in addition to representatives for the University Hospital of North Norway and the Norwegian Center for E-health Research. DIPS plans to develop a prototype system for integrating results from DeepHealth into the DIPS EPJ. A graphical interface (API) will be produced by DIPS over own funding as a concrete commitment. This will greatly aid the potential impact of the project, and will be beneficial for DIPS as well as for the DeepHealth team. It will also enable validation of project results in the context of operational use in the clinic. Helse Nord IKT has been responsible for retrieving data from the electronic patient journals which the current proposed project Deep Learning for Health, PI R. Jenssen, builds on. Helse Nord IKT thus exhibits needed competence and is a natural partner in such a project given their in-depth knowledge of the ICT systems for extraction of data and for technical solutions. They have participated in phase 1 at workshops discussing technical solutions for prototype development and operationalization. Helse Nord IKT will participate in this project as collaborators, and be integral partners in a wider activity in Tromsø on innovative solutions for data-driven health, including aspects related to RRI, law, and ethics. More details about DIPS’ and Helse Nord IKT’s roles in the project are described above under Main activity 1.

Risk mitigation. DeepHealth is a long-term research endeavor of high risk due to the ambitious aim of pushing the frontier of data-driven health using cutting edge deep learning research. Therefore, in addition to establishing a joint plan for partner roles and identifying areas of contribution, we have in Phase 1 also been identifying risks of the project and mitigation procedures, and established back-up plans.

Working with leading international experts in the field, guarantees that alternative research strategies are available in case technicalities come up. Risks, likelihoods, impacts, and actions are shown in Table[1].

Moreover, in order to anchor DeepHealth at an institutional level in Tromsø and nationwide, our scientific advisory board (SAB) is extended with: Dean at the Faculty of Science at UiT M. Hald; Director T. Ingebrigtsen at UNN; Director S. Skrøvseth at NSE; and Director E. Fosse of the Intervention Centre at the Oslo University Hospital and leader of the BigMed ICT Lighthouse [http://bigmed.no/]. These are strong alternatives if it turns out that collaboration with our closest international collaborators is difficult. IBM will be difficult to replace but Hercules Dalianis’ group at Stockholm University possess similar competences and is therefore a good alternative.
Table 1: Risks, likelihoods, impacts, and actions of the DeepHealth project.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Likelihood</th>
<th>Impact</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collaboration with closest int. collaborators difficult (U Amsterdam, TU Berlin, IBM)</td>
<td>10 %</td>
<td>40 %</td>
<td>We have strong alternatives (e.g. within SAB). IBM will be difficult to replace.</td>
</tr>
<tr>
<td>Computational complexity cannot be made feasible for real-time operations</td>
<td>20 %</td>
<td>40 %</td>
<td>Focus more on retrospective aspects.</td>
</tr>
<tr>
<td>Relatively small data sets in some cases after stratification, or problems with availability of enough Da Vinci data.</td>
<td>60 %</td>
<td>40 %</td>
<td>Difficulty with Da Vinci data, puts more focus on EHR and imagery. Small data lifts research on unsup/semi-sup methods.</td>
</tr>
<tr>
<td>Additional EHR data not available from UNN.</td>
<td>5 %</td>
<td>20 %</td>
<td>We also have access to relevant EHR data via U Rey Juan Carlos and health plus.ai.</td>
</tr>
<tr>
<td>Difficulty recruiting personnel.</td>
<td>5 %</td>
<td>70 %</td>
<td>We have very good candidates.</td>
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Strategic initiative by UiT - Center for data-driven health technology. UiT has put in a massive effort to further build machine learning as a strategic research area, particularly for health technology aligned with DeepHealth and UNN, by initiating a center for data-driven health technology. This center will be inter-disciplinary as it will consist of members from the Department of Science and Technology, Department of Mathematics and Statistics, and Faculty of Law. We have also included top professors from the UiT Faculty of Law into the network because in many applications of machine learning algorithms, also in healthcare applications, there is a considerable law component (new regulations, privacy, explanation of algorithmic decision making).
Main activity 5: Dissemination

Description of activity

This activity will present the details of the DeepHealth project (purpose, results) as well as information about machine learning and data exploitation for health in general to the general public for knowledge-building by creating a website. This site will have user request and answer capabilities for interaction purposes. In addition, internal project dissemination (for team members) for streamlining the work process will be established using GitHub and cloud solutions.

What we did

This activity is done as planned. We have created the webpage [http://site.uit.no/deephealthresearch/](http://site.uit.no/deephealthresearch/) where the people and partners of DeepHealth are described. In addition, the webpage describes the purpose of DeepHealth and the projects that we are working and it has a news feed. UiT Machine Learning Group’s Facebook page is also used for dissemination.

Platforms for internal project dissemination and sharing work and data, have been created using the university’s Github system at [https://source.uit.no](https://source.uit.no) and cloud solution at [https://uitno.app.box.com](https://uitno.app.box.com). In addition, a common Sharelatex account is created for making the process of writing papers and research projects together easier.

Jenssen has given several invited talks about DeepHealth research during Phase 1: Kongsberg company technology conference, Tekna Health Data Analysis conference, NORBIS conference and a UiO invited lunch talk.

In addition to dissemination to the general public via the web page, we have also been active disseminating our research in peer-reviewed conferences and journals during Phase 1. In total there are 7 submitted and published journal papers, one book contract, and 8 conference proceedings papers. Figure 13 shows an overview of the publications.

The book manuscript [1], journal paper 1 + conference paper 5 [12][11], journal paper 2 + conference paper 6 [9][8], journal paper 3 [14], journal paper 8 [10], conference paper 1 [16], and conference paper 2 [2] all deal with heterogeneous fusion and missing data. Within this category, the papers [12][11][9][8] are purely methodological, whereas [14][16][2] are papers on EHR-based prediction and prevention (Work package 1). The book manuscript [1] describes methodology useful for analysis and guidance of DaVinci surgical procedure (Work package 3).

Conference paper 4 [17] belongs to the interpretability and uncertainty category, whereas journal paper 7 + conference paper [6, 7] are on the boarder between the two latter categories. These publications are all described other places in this document.
Additional activities done in Phase 1

In addition to the main activities we have described above we opened up two new lines of concrete EHR analysis research in Phase 1 related to recurrent neural networks for handling blood sample time series with missing data. Moreover, in parallel to application-oriented EHR research we have done, we have worked hard in several different directions on foundational research in machine learning, as we have identified that there is a need for developing completely new methodology for use in DeepHealth (for example on how to deal with uncertainty and interpretability in Deep learning). We briefly describe these additional activities below.

Classification of blood time series using recurrent neural networks

![Figure 14: Schema of the GRU-D cell. Modification with respect to the original GRU architecture are highlighted in blue.](image)

In this project we took inspiration from [Z. Che, S. Purushotham, K. Cho, D. Sontag, and Y. Liu, “Recurrent neural networks for multivariate time series with missing values,” CoRR, vol. abs/1606.01865, 2016.](#)

In this project we took inspiration from and introduced the so-called GRU-D recurrent unit for supervised classification of multivariate blood test time series into two classes: patients

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developing wound infections, or not. The novelty of GRU-D is to account for the pattern and temporal structure of missing data. The architecture of the GRU-D network is illustrated in Figure 14 and Figure 15. As a new training criterion, we proposed a weighting scheme based on the frequency of classes, resulting in an improvement of AUC from 0.86 (standard RNN network) to 0.91 (using the GRU networks). More details can be found in our paper that is submitted for publication [16].

Deep compression of blood time series using a recurrent autoencoder

Another important problem we started to work on in Phase 1 is the development of deep neural networks for compressing or distilling time series data from the electronic health records containing missing data (here obtained from blood tests) into a vectorial representation using a specially designed auto-encoder. More precisely, we utilized the deep kernelized autoencoder (dkAE) [5], an architecture that embeds the properties of a given prior kernel in the code representation of an AE through kernel alignment. By introducing the time series cluster kernel (TCK) as prior kernel (also developed by us during Phase 1 [11, 12]), we extended the dkAE framework to time series. Moreover, due TCK's properties, the relationships among the learned codes accounts for the presence of missing data, yielding a more discriminative representation of the data. Figure 16 illustrates the proposed method and architecture. A detailed description of the different components, and the method itself, can be found in [2].

We applied the method to the problem of detecting surgical site infection, based on blood samples only, at patients that have undergone a surgery at the department of gastrointestinal surgery at the University hospital of North Norway. We compared the classification results to other baselines such as a standard autoencoder. The results indicate that the learned codes from our proposed framework not only provide a compact vectorial representation, but the same classifier achieves better results when operating in the code space rather than in the input space. That we are able to do this opens up numerous opportunities to tap in to the vast array of machine learning methodology for visualization, clustering, and classification of the times series when represented by the autoencoder.
**Foundational basic research**

During Phase 1, it became clear that even more disruptive scenarios will be materialized by pushing foundational research on cutting-edge solutions when there are even no labels at all (fully unsupervised and discriminative), for solutions that are interpretable, and for quantifying uncertainty in decisions. After all, the vast majority of data recorded in EHRs are not labelled.

Moreover, for machine learning and deep learning to be adopted in health, interpretability and uncertainty quantification in predictions are key. Traditional solutions such as linear models and logistic regression offers opportunities for interpretability but have severe limitations on complex data such as in this project. Deep learning methods of today are however inherently black-box models.

In close collaboration with Universad Rey Juan Carlos, University of Exeter, and the Norwegian Computing Center, we have been working on these grand fundamental challenges during Phase 1. As a result, in Phase 1, we have developed one of the first fully unsupervised deep discriminative convolutional neural networks for clustering worldwide, presented at the IEEE MLSP conference in Tokyo, Sept. 2017 [7] and a journal extension was submitted [6]. We developed the so-called kernelized autoencoder, which provides a new unsupervised way of representing class/cluster structure in a deep autoencoder representation (receiving best paper award at SCIA June 2017) [5] and are working on a journal extension [4]. Key to this deep learning method is a regularization of the network by incorporating ideas from kernel machines (a different but related framework in machine learning), using a new concept we developed and presented also at IEEE MLSP, denoted the time series cluster kernel [11], utilized towards prediction of postoperative wound infections in several different works [13, 2]. The time series cluster kernel framework was extended and will appear in the Pattern Recognition Journal soon [12].

We developed furthermore a so-called hallucination deep network for tackling missing data [8, 9]. Moreover, inherent in the deep anchor approach (main activity 2) is a clustering procedure to help clinicians define the anchors. This new clustering method was also published as a part of Phase 1 [15]. Finally, on foundational research, we investigated in Phase 1 recurrent neural networks for time series analysis, and realized that in order for us to make contributions on the basic methodology, a comprehensive comparative analysis of the state-of-the-art for RNNs in time series is needed. The manuscript we wrote on this is now contracted with Springer for release as a book in 2018 and is already now available on Arxiv [1].

**Deep Learning workshop**

Jenssen and the consortium behind DeepHealth is organizing the 1st Northern Lights Deep Learning Workshop in Tromsø in January 2018 with top invited speakers, and will build on this international event for providing visibility to DeepHealth. More information about the workshop can be found at the webpage [http://nldl2018.org/](http://nldl2018.org/) (Figure 17).
Figure 17: We will host the 1st Northern Lights Deep Learning Workshop in Tromsø in January 2018.

**List of activities**

Here we summarize all activities done during Phase 1.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Time per</th>
<th>Main result</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1 Workshop in Tromsø on operationalization, clinical use.</td>
<td>Aug</td>
<td>Plan for operationalization in place by developing and testing impact of prototype. Company DIPS crucial partner.</td>
</tr>
<tr>
<td>Getting direct access to EHR data</td>
<td>Apr-Nov</td>
<td>Two members of UiT Machine Learning Group have been partially employed by UNN in order to be granted direct access to the data base, enabling better implementation.</td>
</tr>
<tr>
<td>M2 Recruiting project researchers</td>
<td>Apr-May</td>
<td>Researcher and internship student to work on deep anchor prototype.</td>
</tr>
<tr>
<td>Deep anchor prototype</td>
<td>Apr-Dec</td>
<td>Developing the deep anchor method (very good results), discussing implementation of prototype in clinic (M1).</td>
</tr>
<tr>
<td>Conference paper submitted</td>
<td>Oct</td>
<td>We wrote a paper on the deep anchor method and the results we achieved [3].</td>
</tr>
<tr>
<td>M3 Recruiting project researchers</td>
<td>Apr-May</td>
<td>Internship student employed to work on developing pilot.</td>
</tr>
<tr>
<td>Polyp detection pilot</td>
<td>May-Dec</td>
<td>Pilot study of polyp detection based on colonoscopy imagery.</td>
</tr>
<tr>
<td>Conference paper submitted</td>
<td>Oct</td>
<td>We wrote a paper on the polyp detection pilot [17].</td>
</tr>
<tr>
<td>M4 Two different workshops in Madrid</td>
<td>May, Jul</td>
<td>Active research. Plan for Phase 2. UiT and URJC.</td>
</tr>
<tr>
<td>Workshop in Tromsø</td>
<td>Sep</td>
<td>Participants from Madrid, UNN, NSE, and UiT.</td>
</tr>
<tr>
<td>Workshop in Oslo</td>
<td>Sep</td>
<td>Participants UiT; U Amsterdam; Health plus.ai</td>
</tr>
<tr>
<td>Workshop in Amsterdam</td>
<td>Oct</td>
<td>Participants UiT; U Amsterdam; Health plus.ai</td>
</tr>
<tr>
<td>Workshop in Tromsø on interpretable models (at SCIA)</td>
<td>Jun</td>
<td>Plan research on interpretability.</td>
</tr>
<tr>
<td>Workshop in Tromsø</td>
<td>Nov</td>
<td>Participants: TU Berlin; NR; UNN; NSE; UiT</td>
</tr>
<tr>
<td>Active research. Plan for Phase 2. UiT and U Exeter.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M5 Setting up web-page</td>
<td>Apr-Nov</td>
<td>Dissemination</td>
</tr>
<tr>
<td>Dissemination talk</td>
<td>Apr-Nov</td>
<td>Presenting work [5]. Organizing DeepHealth workshop at the same time.</td>
</tr>
<tr>
<td>Organizing and participating in the Scandinavian Conference on Image Analysis (SCIA) in Tromsø</td>
<td>Jun</td>
<td>Presenting work [5]. Organizing DeepHealth workshop at the same time.</td>
</tr>
<tr>
<td>Participation in MICCAI in Tokyo</td>
<td>Sep</td>
<td>Presenting work [14,15]. Romishing new proteins (UIUC).</td>
</tr>
<tr>
<td>Journal publications</td>
<td>Apr-Dec</td>
<td>Analysis of time series data from the EHR [16].</td>
</tr>
<tr>
<td>Two conference papers submitted</td>
<td>Oct</td>
<td>Analysis of time series data from the EHR [16].</td>
</tr>
<tr>
<td>Journal papers submitted</td>
<td>Apr-Oct</td>
<td>Analysis of time series data from the EHR [16].</td>
</tr>
<tr>
<td>Book publication</td>
<td>Apr-Sept</td>
<td>A book manuscript is contracted with Springer [1].</td>
</tr>
<tr>
<td>Journal paper manuscripts</td>
<td>Oct-Dec</td>
<td>Papers that will be submitted in Nov/Dec [4,13].</td>
</tr>
<tr>
<td>Recruiting project researchers</td>
<td>Apr-May</td>
<td>Researcher and internship students to work on DeepHealth in collaboration with group members. Journal/conf. papers.</td>
</tr>
<tr>
<td>Northern Lights Deep Learning Workshop</td>
<td>Jan 2018</td>
<td>Organize workshop in Tromsø with top invited speakers.</td>
</tr>
<tr>
<td>Participation and meeting at AMIA conference</td>
<td>Nov</td>
<td>Being represented to learn about methods and experiences with designing and evaluating user interfaces in healthcare.</td>
</tr>
<tr>
<td>Recruiting new collaborator</td>
<td>Aug-2018</td>
<td>Build on this event for providing visibility to DeepHealth.</td>
</tr>
<tr>
<td>Organizing special course</td>
<td>Aug-Nov</td>
<td>One of the candidates for Phase 2 postdoc is currently at U Carnegie Mellon, opening up a new collaboration for project.</td>
</tr>
<tr>
<td>Jansen organized a special course on deep learning for the project researcher and the senior students.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Table 2: Activities done in Phase 1. |

List of submitted papers/publications in conferences and journals


Conclusion

To achieve what we aimed for in the main objective of Phase 1, we have further built the DeepHealth consortium, including now 18 partners. Because we identified weaknesses with the DeepHealth project during Phase 1 and to reduce the risk of the project, some of the partners are new and were added during Phase 1. We have been travelling abroad to visit our partners and invited some of them to Tromsø, and we have arranged several workshops in order to map competences, analyze risk and discuss research, both in Norway, Spain, US, Japan and the Netherlands. Firm commitment from partners has been obtained, risk assessment has been conducted, and the consortium has been consolidated and extended.

As we have described above, we have during Phase 1 been very active doing research relevant for the DeepHealth, both purely methodological (since we identified several weaknesses during Phase 1) and concrete, health-oriented research. In fact, due to the momentum we built, we did much more than what we originally planned. Nevertheless, the DeepHealth project is far from solved, new challenges and weaknesses have been identified during Phase 1 and for that reason we conclude that the project should continue to Phase 2.
Letters of support

We have attached the letters of support from all our partners.
Letter of commitment

To whom it may concern.

This is to confirm the strong commitment from the University Hospital North Norway (UNN) to the project “Deep Learning for Health” proposed by R. Jenssen.

As one of the first hospitals worldwide, UNN have allocated resources for retrieving, pre-processing, and making available EHR data, for DeepHealth, from the entire Department of Gastrointestinal Surgery for the years 2004 until today. One of the motivations for doing this is that any reduction in postoperative complications will have a huge impact on the well-being of the individual patient at risk, and even a small reduction will have huge impact on readmissions and overall cost in healthcare. The DeepHealth team members at UNN include Prof Rolv-Ole Lindsetmo (Director Division of Surgery, Oncology and Womens Health) and Prof Arthur Revhaug (Director Research, Education and Innovation, Division of Surgery, Oncology and Womens Health), and our group of surgeons, representing state of the art clinical expertise related to gastrointestinal surgery. We have in recent years worked hard on research for mining electronic health records (EHR) for extracting clinically relevant information and detecting postoperative complications and look forward to continuing the collaboration via the DeepHealth project.

We understand that the Gastrointestinal Surgical Department at UNN will be the main user of the project results. Prototypes of systems and algorithms developed by DeepHealth will be implemented there. Revhaug and Lindsetmo will participate actively in most of the activities in the DeepHealth project and will in particular be responsible for utilization and evaluation of DeepHealth results. Revhaug and Lindsetmo will be official co-supervisors for DeepHealth members. The already long established practice of having half-day evaluation meetings at UNN on alternative Fridays will be continued. We also confirm that one of the postdocs formally will be affiliated with UNN in order to ensure close contact and work methods.

In conclusion, UNN is strongly committed to the project.

Yours sincerely,

Rolv-Ole Lindsetmo and Arthur Revhaug
Stein Olav Skrøvseth,
Director Nasjonalt senter for e-helseforskning /
Norwegian Centre for E-health Research

Robert Jenssen
UiT Machine Learning Group
UiT The Arctic University of Norway

16 November 2017

Letter of commitment

To whom it may concern.

With this letter, I give my support to the project “Deep Learning for Health” (DeepHealth), which is headed by R. Jenssen.

The Norwegian Centre for E-health Research (NSE) was established 1st January 2016, with the objective of contributing knowledge for the Norwegian government’s e-health development, including a common national ICT solution for health and care services. Health analytics is a strategic research area for NSE, and a core aim for the national development in e-health. NSE has long experience in this area. NST (the predecessor to NSE) hosted the Research Council of Norway-funded Tromsø Telemedicine Laboratory, a Centre for Research Based Innovation (SFI – 2006-2014). The project Deep Learning for Health builds on activities started within that Centre (I was a researcher in the project at that time). PI Jenssen was formerly employed in a 20% senior researcher position with NSE. We have great expectations to this project both in terms of advancing basic research on health data analysis methodology, but also for operationalization via the development and testing of prototypes to be used in the clinic.

We have extensive experience in retrieving and analyzing data from EHRs, and will take an active role in that part of the project. We also have competence on monitoring impact of e-health solutions, and understand that we will be important in that respect together with DeepHealth’s clinicians.

In conclusion, NSE is strongly committed to the project.

Yours sincerely,

[Signature]

Stein Olav Skrøvseth
Robert Jenssen  
UIT Machine Learning Group  
UIT The Arctic University of Norway  

Letter of commitment

To whom it may concern

This is to confirm the strong commitment from the Norwegian Computing Center (NR) to the project “Deep Learning for Health” proposed by R. Jenssen in collaboration with NR. UIT Machine Learning Group, directed by Jenssen, and NR, are engaged in a long-term and strategic joint research effort on the topic of deep learning. Jenssen is employed in a 20% position with NR, collaborating especially with Senior Research Scientist Arnt-B. Salberg and Chief Research Scientist L. Eikvil on deep learning for applications (more information at the linked web-site). Jenssen and Salberg are together supervising three PhD students. Two of these students are based in Tromsø on a daily basis, and one is based at NR in Oslo on a daily basis.

In “Deep Learning for Health”, NR’s expertise, built over several years, on image analysis using deep convolutional neural networks, will be crucial. The project is perfectly aligned with NR’s strategy, and will help drive forward research at the institution in this direction, leading to new opportunities for funding e.g. over the H2020 system.

NR will have office space available for project team members in order to spend time in Oslo for seamless collaboration. NR will participate in project workshops and will take part in the dissemination of project results.

In conclusion, NR is strongly committed to the project.
Call: Norwegian Research Council's IKTPLUSS program call "Ubiquitous data and services".

Project: Deep learning for Health (DeepHealth) - Prediction and prevention of postoperative complications

LETTER OF COMMITMENT

With this letter I, Javier Ramos López, in my capacity as legal representative (Rector) of Rey Juan Carlos University hereby confirm on behalf of our institution that my organization intend to commit the project entitled "Deep learning for Health (DeepHealth) - Prediction and prevention of postoperative complications", coordinated by University of Tromsø, addressed to the Norwegian Research Council's IKTPLUSS program call "Ubiquitous data and services".

Our institution is fully committed to be Project Beneficiary and to contribute to the project development by following up the collaboration between University of Tromsø and Rey Juan Carlos University. In particular, our researcher Cristina Soguero-Ruiz did her PhD partly in the Machine Learning Group at University of Tromsø, since then, she has been an associate member and a close long-term collaborator, especially on health related research from a machine learning viewpoint.

The project is well aligned within the activity of both universities. Furthermore, I confirm that the key staff involved in the project, will be available to fulfill the role outlined, and our organization will do everything to cooperate efficiently to achieve the proposed goals.

Name of the Legal Representative: Javier Ramos López

Position: Rector of Rey Juan Carlos University

Date: 20 October 2017
To: Robert Jenssen  
UiT Machine Learning Group  
UiT The Arctic University of Norway

Letter of commitment

To Whom It May Concern:

With this letter, I give my support to the project “Deep Learning for Health” (DeepHealth), which is headed by Assoc. Prof. R. Jenssen.

The project is well aligned with the research interests of my group, which span both basic research in neural networks as well as applications towards health. DeepHealth’s focus on basic research on uncertainty quantification and the development of probabilistic deep models, is especially relevant, as my group is one of the leading groups on Bayesian and variational inference (such as e.g. work on variational auto-encoders and Bayesian deep learning). I have delivered several keynote talks on such topics. My TEDx talk was entitled “Can we create a world without disease” where I highlight the issue of surgical procedures and postoperative complications. With such common interests in place, my group will collaborate with Jenssen’s team on novel and interpretable methodology development, exchange of people/students, as well as sharing of source code and data, when relevant.

I confirm that the AMLAB at the University of Amsterdam will host one of the project’s postdoctoral fellows and support routine expenses associated with the research to be carried out during this stay.

The project is also well aligned with the activities of a new joint research lab, AML4Health, that CWI and UvA are co-founding in November. In this
many machine learning projects related to healthcare will be bundled creating a synergetic environment for researchers in this exciting field. The DeepHealth project will be a perfect fit to be hosted in this lab.

The project will also collaborate closely with the startup Healthplus.ai headed by Bart Geerts (MD) for the purpose of operationalization and tech transfer.

If you have any questions, please feel free to contact me.

Max Welling,

Professor of Computer Science,
University of Amsterdam,
Institute of Informatics
Science Park 904, Room C3.259
Phone: +31 (0)20 525 8256 (+31 (0)652824913)
Email: m.welling@uva.nl / welling.max@gmail.com
Dear Professor Dr. Jenssen,

This letter is to verify my full support for the project “Deep Learning for Health” with Assoc. Prof. R. Jenssen as the PI. Clearly, I am aware of the contents of the proposal, which I find extremely interesting and timely. The foundational research focus on deep learning methodology is very much aligned with that of my group, in particular concerning interpretability of deep models. Our group is one of the first research groups worldwide to pursue research in this direction. Recently, I could deliver keynote talks and tutorials on the topic at for instance SCIA 2017 in Tromsø, as well as in ICASSP 2017, and NIPS 2017. Also I will run a workshop on interpretable AI at this year’s NIPS conference.

My group will collaborate closely with Jenssen’s team on novel and interpretable methodology development and theory, exchange of people/students, as well as share source code and data.

I furthermore confirm that the Machine Learning Group at the Technical University of Berlin will host one of the project’s postdoctoral fellows and support routine expenses associated with the research to be carried out during this stay.

I look very much forward to further intensify the fruitful collaboration with Prof. Jenssen’s team.

Please let me know in case I can provide you with any additional information.

Sincerely,

Prof. Dr. Klaus-Robert Müller
To whom it may concern

I am aware of the contents of the proposal “Deep Learning for Health”, which builds on a long-standing relation between PI Jenssen and his collaborators at the Norwegian Center for E-health Research and the University Hospital of North Norway, and my group at IBM. A researcher from the group in Tromsø, Norway visited IBM Thomas J. Watson Research Center in Yorktown Heights for a year, conducting research that the proposed project builds on.

The Center for Computational Health at IBM has been active in foundational and applied research on the mining of patient data from electronic health records for several years, taking international leadership. For example, IBM has published and patented algorithms based on new measures of patient similarity for predictive analysis using machine learning related to mortality and re-hospitalization, and I have myself given several keynote talks on such topics, as well as organizing workshops and conferences (e.g. within ICPR and AMIA conferences). Jenssen was an invited speaker at one such workshop in December 2016. Our group has published recent work on deep learning in a health analytics context, which is aligned with the focus of this project.

With this letter, I want to state my personal opinion that “Deep Learning for Health” will move forward the field of health analytics and machine learning. I confirm that we will examine ways to work together with this initiative, including considering hosting the project’s Post-doctoral fellow for a long-term stay of up to 10 months.

Best,

Jianying Hu
Global Science Leader, AI for Healthcare
Program Director, Center for Computational Health
IBM Thomas J. Watson Research Center, Yorktown Heights, NY USA
Robert Jenssen  
UiT Machine Learning Group  
UiT The Arctic University of Norway

Letter of commitment

With this letter, I give my support to the project "Deep Learning for Health" (DeepHealth), which is headed by Assoc. Prof. R. Jenssen.

The project is well aligned with the research interests of my group, which span deep and recurrent neural networks, time series analysis, complex and time-varying networks, with applications on medical time series (e.g., EEG and ECG signals) and in systems neuroscience (e.g., dynamics of neuronal functional connectivity). I have an ongoing, long-term collaboration with the group of Prof. Jenssen and we have already published several papers together in international conferences and first-rate journals, such as IEEE Transactions.

DeepHealth's focus on developing deep learning methods for analyzing both static (e.g., images) and dynamic (e.g., time series) medical data is very relevant to my research. Currently, my group is collaborating with neuroscientists and medical doctors on projects involving EEGs for the detection of the onset of epileptic seizures by means of time series analysis methods and recurrent neural networks. In addition, my group is collaborating with partners in Switzerland on a project involving the analysis of ECG signals for predicting the onset of atrial fibrillation. The project aims at developing prediction methods that can run on embedded devices.

Within the DeepHealth focus and because of the common interests, my group will collaborate with Jenssen's team on novel and interpretable methodology development, research methodology, exchanging knowledge, data, and research students and fellows. I confirm the full commitment of my group and the Department of Computer Science at the University of Exeter to host PhD students and research fellows working on the DeepHealth project.

Yours sincerely,  
Dr. Lorenzo Livi
To whom it may concern

I am a Senior Lecturer in Data Science and Intelligent Systems at the Department of Engineering Mathematics of the University of Bristol, and a member of both the Digital Health Engineering Group and the Intelligent Systems Group.

Digital health is currently one of the research priorities of the University of Bristol and involves collaborative activities with the National Health System and the Bristol City Council. These strengths are exemplified by a broad range of world-leading research capability at Bristol, together representing £100M of investment. More concretely, the recently created Digital Health Engineering Group focuses on the acquisition, communication and analysis of data associated with long term health conditions, involving a cross-disciplinary team of academics in areas of machine learning, microelectronics and wireless sensors, communications and smart materials. The group leverages more than £15M in several research initiatives, including the EPSRC SPHERE platform, the MRC Cuboid or the H2020 EurValve, which are developing an integrated suite of robust, scalable, pervasive sensing and data analytics technologies. One of the key capabilities that needs further study involves the design and implementation of novel supervised and unsupervised machine learning pipelines that can process raw data from heterogeneous sensors into knowledge.

Throughout the years, R. Jenssen has become a close and valued colleague. I have visited R. Jenssen at UiT The Arctic University of Norway for collaboration, and I have hosted Jenssen in Bristol for the same purposes. We share research interests in machine learning and deep learning in particular, as well as in the application of such methods in the healthcare domain. The project “Deep Learning for Health” fits naturally as an activity of mutual research interests between myself and Jenssen, and our respective groups. My group is therefore fully committed to participating in this innovative project as collaborators. We will continue to exchange ideas and expertise as we already do, and to transfer knowledge between the groups by mutually beneficial visits and participation in scientific project workshops. Our expertise on health-related projects will be shared with Jenssen and his team, and vice versa, and we envision joint publications, as well as sharing of code and data.

I would therefore like to express my strongest and unconditional support for “Deep Learning for Health”. If there are any questions I can answer, please feel free to contact me again.

Sincerely,

Raul Santos Rodriguez
Kista, October 23, 2017

Letter of Support for project proposal Deep Learning for Health

To whom it may concern

I have been invited as a collaborator for the project Deep Learning for Health by Associate professor Robert Jenssen, UiT Machine Learning Group, UiT The Arctic University of Norway

I fully support his proposal as it is perfectly aligned with my own research interests and that of my Clinical Text Mining Group, with the potential to obtain high impact results and to move the research front in the field.

I have already partnered with Jenssen and the team behind Deep Learning for Health in another proposal, to the Health Trust Fund of North Norway (Helse Nord), entitled Natural language processing to extract knowledge from clinical notes in electronic health records.

The combination of natural language processing (NLP) and deep models is highly promising, and my group has already investigated similar topics e.g. in the work “Applying deep learning on electronic health records in Swedish to predict healthcare-associated infections” published in ACL.

In conclusion, I fully endorse Deep Learning for Health and look forward to a fruitful and high impact collaboration.

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Letter of commitment to Deep Learning for Health

To whom it may concern

DIPS AS fully support the project Deep Learning for Health, and will contribute to the project by developing software that enable clinical decision support based on analysis of big data.

DIPS AS has participated in the pre-project phase. Including participation in workshop in Tromsø September 6, 2017 by Chief Product Officer Finn Harald Stokland at DIPS AS, and the UiT team behind the proposal “Deep Learning for Health”, in addition to representatives for the University Hospital of North Norway and the Norwegian Centre for E-health Research.

DIPS AS is a provider of ICT solutions for electronic health records (EHR). The system is used by the University Hospital of North Norway, as well as many other hospitals in Norway. As such, “Deep Learning for Health” (DeepHealth) is based on EHR data extracted from the DIPS EHR system. A prioritized focus area for DIPS is to enable predictive analytics within the DIPS EHR system. DIPS AS will develop and integrate analyse results from DeepHealth (and other projects/vendors) into the DIPS EHR graphical interface (DIPS Arena). This will be produced by DIPS AS own funding as a concrete commitment. DIPS AS will also contribute to the project by helping the clinic to give DeepHealth support into a test environment, and we will also enable validation of project results in the context of operational use in the clinic. All this will greatly aid the potential impact of the project, and will be beneficial for DIPS AS as well as for the DeepHealth team.

Sincerely,

Finn Harald Stokland
Chief Product Officer, DIPS AS
Per Christian Lindberg
Head of Department for public relations
Helse Nord IKT
Cellphone: 909 76 749
E-post: per.christian.lindberg@hnikt.no

Robert Jenssen
UIT Machine Learning Group
UIT The Arctic University of Norway

Letter of support

Helse Nord IKT has previously been engaged in the Centre for Research based Innovation (SFI) "Tromsø Telemedicine Laboratory" (2006-2014) as a public partner

https://www.forskningsradet.no/prognett-sfi/Artikkel/Tromso_Telemedicine_Laboratory/1224067029822

We fully support the project Deep Learning for Health, PI R. Jenssen, as it builds on the activities in the SFI related to extraction and analysis of recorded health data in electronic medical records obtained from the ICT system at the University Hospital of North Norway. Helse Nord IKT is responsible for the maintenance and management of the ICT systems for all the hospitals in Helse Nord. Helse Nord IKT is thus a natural partner in such a project given our in-depth knowledge of the ICT systems for extraction of data and technical solutions.

Sincerely Yours

Med venlig hilsen

Per Christian Lindberg
Head of Department for public relations
Helse Nord IKT

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Robert Jenssen  
UiT Machine Learning Group  
UiT The Arctic University of Norway  

Letter of commitment  

With this letter, I give my support to the project “Deep Learning for Health” (DeepHealth), which is headed by Assoc. Prof. R. Jenssen.  

The project is well aligned with the interests and work of my company, which span development of neural networks, application and clinical validation in health, and certifying and supplying these algorithms as scalable solutions to health care providers by incorporation of the algorithm in their workflow.  

DeepHealth’s focus on the application of their research on uncertainty quantification and the development of probabilistic deep models, is especially relevant, as our company has developed a model to predict infections after operations with data from Dutch hospitals. Currently, Healthplus.ai is in the process of improving, re-validating, testing, publishing and implementing the post-operative infection predictor algorithm with three major hospitals in Western Europe. We are willing to share details on our current results.  

Our company has a broader health and health care focus and is currently expanding the number of solutions it is developing. It is thus also possible to co-operate in other clinical and health challenges.  

Within the DeepHealth focus and because of the common interests, our company will collaborate with Jenssen’s team on novel and interpretable methodology development, research methodology, exchanging knowledge, and potentially exchange data. I confirm that the healthplus.ai can and plans to host one of the project’s postdoctoral fellows. Ultimately, our special focus will be to operationalize the algorithms for the University of Trømso Hospital and potentially other Norwegian hospitals.  

Yours sincerely,  

Bart Geerts  
Founder and CEO
Letter of support

To whom it may concern

This is a letter of support for the proposed project Deep Learning for Health - DeepHealth.

Not only that I am confident that deep learning methods represent a great potential for major breakthroughs in healthcare and other related fields, but I’m also confident that DeepHealth is very well aligned with the research interests of myself and my group. My group has long experience in analysis of data from electronic health records for outcomes research. In particular, my group has a joint work with Jenssen and his group under consideration for publication:

“Maximizing interpretability and cost-effectiveness of Surgical Site Infection (SSI) predictive models using feature-specific regularized logistic regression” by Primoz Kocbek, Nino Fijacko, Cristina Soguero Ruiz, Karl Øyvind Mikalsen, Uros Maver, Petra P. Brzan, Andraz Stozer, Robert Jenssen, Gregor Stiglic.

In addition, one of my students is currently visiting Jenssen’s group as an Erasmus+ student. I see this visit as a step to stronger collaboration in the future, as both labs share many research topics in healthcare analytics.

DeepHealth will further open up several new opportunities for collaboration between the two groups, including exchange of students, joint workshops, sharing of code and data, leading to joint papers and algorithms for testing for operational use in the clinical environment.

In conclusion, I fully endorse the DeepHealth proposal.

Yours sincerely,

Gregor Stiglic
Dear Jenssen,

Thank you for taking into consideration the proposal of the research project Deep learning for Health (DeepHealth) - Prediction and prevention of postoperative complications.

I write on behalf of Mostoles University Hospital in support of DeepHealth project. We strongly support this proposal and the ideas presented in it. Going beyond the frontier in machine learning methods and specially in deep learning for enhancing the prediction and prevention of postoperative complications is a necessity in current society.

This proposal is a great opportunity to establish links between your group and our hospital to further exploit the latest research in data-driven methods. As a clinician, I am enthusiastic in implementing these methods, since having a powerful tool to get insight from medical data would help both patients and healthcare managers.

In conclusion, I would like to reiterate my readiness to work closely with you and to express my strong interest in DeepHealth and in the medical research described in your proposal. I am keen in developing links with your group to further exploit the project results and participate in the dissemination plan.

Sincerely,

Rafael García Carretero
Internal Medicine Department, Mostoles University Hospital
Madrid, Spain

October 2017
Robert Jenssen  
Associate Professor  
Department of Physics and Technology  
University of Tromsø (UiT)  
Tromsø, Norway  

October 2017  

Dear Robert,  

We thank you for making us aware of the research project *Deep learning for Health (DeepHealth) - Prediction and prevention of postoperative complications* under evaluation for Phase 2 funding over the IKTPLUSS “Ubiquitous data and services” call.  

With this letter, we would like to express our full support for your proposal and acknowledge our strong interest of *DeepHealth* in the relevant clinical problems described in this proposal. We are keen in developing links with your group to further exploit the project results and participate in the dissemination plan.  

Sureste University Hospital has clear research objective such as: To promote and coordinate the implementation and development of research programs or promote the optimal utilization of the resources placed at the service of research, ensuring its effectiveness, efficiency and quality.  

We understand that this is a step further to extend our collaboration to future H2020 projects.  

Best regards,  

Ángel Gómez  
Medical Director  
Hospital Universitario del Sureste