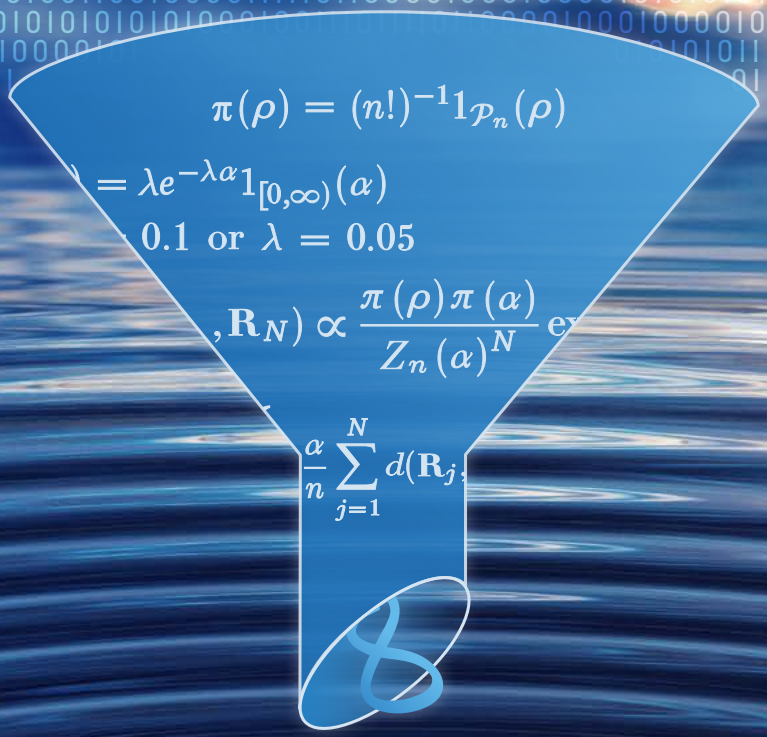
BigInsight

STATISTICS FOR THE KNOWLEDGE ECONOMY

FINAL REPORT



Norwegian Centre for Research-based Innovation

BigInsight

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FOREWORD

by centre director

Dear partners, colleagues, friends and followers of BigInsight – centre for research-based innovation, 2015–2024. This final report sums up the work in, results from and impact of BigInsight. More detailed presentations of research results are to be found in the annual reports and publications.

Anders Løland
Research director, NR
Centre director

FOREWORD

by head of host institution

Dear partners and friends; BigInsight has been a tremendous success! In close cooperation with all participating research institutions and user partners, BigInsight has brought innovative solutions into beneficial use, and, at the same time provided new methods for extracting reliable knowledge from data, scalable for future challenges and further innovations. These achievements are supplemented by a new generation of researchers with PhDs from BigInsight, building a basis for the Norwegian society's need for expert knowledge in machine learning, statistical modelling and AI. On behalf of NR, as the host of BigInsight, I will express my gratitude to all of you who have participated in creating this success. Numerous individuals have been extremely important. However, a special thanks goes to the two excellent directors of BigInsight, Professor Arnoldo Frigessi through most of the period, followed by Research director Anders Løland for the final years.

André Teigland
CEO of NR

SUMMARY

Objectives and vision

When we started in 2015, BigInsight was the first AI centre in Norway. We did not call it AI at the time, but machine learning: "BigInsight's objective is to develop methods, algorithms and computational tools in model based statistics and machine learning to solve innovation challenges at our partners and in science and society." More specifically, we identified two broad, yet precise challenges: personalised solutions and prediction of transient phenomena. These two areas have developed in these nine years to become main pillars of contemporary machine learning.

Consortium and categories of partners

The consortium consists of one research institute (NR, host), two universities (UiO and UiB), three public research organisations (OUS, NIPH, Cancer Registry of Norway), three public service partners (NAV, Skatteetaten, Statistics Norway), and six private companies (DNB, Gjensidige, ABB, DNV, Telenor, Norsk Hydro). Of these, Statistics Norway joined BigInsight in 2018, while all the others were part of the centre from day one. All the partners are large organisations and key players in the Norwegian economy and welfare state.

Scientific results

The scientific footprint of BigInsight is substantial. We have published more than 200 scientific papers and contributed to important new statistical and machine learning methods for example for anomaly detection and monitoring of vessels, personalised computer simulations of breast cancer treatment for tailored treatments, machine learning for prediction of mortgage defaults, Explainable AI taking feature dependence into account, and modelling of COVID-19 in Norway. We have become internationally renowned in Explainable AI – a field that did not exist when BigInsight started in 2015. The foundation for the COVID-19 modelling was laid in BigInsight before the pandemic, and during the pandemic we conducted real time research, where the innovation took place immediately, while the research was published later. BigInsight also produced a considerable number of open software packages.

Results and impact for industry, public sector and society at large

All partners have had a keen interest in the development of new or improved processes or services, building up a strengthened knowledge base, improved access to competent personnel and research institutions, and recruitment of qualified personnel. Some partners that also make use of NR's contracted research have pointed out that strengthening NR's competence and foundation is in their interest as well as in NR's interest. Possibly somewhat surprising, many of the partners really appreciated the informal exchange of knowledge and ideas between private and public actors, and the improved network it provided. From the annual BigInsight day, hosted by the user partners, to the weekly BigInsight lunches as well as other informal or organised meetings across the centre set the stage for this. In the report, we present some of our success stories, which include "Benefits for the maritime industry", "First in Norway to request authorization from the Norwegian Data Protection Authority for Machine Learning research on personal data", and "The COVID-19 story". BigInsight's greatest achievement and societal impact was the modelling of COVID-19 during the pandemic in Norway.

Researcher training and master's level education

BigInsight has significantly impacted research and education at the UiO, fostering a thriving data science community. This impact is evident in the establishment of the annual Data Science Day, which attracts 500 attendees, and a new master's program in data science, a joint venture between the Departments of Mathematics and Informatics. The centre also influenced the mathematics curriculum, introducing courses focused on big data and machine learning, reflecting the growing importance of these fields. Over 45 master's students completed theses with BigInsight, benefiting from joint supervision by university staff, NR researchers, and partner representatives, strengthening connections between these groups. BigInsight supported numerous PhD students, with 26 successfully defending their theses by February 2025, demonstrating its commitment to developing future researchers. The centre also hosted over 30 postdoctoral researchers, contributing to both academia, with some securing permanent positions, and industry, as others transitioned to business roles. Finally, BigInsight's activities contributed to the establishment of dScience, a centre supporting computational and data science research at UiO.

International cooperation

BigInsight's international collaborations have led to several EU funded projects: RESCUER and BD4QoL, both of which utilize data-driven methods to improve breast cancer and head and neck cancer treatments respectively, and ENFIELD, European AI Lighthouse focused on promoting adaptive, green, and trustworthy AI. BigInsight has also played a significant role in the capacity development of higher education in Ethiopia. Besides, BigInsight has had partnerships with STOR-i, University of Lancaster, The Medical Research Council Biostatistics Unit, University of Cambridge, and the Department of Mathematics, University of Minneapolis. Further, BigInsight was a founding partner of a Nordforsk project aimed at creating a joint Nordic long-term academic collaboration on pandemic preparedness using advanced mathematical modelling and systematically collected health data.

Added value of organising the activities as a centre

BigInsight's results would have been much less pronounced if it had not been organised as a joint centre for research and user partners. The size made it possible to take more risk, divert resources to new ventures, such as Explainable AI, set the stage for formal and informal cooperation across the centre, and, maybe most importantly, be an inspiring place to work.

Legacy of the centre

The centre lives partly on through Integreat, a Centre of Excellence funded by the Research Council of Norway from 2023 with UiO, UiT (The Arctic University of Norway) and NR as partners. A large consortium around BigInsight has applied for a Research Centre for Artificial Intelligence, funded by The Research Council of Norway. This centre – called TRUST – will be approximately twice as big as BigInsight. The funding will be assigned in June 2025.

SAMMENDRAG

Mål og visjon

Da vi startet i 2015, var BigInsight det første KI-senteret i Norge. Vi kalte det ikke KI (kunstig intelligens) den gangen, men maskinlæring: "BigInsights mål er å utvikle metoder, algoritmer og beregningsverktøy innen modellbasert statistisk modellering og maskinlæring for å løse innovasjonsutfordringer hos våre partnere og i vitenskap og samfunn." Mer spesifikt identifiserte vi to brede, men presise utfordringer: personlig tilpassede løsninger og prediksjon av forbigående fenomener. Disse to områdene har utviklet seg i løpet av de ni årene til å bli hovedpilarer i moderne maskinlæring.

Konsortium og kategorier av partnere

BigInsight har bestått av ett forskningsinstitutt (NR, vert), to universiteter (UiO og UiB), tre offentlige forskningsorganisasjoner (OUS, Folkehelseinstituttet, Kreftregisteret), tre offentlige virksomheter (NAV, Skatteetaten, Statistisk sentralbyrå) og seks private selskaper (DNB, Gjensidige, ABB, DNV, Telenor, Norsk Hydro). Av disse kom Statistisk sentralbyrå med i BigInsight i 2018, mens alle de andre var med fra dag én. Alle partnerne er store organisasjoner og nøkkelaktører i norsk økonomi og velferdsstaten.

Vitenskapelige resultater

Det vitenskapelige fotavtrykket til BigInsight er betydelig. Vi har publisert mer enn 200 vitenskapelige artikler og bidratt til viktige nye statistiske modeller og og maskinlæringsmetoder, for eksempel for deteksjon av anomalier og overvåking av fartøy, personlig tilpassede datasimuleringer av brystkreftbehandling for skreddersydd behandling, maskinlæring for prediksjon av mislighold av boligåln, forklarbar KI som tar hensyn til avhengighet, og modellering av COVID-19 i Norge. Vi har blitt internasjonalt anerkjent innen forklarbar KI – et felt som ikke eksisterte da BigInsight startet i 2015. Grunnlaget for COVID-19-modelleringen ble lagt i BigInsight før pandemien, og under pandemien drev vi sanntidsforskning, der innovasjonen skjedde umiddelbart, mens forskningen ble publisert senere. BigInsight produserte også et betydelig antall åpne programvarepakker.

Resultater og betydning for industri, offentlig sektor og samfunnet ellers

Alle partnerne har hatt en stor interesse for utvikling av nye eller forbedrede prosesser eller tjenester, oppbygging av et styrket kunnskapsgrunnlag og forbedret tilgang til kompetent personell og forskningsinstitusjoner, samt rekruttering av kvalifisert personell. Noen partnere som parallelt har benyttet seg av NRs oppdragsforskning har påpekt viktigheten av å sikre NRs kompetanse og styrke, da dette er i deres interesse så vel som i NRs interesse. Muligens noe uventet satte mange av partnerne stor pris på den uformelle utvekslingen av kunnskap og ideer mellom private og offentlige aktører, og det forbedrede nettverket det ga. Alt fra den årlige BigInsight-dagen, som ble arrangert hos brukerpartnerne, til de ukentlige BigInsight-lunsjene samt andre uformelle eller organiserte møter på tvers av senteret, la grunnlaget for dette. I denne rapporten presenterer vi noen av våre suksesshistorier, som inkluderer "Fordeler for maritim industri", "Først i Norge med å søke om tillatelse fra Datatilsynet for maskinlæringsforskning på personopplysninger" og "COVID-19-historien". BigInsights største bidrag og samfunnsmessige betydning var modelleringen av COVID-19 under pandemien i Norge.

Forskertrening og mastergradsutdanning

BigInsight har preget forskning og utdanning ved UiO og skapte et blomstrende datavitenskapsmiljø. Dette er tydelig i etableringen av den årlige Data Science Day, som tiltrekker seg cirka 500 deltakere, og et nytt masterprogram i datavitenskap, et fellesforetak mellom Matematisk institutt og Institutt for informatikk ved UiO. Senteret også påvirket matematikkpensumet og introdusert kurs fokusert på store data og maskinlæring, noe som gjenspeiler den økende betydningen av disse feltene. Over 45 masterstudenter fullførte oppgaver med BigInsight og dro nytte av felles veiledning fra universitetsansatte, NR-forskere og brukerpartnere, noe som styrket samarbeidet i senteret. BigInsight finansierte mange doktorgradsstudenter, hvorav 26 fullførte sine avhandlinger innen februar 2025, noe som viser senterets engasjement for å utvikle fremtidige forskere. Senteret var også vert for over 30 postdoktorer. Noen av disse har fått faste stillinger i akademia, mens andre jobber i næringslivet. Dessuten bidro BigInsights aktiviteter til etableringen av dScience, et senter som støtter beregnings- og datavitenskapelig forskning ved UiO.

Internasjonalt samarbeid

BigInsights internasjonale samarbeid har ført til flere EU-finansierte prosjekter: RESCUER og BD4QoL, som begge bruker datadrevne metoder til å forbedre behandling av henholdsvis brystkreft og hode- og nakkekreft, og ENFIELD, European AI Lighthouse, som fokuserer på å fremme adaptiv, grønn og pålitelig AI. BigInsight har også spilt en betydelig rolle i utviklingen av høyere utdanning i Etiopia. I tillegg har BigInsight hatt partnerskap med STOR-i, University of Lancaster, The Medical Research Council Biostatistics Unit, University of Cambridge og Department of Mathematics ved University of Minneapolis. Videre bidro BigInsight til å starte et Nordforsk-prosjekt som hadde som mål å skape et felles nordisk langsiktig akademisk samarbeid om beredskap for pandemier ved hjelp av avansert matematisk modellering og systematisk innsamlede helsedata.

Merverdi ved å organisere aktivitetene som et senter

BigInsights resultater ville vært mye mindre uttalte om det ikke hadde vært organisert som et felles senter for forsknings- og brukerpartnere. Størrelsen gjorde det mulig å ta mer risiko, omfordele ressurser til nye satsinger, som for eksempel forklarbar AI, legge til rette for formelt og uformelt samarbeid på tvers av senteret, og, kanskje viktigst, være et inspirerende sted å jobbe.

Fremtidsplaner for senteret

Senteret lever delvis videre gjennom Integreat, fra 2023 et Senter for fremragende forskning finansiert av Norges forskningsråd der UiO, UiT (Norges arktiske universitet) og NR er partnere. Et stort konsortium rundt BigInsight har søkt om et Forskningssenter for kunstig intelligens, finansiert av Norges forskningsråd. Dette senteret – kalt TRUST – vil være omtrent dobbelt så stort som BigInsight. I juni 2025 blir det avgjort om TRUST får finansiering.

VISION / OBJECTIVES

This was a journey! Here we are, now in 2025, surrounded, fascinated, engaged, as well as scared by AI. When we started in 2015, BigInsight was the first AI centre in Norway. We did not call it AI at the time, but machine learning:

"BigInsight's objective is to develop methods, algorithms and computational tools in model based statistics and machine learning to solve innovation challenges at our partners and in science and society."

More specifically, we identified two broad, yet precise challenges: personalised solutions and prediction of transient phenomena. These two areas have developed in these ten years to become main pillars of contemporary machine learning. We can proudly say that we did recognise these important trends, developing methods and algorithms that can be used to deliver to each individual, being a patient or a customer, the best solution and to study systems that are not in equilibrium, that can be observed intensively (via sensors) and can be controlled. We have developed generic methods for these purposes. For example, we have used neural networks to predict the default of those loaning from DNB: This was the first time, in 2016, that the bank recognised the usefulness of AI. Later, BigInsight was the first to request authorization to The Norwegian Data Protection Authority to conduct machine learning research using personal data; we were the first to develop Shapley values to explain black-box AI models for data with complex dependence; we were the first to prove the usefulness of mobile phone mobility data to predict the spread of infectious diseases, in this way being prepared to deliver models in COVID time to the Norwegian government. And much more!

We could not have done this without our private and public partners. Together, we understood where the existing methods were failing, and which data would have been needed to develop modern ML solutions; together we tried and failed – and we succeeded! For example, just after we had started, we understood the limitations of many black-box algorithms, which were reducing trust from users and impeding their use in the real-world. Therefore, we started a new innovation objective, Explaining AI, to understand and develop approaches to open the boxes. Again, we were among the first in Norway. Researchers and partners, we all have grown, not just because AI is developing at speed around us, but because we did try to use AI in practice.

When the time comes to close the door of BigInsight, to put our centre into the past, or better – yes, we dare to say it – to place BigInsight into the history of the development of AI in Norway, we are convinced that we have been able to make an excellent use of the generous investment of The Research Council of Norway and of our partners, to solve important problems, to contribute to innovation and to build the foundations of new developments, which indeed are already happening. Stay tuned!

BASIC FACTS ABOUT THE CENTRE

Partners

Host institution and research partner

Norsk Regnesentral (Norwegian Computing Centre, NR)

Research partners

University of Oslo (UiO)
University of Bergen (UiB)

Company partners

ABB
DNB
DNV
Gjensidige
Norsk Hydro
Telenor

Public partners

NAV (Norwegian Labour and Welfare Administration)
SSB (Statistics Norway) from 06.06.2017
Skatteetaten (Norwegian Tax Administration)
Oslo universitetssykehus (OUS, Oslo University Hospital)
Folkehelseinstituttet (Norwegian Institute of Public Health, NIPH)
Kreftregisteret (Cancer Registry of Norway)

Organisation

Legal organisation

BigInsight is hosted by NR.

Legal and administrative responsible

Research director Lars Holden.

Centre leader

Professor Arnoldo Frigessi, UiO and OUS,
Director from April 2015 to September 2023.
Research Director Anders Løland, NR,
Director from September 2023.

Administrative Coordinator

Unni Adele Raste

Board in 2024

Erlend Willand-Evensen, Gjensidige, chairman
Stian Braastad, ABB
Karl Aksel Festø, DNB
Knut Erik Knutsen, DNV
Birgitte F. De Blasio, Folkehelseinstituttet
Valentin Johannes Koestler, Hydro
Jon Vegard Sparre, NAV
Lars Holden, Norsk Regnesentral
André Teigland, Norsk Regnesentral
Martin Sending, Oslo University Hospital
Alexander Bjerke, Skatteetaten
Xeni Dimakos, SSB
Gorm Andreas Grønnevet, Telenor
Bård Støve, University of Bergen
Nadia Slavila Larsen, University of Oslo

Observer: Siv Johansen Soriano / Terje Strand,
Research Council of Norway.

The board had two yearly meetings.
All partners were represented in the Board.

Scientific Advisory Committee

Professor Idris Eckley, Lancaster University, UK (chair)

Professor Samuel Kaski, Aalto University, Finland and University of Manchester, UK

Professor Geoff Nicholls, University of Oxford, UK

Professor Marina Vannucci, Rice University, Houston, USA

Professor Veronica Vinciotti, University of Trento, Italy

Senior researchers

Kjersti Aas, NR

Arnoldo Frigessi, UiO

Ingrid Glad, UiO

Clara-Cecilie Günther, NR (until 31.08.2022)

Ingrid Hobæk Haff, UiO

Martin Jullum, NR

Alex Lenkoski, NR

Anders Løland, NR

Carlo Mannino, UiO

Hanne Rognebakke, NR

Ida Scheel, UiO

André Teigland, NR

Magne Thoresen, UiO

FINANCING THROUGH THE LIFE OF THE CENTRE

Summary sheet for the main categories of partners (in millions of NOK)

CONTRIBUTOR	CASH	IN-KIND	TOTAL
Host		11	11
Research partners	8	70	78
Companies	34	27	61
Public partners	15	30	45
RCN	92	0	92
Sum	149	139	287

Distribution of resources

TYPE OF ACTIVITY	NOK MILLION
Research projects	261
Common centre activities	1
Administration	25
Total	287

RESULTS – KEY FIGURES

	TOTAL
Scientific publications (peer reviewed)	210
Dissemination measures for users	Annual BigInsight Days + BigInsight Celebration Day in 2023 Bi-weekly BigInsight Wednesday lunchs, informal gathering of staff and students with a lecture on relevant topics Bi-weekly Tuesday seminar in statistics at the Department of Mathematics, UiO Monthly Thursday seminar in biostatistics at the Department of Biostatistics, UiO New master program in Data Science at UiO (started 2018) BigInsight Career Day (2018) DataScienceDay@UiO: 7 Explaining AI/Black box seminars: 20 Many ad-hoc seminars and workshops with user partners
Dissemination measures for the general public	Forskningstorget (The research fair) in Oslo (2017) Arendalsuka (yearly since 2020) 1st Oslo Invitational Workshop on Model-Agnostic Explainable AI (2024) National seminar on machine learning for AML (2024) Appearances in national TV and radio, including Abels tårn Produced and participated in numerous podcasts More than hundred interviews or references to BigInsight's research in national newspapers, particularly during the COVID-19 pandemic
PhD degrees completed	26
Master degrees	47
Number of new/improved methods/models/prototypes finalised	More than 30
Number of new/improved products/processes/services finalised	More than 15
Patents registered	None
New business activity	Not directly

210

Scientific publications (peer reviewed)

26

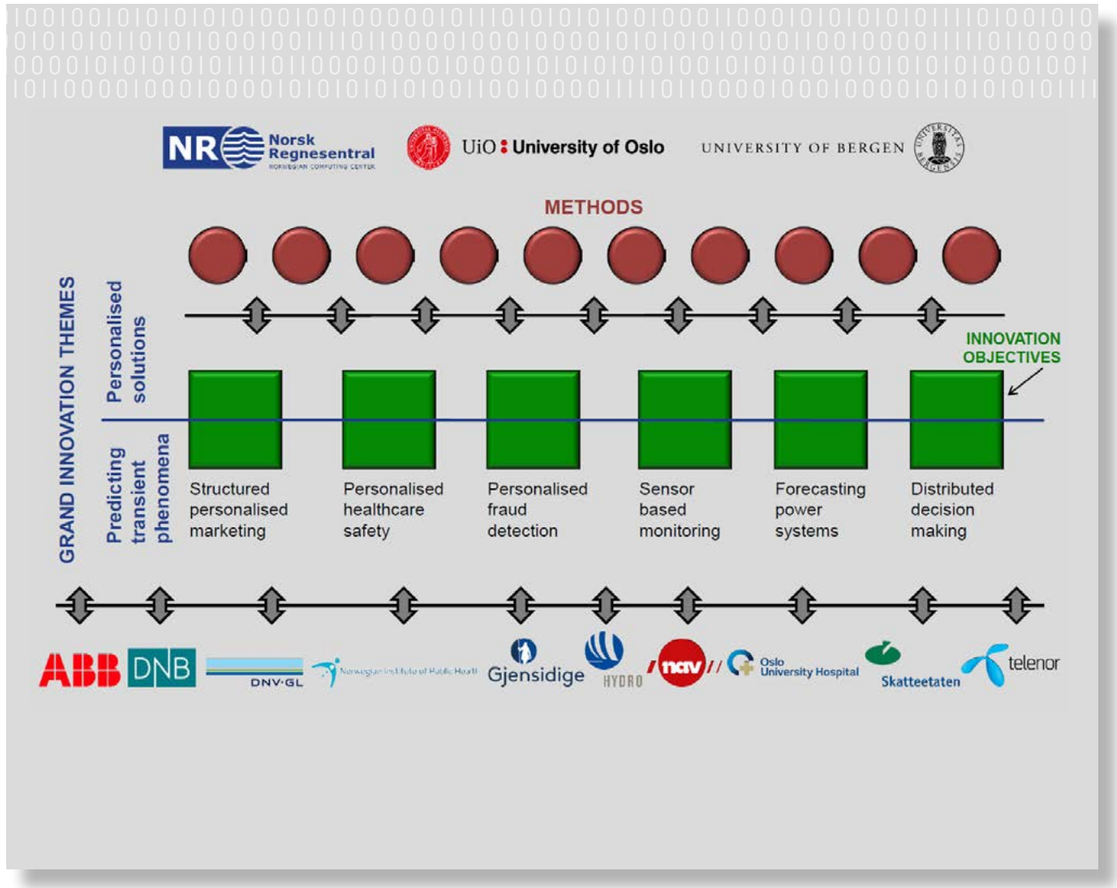
PhD degrees completed

>30

innovative solutions

Methods and algorithms developed and implemented at BigInsight are explainable, accurate, fair and open.

BigInsight – Statistics for the knowledge economy



Original research plan with innovation objectives.

RESEARCH

The original research plan was to focus on two Central Innovation Themes, shared by the partners: *personalised solutions* and *predicting transient phenomena*. These themes were chosen to manage the complexity, diversity and dimensionality of the data, and our partner's demanding objectives, posed fundamentally new challenges to statistical inference. The plan was therefore to develop original, cutting-edge statistical, mathematical and machine learning methods, produce high-quality software implementing these approaches and thereby deliver unique, powerful, and operational solutions. The centre was divided into six innovation objectives:

1. Structured personalised marketing
2. Personalised healthcare safety
3. Personalised fraud detection
4. Sensor based monitoring
5. Forecasting power systems
6. Distributed decision making

Each partners participated in one or more innovation objective, and no innovation objective had only one partner.

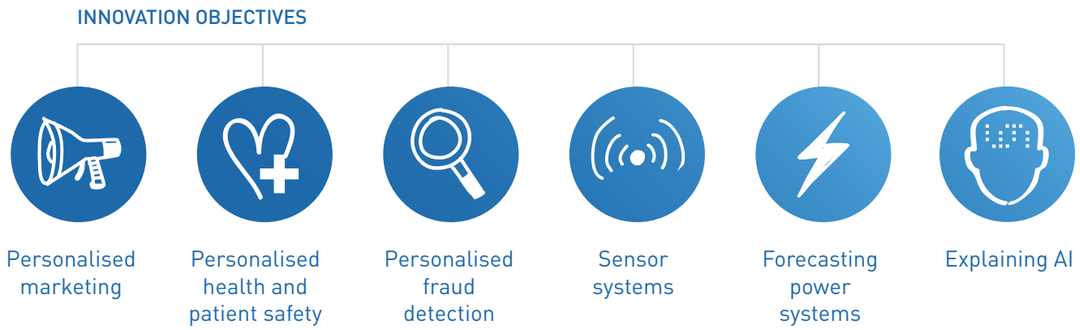
How was the research plan revised underway (including how feedback from the midterm evaluation was followed up)?

The plan turned out to be (surprisingly!) robust and foresighted, given that the centre turned out to exist for nine years. The initial plan was to fulfil "the promise of the big data revolution, we shall produce deep analytical tools to extract knowledge from complex data and deliver BIG INSIGHT". The centre shifted quite early some of the initial focus on the technical handling of big data to deep analytical tools, such as more complex machine learning methods that also dealt with big data.

One important change was the inclusion of a new innovation objective called *Explaining AI* which replaced *Distributed decision making*. *Explaining AI* was developed organically in BigInsight since we developed cutting edge machine learning models that were better than traditional models, but they were seen as black boxes which were difficult to understand fully by BigInsight's researchers and partners. It turned out that this happened in parallel with the new international research field called *Explainable Artificial Intelligence (XAI)*, in which BigInsight has played an important role, especially in the development of so-called Shapley values for machine learning models.

The feedback from the midterm evaluation was in general very positive. BigInsight received six specific recommendations, which in brief was to showcase our data science expertise and publish more in top journals, especially in machine learning, and to develop reusable techniques from client projects and increase the number of industrial PhD ("Nærings-PhD") students and master students connected to our user partners. The centre managed to publish more in top machine learning journals, also due to the new innovation objective Explaining AI. We were not able to increase the number of industrial PhD students as much as we aimed for, possibly due the COVID-19 pandemic.

Final innovation objectives



Highlights of scientific results

Anomaly detection in sensor data

Who: Emanuele Gramuglia (PhD student), Clara Bertinelli Salucci (PhD student), Azzeddine Bakdi (Post doc), Riccardo De Bin, Ingrid Glad, Geir Storvik (Dept. Mathematics UiO), Martin Tveten (PhD student Dept. Mathematics UiO, later NR), Morten Stakkeland (ABB and Dept. Mathematics UiO), Erik Vanem (DNV and Dept. Mathematics UiO) and more BigInsight-people at UiO, NR, DNV, ABB.

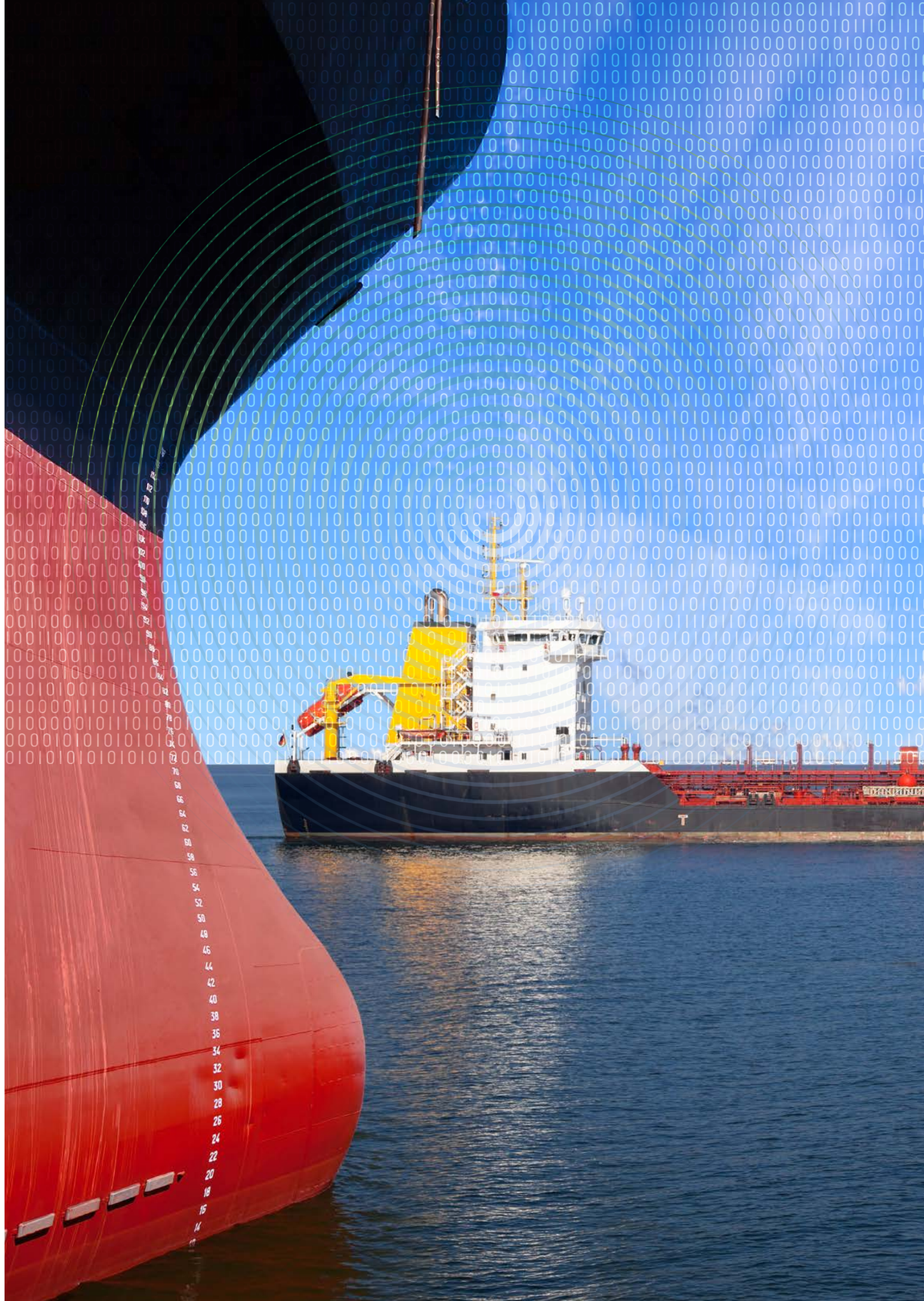
What: BigInsight has developed new approaches to safety surveillance, condition monitoring and performance monitoring of vessels or equipment based on large arrays of sensors. The Sensor Systems group in Biginsight has done research motivated by problems and data from the maritime industry in collaboration with DNV and ABB. Examples of important results include research on new methods for automatic detection of developing faults or anomalies based on sensor and ship log data. Papers 1, 2 and 3 are examples of such research that has been implemented in these two partner companies. Log files containing textual messages with associated time stamps are generated by many technologies and systems for condition monitoring. Paper 1 proposes a clustering technique which provides a tool to discover and identify patterns or macrolevel events in such categorical time series, using a Bayesian approach and reversible jump MCMC. A BigInsight PhD student was hired for a period at ABB to implement the method of paper 1 in their equipment. Paper 2 is also about condition monitoring, presenting a novel, scalable approach to detecting anomalous mean structure in a subset of correlated multivariate time series and has been applied to subsea pump data in collaboration with DNV. Paper 3 is about real time monitoring of a propulsion motor, being able to predict the critical event of overheating in due time before such a serious event would happen, and thus being able to avoid a disaster. The methodology of paper 3 has been implemented at ABB.

Other impactful BigInsight research in the sensor group has been on battery health monitoring for electric vessels, as published in several papers, represented by paper 4. A Multivariable Fractional Polynomial regression model is applied to data under dynamic operating conditions. The method is computationally very efficient and interpretable and compares well with a more complicated machine learning model. Through the development of battery monitoring methods based on sensor data, the electric vessels do not need to be taken out of operation for battery controls. This research has involved DNV and the battery provider Corvus Energy, where one of the BigInsight post docs later was hired as Battery Data Analyst.

Another example of both economic and safety critical impact are a couple of papers on autonomous shipping, as in paper 5, which formulates a completely new way of creating realistic test beds for the steering algorithms of autonomous ships. Using historical AIS data that tracks the movements of all traffic at sea, ship registries, weather data, digital maps, and ship collision avoidance rules, this data science project presents algorithms that quantify collision and grounding risks in short time windows ahead and create a large data base of scenarios of known difficulties in any geographical area. This database is used to draw test situations in which autonomy algorithms can be tested and compared to historical human solutions. The system is in operation/development at DNV in Trondheim, where a BigInsight post doc helped implementing the codes in their autonomy testing facilities there. In addition to testing algorithms, the system can also be used for training such algorithms.
See also the corresponding success story later in this report.

Selected papers:

1. E Gramuglia, G Storvik, M Stakkeland (2021). Clustering and automatic labelling within time series of categorical observations—with an application to marine log messages *Journal of the Royal Statistical Society Series C: Applied Statistics*
2. M Tveten, IA Eckley, P Fearnhead (2022). Scalable change-point and anomaly detection in cross-correlated data with an application to condition monitoring. *Annals of Applied Statistics*
3. KH Hellton, M Tveten, M Stakkeland, S Engebretsen, O Haug, MT Aldrin (2021). Real-time prediction of propulsion motor overheating using machine learning. *Journal of Marine Engineering & Technology*
4. CB Salucci, A Bakdi, IK Glad, E Vanem, R De Bin (2022). Multivariable fractional polynomials for lithium-ion batteries degradation models under dynamic conditions. *Journal of Energy Storage*
5. A Bakdi, IK Glad, E Vanem, Ø Engelhardtsen (2019). AIS-based multiple vessel collision and grounding risk identification based on adaptive safety domain. *Journal of Marine Science and Engineering*



Personalised computer simulations of breast cancer treatment

Who: Xiaoran Lai (PhD student), Alvaro Köhn-Luque (researcher), Arnoldo Frigessi, OCBE UiO and OUS

What: BigInsight produced the first digital twin of a breast tumour. This has been an exceptional achievement. In personalised treatment, the aim is to give to each patient the right treatment, often a combination of drugs. This is a very difficult problem, because there are multiple drugs, in the case of breast cancer more than 50, the drugs can be given in combination, exploiting synergistic effects, and the treatment regime and dose need to be determined.

Currently, oncologists rely on standard treatment choices, often supported by extensive randomised clinical studies and experience. The question is how to predict the effect of treatments, regimes and doses for each individual patient, with the aim of optimising the long-term outcome.

Our answer has been to build an in-silico copy of the tumour, which can then be "treated" with many drug combinations, regimes and doses, to determine, by means of simulation, the best option for the patient. The digital twin has to be a good-enough copy of the real tumour, so that what-if studies can be trusted. We used multitype measurements acquired routinely on a single breast tumour, including histopathology, MRI, and molecular profiling, to personalize parts of a complex multiscale model of breast cancer treated with chemotherapeutic and antiangiogenic agents. The model accounts for drug pharmacokinetics and pharmacodynamics. We developed an open-source computer program that simulates cross-sections of tumors under 12-week therapy regimens and used it to individually reproduce and elucidate treatment outcomes of 4 patients. Two of the tumors did not respond to therapy, and model simulations were used to suggest alternative regimens with improved outcomes dependent on the tumor's individual characteristics. It was determined that more frequent and lower doses of chemotherapy reduce tumour burden in a low proliferative tumour while lower doses of antiangiogenic agents improve drug penetration in a poorly perfused tumour. Furthermore, using this model, we were able to correctly predict the outcome in another patient after 12 weeks of treatment.

In summary, our model bridges multitype clinical data to shed light on individual treatment outcomes. In a series of published papers, we described our digital twin, how the parameters can be estimated, extended the model to handel a full biopsy and started to actually validate the model. Our work started several extensions, and now the team has digital twins of blood tumours and has started to combine mechanistic modelling with machine learning. The team also obtained significant additional funding from The Research Council of Norway, UiO, OUS and EU. For a popular science article, see the story in Aftenposten from 20201.

Selected papers:

1. Lai, X., Geier, O. M., Fleischer, T., Garred, Ø., Borgen, E., Funke, S. W., ... & Frigessi, A. (2019). Toward personalized computer simulation of breast cancer treatment: A multiscale pharmacokinetic and pharmacodynamic model informed by multitype patient data. *Cancer research*

2. Pesonen, Henri, Umberto Simola, Alvaro Köhn-Luque, Henri Vuollekoski, Xiaoran Lai, Arnoldo Frigessi, Samuel Kaski et al. (2023). ABC of the future. *International Statistical Review*

3. Lai, Xiaoran, Håkon A. Taskén, Torgeir Mo, Simon W. Funke, Arnoldo Frigessi, Marie E. Rognes, and Alvaro Köhn-Luque (2022). A scalable solver for a stochastic, hybrid cellular automaton model of personalized breast cancer therapy. *International Journal for Numerical Methods in Biomedical Engineering*

1 https://www.aftenposten.no/viten/i/1n3wkK/kan-statistikk-og-matematikk-redde-like-mange-liv-som-nye-medisiner

Aftenposten

Viten | Forskning og vitenskap

Kan statistikk og matematikk redde like mange liv som nye medisiner?

Med statistiske datamodeller kan vi simulere effekten av millioner av behandlingsalternativer og finne den beste behandlingen for hver enkelt kreftpasient.

Vi har sannsynligvis tilgang på effektive behandlinger for de fleste svulster, kanskje for alle, men å finne dem manuelt, er som å finne nålen i høystakken, skriver artikkelforfatterne. Her bilde fra en biopsi av brystkreftsvulst. *Foto: David A. Litman/Shutterstock/NTB scanpix*

Arnoldo Frigessi, Alvaro Köhn Luque, Olav Engebråten, Vessela Kristensen, Carl Henrik Gørbitz

Publisert: 28.01.2020 08:30 | Oppdatert: 28.01.2020 17:03

Personlig kreftterapi

Den gode nyheten er at forskere ved Universitetet i Oslo og Oslo universitetssykehus nå har vist at hvert av de tre trinnene kan gjennomføres. Vi har brukt modeller og statistiske metoder til å simulere forløpet til en håndfull ekte pasienter og oppnådd

Modelling COVID-19 in Norway – the scientific story

Who: Birgitte Freiesleben de Blasio – NIPH and OCBE, Arnoldo Frigessi – OCBE UiO, OUS and NR, Francesco Di Ruscio – OCBE and NIPH, Solveig Engebretsen – OCBE and NR, Kenth Engø-Monsen – Telenor Research, Geir Storvik – Dept. Mathematics UiO

What: BigInsight's research has been essential for the management of the COVID pandemic in Norway. From the very start of the pandemic, we have developed and run our mathematical and statistical models to (1) estimate the reproduction number R in each region of Norway, (2) to perform prediction of the number of hospitalised COVID patients; and (3) to perform what-if studies on the efficacy of interventions (vaccines, lockdown and re-opening strategies, etc.). Our results were regularly used by the National Institute of Public Health (NIPH), the Norwegian Directorate of Health, hospitals (including OUS), and national and local governments, to take key decisions. During the pandemic, BigInsight, OCBE and NIPH had a joint modelling team constantly on duty, also responsible for communication with the public (weekly reports) and the media. Norway's handing of the pandemic is recognised as very successful, and this is also thanks to our contribution.

Stochastic compartmental metapopulation models were known to be useful for situation awareness, forecasting and scenario simulation in epidemics. Informed by multiple sources of data (incidence of cases, hospital admissions), they allow us to quantify the strength of viral transmission (the R number), to estimate the number of infected individuals, and to predict the future number of infected and of hospitalized patients. Individual-based models were known as mathematical representations of an interacting population, with their demography and transmission networks in different social layers (households, schools, workplaces). BigInsight had projects and PhD students in models for epidemics, which turned out to be essential for our COVID work:

- We developed a new spatio-temporal stochastic model for the spread of an infection based on mobile phone mobility and a sequential Approximate Bayesian Computation (ABC) for efficient inference. This was tested on data from Bangladesh. In 2019, Solveig Engebretsen defended her PhD thesis and then started at NR.
- We developed an individual-based model, reproducing the Norwegian population's socio-demography, representing households, hospitals and nursing homes, calibrated to 2008–2015 and applied to MRSA bacteria. In 2019 PhD Francesco Di Ruscio defended his thesis. He was associated to Biginsight, and later started at NIPH.

Our contribution during the COVID pandemic started immediately in February 2020, when the BigInsight team with staff from OCBE, NIPH, NR and Telenor formed the Oslo COVID-modelling group. Throughout the pandemic, our relentless efforts, built on expertise and new scientific findings, allowed us to produce essential modelling results for Norway. Below, key methods developed during this period, which were in daily use and turned out to be powerful instruments for epidemic management for Norway:

- We extended the model from Bangladesh to Norway, using the Norwegian Telenor mobile phone mobility data (updated every six hours during the whole pandemic).
- Real-time inference was crucial, with data arriving on Monday mornings and results required by Wednesday mornings. Existing algorithms couldn't handle time-piecewise constant reproduction numbers (changing every 2-3 weeks). To address this, we created a novel sequential ABC, named split-seq ABC, enabling efficient use of our stochastic metapopulation models with a high parameter count.
- Daily changing reproduction numbers are more precise than time-piecewise constant reproduction numbers. We developed a new model with daily-varying reproduction number, to quantify the viral transmission in real time. We proposed a state-space formalisation of the model and a sequential Monte Carlo approach which also runs in real-time.
- Throughout the COVID years, we routinely received specific inquiries from the government and others, involving decisions on optimal interventions. To address these what-if scenarios, we enhanced our individual-based model, dividing Norway into 13,521 cells, each with the actual population. The model incorporated various age-structured contact routes, such as community, household, school, and workplace, utilizing Telenor mobility data. This refined model proved instrumental in guiding decisions, including optimizing vaccination strategies and the post-Omicron lockdown reopening. It stands as the most advanced individual-based model

for Norway, surpassing the level of detail found in comparable models, such as the UK ones.
- In addition, we produced results on specific aspects of COVID epidemiology, which had impact on the management of the pandemics. For example, we compared Omicron's epidemic growth to Delta's, using December 2021 – January 2022 contact tracing data. We found increased Omicron susceptibility despite three-dose vaccination, with infected individuals efficiently spreading the virus, while three-dose vaccinated contacts had lower infection risk.
- Our contribution after the COVID pandemic: We continue to publish our methods and findings, to document our work and to prepare for future pandemics. For example, our analysis revealed that mandating recommendations to reduce contacts did not result in fewer contacts compared to just recommendations. Consequently, less intrusive and costly non-mandatory measures may prove effective in Norway in the future.

Funding came from BigInsight, The Norwegian Research Council, Nordforsk, UiO, NIPH, Telenor, NR. Sigma2, which is responsible for providing the national e-infrastructure for computational science in Norway, offered significant supercomputing resources which were essential.

Selected papers:

1. Engebretsen, S., Engø-Monsen, K., Aleem, M.A., Gurley, E.S., Frigessi, A. and De Blasio, B.F., (2020). Time-aggregated mobile phone mobility data are sufficient for modelling influenza spread: the case of Bangladesh. *Journal of the Royal Society Interface*

2. Di Ruscio, F., Guzzetta, G., Bjørnholt, J.V., Leegaard, T.M., Merler, S. and De Blasio, B.F., (2019). Quantifying the transmission dynamics of MRSA in the community and healthcare settings in a low-prevalence country. *Proceedings of the National Academy of Sciences*

3. Engebretsen, S., Diz-Lois Palomares, A., Rø, G., Kristoffersen, A.B., Lindstrøm, J.C., Engø-Monsen, K., Kamineni, M., Hin Chan, L.Y., Dale, Ø., Midtbø, J.E. and Stenerud, K.L., Di Ruscio, F., White, R., Frigessi, A., De Blasio, B.F. (2023). A real-time regional model for COVID-19: Probabilistic situational awareness and forecasting. *PLOS Computational Biology*

4. Storvik, G., Diz-Lois Palomares, A., Engebretsen, S., Rø, G.Ø.I., Engø-Monsen, K., Kristoffersen, A.B., de Blasio, B.F. and Frigessi, A. (2023). A sequential Monte Carlo approach to estimate a time-varying reproduction number in infectious disease models: the COVID-19 case. With discussion. *Journal of the Royal Statistical Society Series A*

5. Chan, L.Y.H., Rø, G., Midtbø, J.E., Di Ruscio, F., Watle, S.S.V., Juvet, L.K., Littmann, J., Aavitsland, P., Nygard, K.M., Berg, A.S. and Bukholm, G., Kristoffersen, A.B., Engø-Monsen, K., Engebretsen, S., Swanson, D., Diz-Lois Palomares, A., Lindstrøm, J.C., Frigessi, A. De Blasio, B.F. (2024). Modeling geographic vaccination strategies for COVID-19 in Norway. *PLOS Computational Biology*

6. Jalali, N., Brustad, H.K., Frigessi, A., MacDonald, E.A., Meijerink, H., Feruglio, S.L., Nygård, K.M., Rø, G., Madslien, E.H. and De Blasio, B.F. (2022). Increased household transmission and immune escape of the SARS-CoV-2 Omicron compared to Delta variants. *Nature Communications*

7. Kamineni, M., Engø-Monsen, K., Midtbø, J.E., Forland, F., de Blasio, B.F., Frigessi, A. and Engebretsen, S. (2023). Effects of non-compulsory and mandatory COVID-19 interventions on travel distance and time away from home in Norway (2021). *Eurosurveillance*

Machine learning for prediction of mortgage defaults

Who: Håvard Kvamme, PhD student at UiO from 2016 to 2019, Nikolai Sellereite, research scientist at NR, Kjersti Aas, research director at NR, Steffen Sjursen, data scientist at DNB.

What: The ability to discriminate bad customers from good ones (credit scoring) is very important for banks and other lending companies. In one of BigInsights first projects, DNB wanted to investigate how transaction data could be used to predict mortgage defaults. Transaction data had previously been used for credit scoring, but the status quo was to use models with heuristic hand-crafted explanatory variables. It is often hard for humans to find appropriate variables. Hence, it would be nice to be able to automate this feature engineering. At that time, in 2016, deep learning, especially Convolutional Neural Networks (CNNs), had had a dramatic impact in fields like image classification and text mining. The success was mainly due to the CNNs learning themselves how to create good explanatory variables. Hence, we decided to investigate how to use a CNN to automate the feature extraction from the transaction data. To the extent of our knowledge, we were the first to apply CNNs to consumers' account balances to predict mortgage defaults. Our anonymised data set consisted of a sample of 21,000 customers. For every customer we had the daily balances on their checking account, savings account and credit card, in addition to the daily number of transactions on the checking account and the daily amounts that are transferred into the checking account. We trained one CNN for each time series and then the resulting predictions were averaged to give a final prediction for each customer. The results were very promising. 95% of the customers were classified as low-risk, compared to 80% with DNB's current model at that time, meaning that the manual resources in the bank could be focused on more complex cases. Further, 50% of those who actually defaulted were found in the group consisting of the 1% with the highest risk according to the model.

In addition to being implemented into DNB's risk models documented later in this report, this work resulted in the paper *Predicting mortgage default using convolutional neural networks*, published in the journal *Expert Systems With Applications* and an article in the Norwegian daily newspaper *Dagens Næringsliv.*

Selected paper:

Kvamme, Håvard; Sellereite, Nikolai; Aas, Kjersti; Sjursen, Steffen A. Søreide (2018). Predicting mortgage default using convolutional neural networks. *Expert Systems with Applications*

Roboten gir lån hvis den får gode vibrasjoner fra kontoen din

DNB vil sette en robot til å analysere kontobevegelsene dine. Hvis den liker «vibrasjonene» kan flere få lånetilbud.

Tron Even Skyberg, divisjonsdirektør og leder for risikokvantifisering i DNB håper å få god nytte av forskningen til Steffen Sjursen, prosjektleder for risikomodellering i DNB, Nikolai Sellereite, forsker Norsk Regnesentral, Håvard Kvamme, stipendiat UiO, og Kjersti Aas, prosjektleder i Norsk Regnesentral. Foto: Gunnar Lier

Facsimile from the Norwegian daily newspaper Dagens Næringsliv, April 30, 2017.

Explainable AI taking feature dependence into account

Who: Kjersti Aas, research director at NR, Martin Jullum, senior research scientist at NR, Lars Henry Berge Olsen, PhD student at UiO from 2020 to 2024, Annabelle Redelmeier, research scientist at NR, Anders Løland, research director at NR, Ingrid Glad, Professor at UiO.

What: In many applications, complex machine learning (ML) models like deep neural networks, random forests and gradient boosting machines are currently outperforming the traditional linear/logistic regression models. Usually, there is a clear trade-off between model complexity and model interpretability, meaning that it is often hard to understand why the ML methods perform so well. In response, a new line of research emerged around 2016 to help users to interpret the predictions from ML methods.

In BigInsight we have mainly focused on one category of these methods; Shapley values. Shapley values is a model-agnostic method – meaning that it works for any model – for explaining individual predictions with a solid theoretical foundation. The main disadvantage with this method is that the computational complexity grows exponentially with the number of features. This has led to approximations, of which the so-called Kernel SHAP method is the best known. The Kernel SHAP method assumes (partly) feature independence, which is very rear in the real world. Hence, the main contribution of the work in BigInsight has been to extend the Kernel SHAP method to handle dependent features.

In addition to being of relevance to several of our BigInsight partners (e.g. NAV and DNB), this work has resulted in ten scientific papers, of which especially the first, *Explaining individual predictions when features are dependent: More accurate approximations to Shapley values*, which was published in the journal *Artificial Intelligence,* has gained a lot of interest.

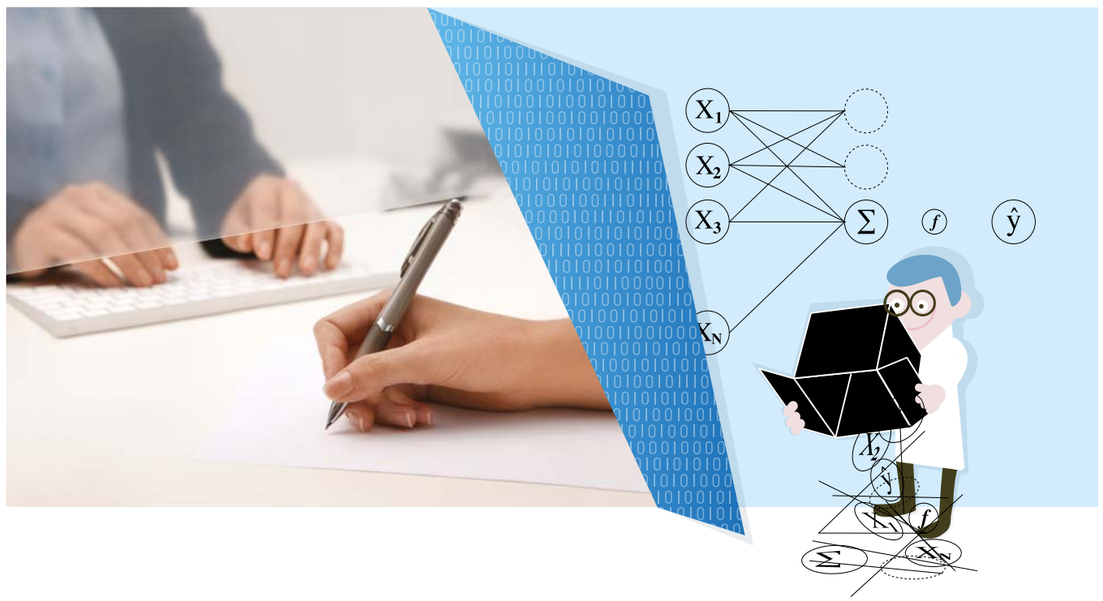
Selected papers:

1. Aas, Kjersti; Jullum, Martin; Løland, Anders (2021). Explaining individual predictions when features are dependent: More accurate approximations to Shapley values. *Artificial Intelligence*

2. Aas, Kjersti; Nagler, Thomas; Jullum, Martin; Løland, Anders (2021). Explaining predictive models using Shapley values and non-parametric vine copulas. *Dependence Modeling*

3. Olsen, Lars Henry Berge; Glad, Ingrid Kristine; Jullum, Martin; Aas, Kjersti (2022). Using Shapley Values and Variational Autoencoders to Explain Predictive Models with Dependent Mixed Features. *Journal of Machine Learning Research*

4. Olsen, Lars Henry Berge; Glad, Ingrid Kristine; Jullum, Martin; Aas, Kjersti (2024). A comparative study of methods for estimating model-agnostic Shapley value explanations. *Data mining and Knowledge Discovery*



Awards

In addition to many of our research results being presented to international conferences as invited lectures, we highlight the following awards, given to BigInsight staff:

- Norges 50 fremste Techkvinner: Kjersti Aas, Line Eikvil, Solveig Engebretsen, Ingrid Glad
- Norsk Regnesentral Master Prize 2016: Solveig Engebretsen for her master thesis titled "Monotone Regression – in high (and lower) dimensions".
- Professor Sylvia Richardson (from SAC) was awarded with an honorary doctorate degree from the University of Oslo in 2017.
- The prestigious Aker Scholarship was awarded to master student Camilla Lingjærde who in 2019 started as a PhD studen at the BSU, University of Cambridge.
- The paper "Toward Personalized Computer Simulation of Breast Cancer Treatment: A Multiscale Pharmacokinetic and Pharmacodynamic Model Informed by Multitype Patient Data", published in Cancer Research was in 2019 awarded the "Prize for transdisciplinary publication 2019" awarded by The Centre for Digital Life Norway.
- D2 Ledestjerner 2020: Solveig Engebretsen
- Sverdrup Price 2021: Arnoldo Frigessi
- Arnoldo Frigessi was awarded the honour of Knight of the Order of Merit of the Italian Republic, by the President of the Italian Republic in Oslo, 12 December 2021.
- Birgitte Freiesleben De Blasio was elected member of Royal Academy of Science (Det Norske Videnskapsakademi) in the nominations made in 2021.
- Norsk Regnesentral Master Prize 2021: Ingrid Dæhlen for her master thesis titled "Empirical and Hybrid Likelihood".
- Krafthack 2022: Martin Tveten and Per August Moen
- Sverdrup Price 2024: Ingrid Kristine Glad
- NORA Lifetime achievement Award 2024: Arnoldo Frigessi

Martin Tveten (NR) and Per August Moen (UiO) win Krafthack 2022. Photo: Statkraft.

INTERNATIONAL COOPERATION

The international collaboration of BigInsight has been important and significant.

Our work on the digital twin in personalised cancer treatment has led to two Horizon 2020 projects and one Horizon Europe project:

RESCUER – RESistance Under Combinatorial Treatment in ER+ and ER- Breast Cancer – is a consortium of fifteen organizations from ten different countries (Belgium, Finland, France, Germany, Israel, Norway, Spain, Sweden, United Kingdom, United States) gathering all the relevant expertise and facilities to solve the challenge of identifying novel characterization methods for breast cancer drug resistance and new knowledge on effective combinatorial treatments. This EU project was coordinated by UiO, with Frigessi as co-PI.

BD4QoL – Big Data for Quality of Life – is a consortium of 16 organizations and one clinical linked party, located in 7 different European countries. The aim is to use Artificial Intelligence-assisted mobile applications to improve the quality of life of head and neck cancer patients through personalized monitoring, support and care after treatment. The app is validated in a large randomized clinical trial that will assess the effectiveness of an AI-based, patient self-empowerment platform. The introduction in the care workflow of innovative e-health solutions supported by large amounts of integrated unconventional and healthcare data, collected by mobile technologies, and Artificial Intelligence algorithms will lead to benefits for thousands of head and neck cancer patients who survive the disease. The Norwegian node is lead by Frigessi.

ENFIELD – European Lighthouse to Manifest Trustworthy and Green AI – is a unique European Centre of Excellence that excels in fundamental research in the pillars of Adaptive, Green, Human-Centric, and Trustworthy AI that are new, strategic and of paramount importance to successful AI development, deployment, and acceptance in Europe. NR is one of 30 partners from 18 European countries.

We have also received further international funding from the European Partnership for Personalised Medicine and The Research Council of Norway.

Capacity development at Hawassa University, Ethiopia

BigInsight was a partner of the Norwegian Programme for Capacity Development in Higher Education and Research for Development (NORHED) project at Hawassa University (Ethiopia), together with NTNU. In June 2017, for the first time ever in Ethiopia, a PhD degree in Statistics was awarded by an Ethiopian university. Denekew Belay, Markos Erango, Negussie Yohannes defended their theses with success. All three students had spent at least one year in Oslo and were part of the BigInsight student community. We are proud to have been able to contribute to statistical capacity building in Ethiopia. The project ended in 2022, and more than 12 Phd students have graduated. They are all employed as lecturers in various universities in Ethiopia, providing an important contribution to capacity building of the country.

In 2022, BigInsight collected and sent several books for teaching and research in statistics and epidemiology to Jimma university in Ethiopia

STOR-i at the University of Lancaster, UK

BigInsight has partnered with STOR-i, Statistics and Operational Research in partnership with Industry, at the University of Lancaster, which is a joint venture between the Departments of Mathematics & Statistics and Management Science of the University of Lancaster. STOR-i offers a unique interdisciplinary PhD programme developed and delivered with 40 important UK industrial partners. The centre is at the forefront of international research effort in statistics and operation research, establishing an enviable track record of theoretical innovation arising from real world challenges. Professors Jonathan Tawn, Idris Eckley (who co-lead the centre) and David Leslie co-supervised PhD students together with BigInsight staff, on recommender systems, reinforced learning, multivariate extremes, non-parametric isotonic spatial regression, Bayesian modelling, multivariate sensor data, and pair copula models. BigInsight and STOR-i have co-organised industrial statistics sessions in international conferences and exchange chairing each other's scientific advisory boards.

Professors Idris Eckley, Jonathan Tawn and Kevin Glazebrook, leading STOR-i at University of Lancaster"

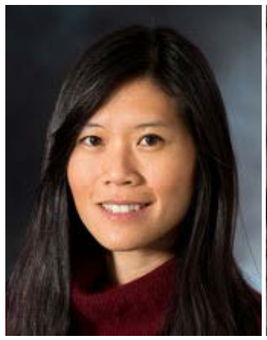
University of Cambridge, UK

A further long-term collaboration of BigInsight has been with The Medical Research Council Biostatistics Unit (BSU) that is part of the University of Cambridge, School of Clinical Medicine. It is a major centre for research, training and knowledge transfer, with a mission «to advance biomedical science and human health through the development, application and dissemination of statistical methods». BSU's critical mass of methodological, applied and computational expertise provides a unique environment of cutting-edge biostatistics, striking a balance between statistical innovation, dissemination of methodology and engagement with biomedical and public health priorities. BigInsight and the BSU have several joint projects in health and molecular biology. We are both partners in RESCUER, a Horizon 2020 project. One postdoc from Oslo and one PhD student from Oslo have been working at BSU. The director of the BSU, Professor Sylvia Richardson, has been awarded a honorary doctor degree by UiO.

Professor Sylvia Richardson, MRC Biostatistics Unit, Cambridge

University of Minneapolis, USA

The collaboration with the Department of Mathematics, University of Minneapolis, USA, started in 2018 when Professor Jasmine Foo and associate Professor Kevin Leder spent a year at BigInsight, working at the interface between mathematics, cancer biology, clinical oncology, machine learning and statistics. The scientific core of this collaboration was the development of new methods for integrating patient data into mathematical models of cancer, contributing to better treatment for cancer patients. In addition, we developed new educational opportunities in mathematical modelling of cancer at master's and PhD's levels at UiO and UMN. The collaboration was also supported by an INTPART project funded by The Research Council of Norway that BigInsight obtained.



Jasmine Foo, Deputy Director, Institute for Mathematics and its Applications, Professor, School of Mathematics, University of Minnesota

Kevin Leder, Associate Professor, Industrial and Systems Engineering, University of Minnesota

NordicMathCovid, Nordic countries

BigInsight was a founding partner of the Nordforsk project «Data streams and mathematical modelling pipelines to support preparedness and decision making for COVID-19 and future pandemic». The goal of this programme was to, for the first time, create a joint Nordic long-term academic collaboration on pandemic preparedness using advanced mathematical modelling and systematically collected health data from a broad range of sources. In its initial phase the programme involved Finland (Aalto), Norway (BigInsight), and Sweden (Stockholm). The programme participants comprised epidemiologists, statisticians, mathematicians, and computer scientists. The aim of the programme was to use public health data combined with real-time data streams representing social activity and human mobility, together with advanced mathematical modelling and computational methods to address several of the most urgent questions for COVID-19 and future pandemics: What effects do community structure, individual heterogeneities, and spatial mobility have on reproduction numbers, community immunity, and the efficacy of different preventive measures? How can real-time data streams of social activity and human mobility combined with clinical health data aid in making more accurate predictions and more informed control decisions related to structurally and geographically targeted nonpharmaceutical interventions? How can Nordic health data and novel data streams of relevance for the ongoing COVID-19 and future pandemics be shared and published in a way that allows for better analyses without compromising data privacy of the individuals? The programme developed methods, tools, and operational procedures for implementing cross-Nordic interoperable public health data pipelines, novel methodology published in international scientific journals, and support the national public health institutes in their aim to keep disease spreading low without causing too high burden on Nordic societies.

Scientific Advisory Committee

The Scientific Advisory Committee of BigInsight met twice in Oslo in person and twice remotely. The chair of the SAC, Professor Idris Eckley and Frigessi had a monthly remote meeting during the whole period of the centre. The contribution of the SAC has been important for BigInsight.

Visiting programme

BigInsight had an active visiting programme for international Phd students and researchers, and we welcomed over longer periods visitors from USA, Italy, Germany, and UK. Shorter visits from international scholars were linked to seminars.

Photo: norden.org

TRAINING OF RESEARCHERS

The establishment of BigInsight seeded a new direction of research and education at the University of Oslo. Together with the SFI Sirius at the Department of Informatics, BigInsight laid the ground for establishing a data science community at UiO. This collaboration between the two SFIs resulted in the establishment of the Data Science Day at UiO, which has gathered 500 academics/students/industry every year since 2016, and, even more important, the establishment of a new Master Program in Data Science, from 2018. The master program in Data Science is a joint program between Department of Mathematics and Department of Informatics, can receive up to 20 students every year, and attracts a lot of applicants. This direction of study has also influenced the curriculum at the Department of Mathematics, offering courses more tailored for large data and machine learning that traditional statistics. Furthermore, it is fair to say that the activities of BigInsight and Sirius eventually contributed to the establishment of dScience, a centre supporting and coordinating research in computational and data sciences at the University of Oslo, established in 2021.

BigInsight has trained many master students, PhDs and post docs during the centre period. The master students have been enrolled in the Data Science master program, as well as in the Statistics master program at UiO. A few students have written their master thesis in other universities, when BigInsight associates there have been main supervisors. So far, circa 45 master students have finished their master theses with topics from BigInsight and supervisors from the centre. The master projects have sometimes been associated with ongoing PhD projects, and sometimes been independent projects. Supervision has involved academic staff at the Department of Mathematics, with lots of help and support from NR researchers, partner representatives and other BigInsight researchers, from for example the Biostatistics Department (OCBE), NTNU, and UiB. The joint supervision of many master projects under BigInsight, has led to new acquaintances and stronger connections between the involved parties.

The PhD students have been employed at either the Department of Mathematics or at the Biostatistics Department (OCBE), both at the University of Oslo. The PhD candidates have been enrolled in the PhD programs of the respective faculties (MN and Med) and have had supervision teams consisting of both UiO academics, NR researchers and often partner representatives. Among the 26 who successfully defended their PhD thesis within February 2025, around 50% had Norwegian background. The centre did not do anything special to recruit Norwegian talents, but we believe that they were attracted by the interesting and timely topics of research, and the SFI construction. The other 50% had background from Europe or China, and they were all considered to be very strong. 30% of the 26 candidates were female. In addition to the 26 finished theses, 2 candidates, with funding from other sources, but scientifically related to BigInsight, are in the beginning of 2025 still pursuing their PhD.

More than 30 post doc researchers have been part of BigInsight, with varying degree of involvement. Among the 6 post docs directly funded by BigInsight, two were Norwegian, and the others were recruited from Algeria, Estonia, Spain and Italy. The fraction of female post docs was a bit lower than for the PhD candidates (25%). The post docs have either remained in academia, several now have permanent positions at UiO or other Norwegian universities, and some have moved abroad, or are working in industry or business.

In what follows, a selection of BigInsight candidates have answered to the three points:
1. Why they chose to join the centre.
2. How they experienced working at the centre.
3. Where they work and their plans since/after completing their respective degrees.

Solveig Engebretsen, BigInsight PhD in 2019, now senior research scientist at NR:

I applied to a PhD project from the BigInsight centre because of the motivating application with evident importance and usefulness.

I experienced the centre as highly competent with interesting applications and great cross-disciplinary collaborations. I enjoyed both my own project, but also learning about other projects in seminars and BigInsight Days, etc. I particularly enjoyed being able to apply the knowledge and output of my PhD project during the COVID-19 pandemic. It was a great opportunity to work with real-time research, with a much higher pace than everyday research, and a lot more pragmatic solutions.

I work at the NR with applying and developing statistical methods for practical applications, very much in the spirit of BigInsight!

Andreas Brandsæter, BigInsight industrial PhD in 2020, now assoc. Professor University College Volda:

I was working as a researcher in DNV, one of the project partners, and was already interested in the topics of the SFI.

I thrived well working at the centre, really enjoyed working in the intersection between academia and industry.

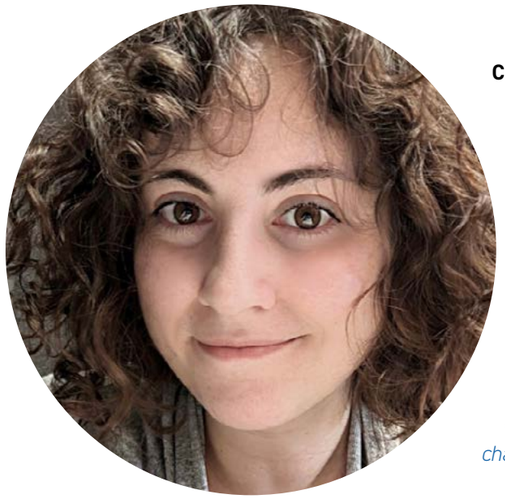
Currently I work as an associate Professor and Volda university college (and associate Professor II at NTNU). I continue doing research on the topics from the SFI and continue collaboration with the partners from the project, both academic and industry partners.

Martin Tveten, BigInsight PhD in 2021, now senior research scientist at NR:

I joined as a master student during the first couple of years of the centre. I wanted to do a master thesis and later a PhD there because the centre was about modern topics in statistics and data science. I was inspired by the idea of being in a bigger group that worked on similar projects, aiming to be at the research front.

I had a lot of fun and interesting talks with my colleagues. I had a fantastic and supportive supervisor in Ingrid Glad. I enjoyed the topics of changepoint and anomaly detection in sensor data that I worked on. I also had the opportunity to go to Lancaster University and collaborate with professors on a project there.

I still work on the same topics as a researcher at NR. I've basically spent my four years since the PhD applying the changepoint and anomaly detection "hammer" on several applied research problems across different fields: Monitoring wind parks and predictive maintenance with Statkraft, condition monitoring of ship engines with ABB, and anomaly detection of technical equipment in commercial buildings using sound sensors with the start-up Soundsensing AS, to mention only a few. The interest in these topics is growing in the industry. I aim to build a strong research group on industrial anomaly and fault detection at Norsk Regnesentral.



Clara Bertinelli Salucci, BigInsight PhD in 2024, now post doc at UiO:

I chose to join BigInsight because it offered a brilliant opportunity to collaborate with top researchers and industry leaders in Norway, within an academic and multidisciplinary environment.

I thoroughly enjoyed the highly collaborative atmosphere and found the projects to be ambitious but within reach, making them both challenging and extremely rewarding.

After completing my PhD at BigInsight, I pursued a postdoc position to deepen my expertise in statistical inference and further advance my research career.

Lars Henry Berge Olsen, BigInsight PhD in 2025, now research scientist at NR:

I joined the centre as they offered an interesting PhD position on the topic of Explainable AI, which caught my academic interest.

I enjoyed working at the centre and all that it offered, e.g., the Wednesday seminar series which I co-hosted for 1 ½ years. The community was open and nice, and I found the yearly BigInsight Day to be informative and it helped to bridge the gap between academia and the industry.

Currently, I work at NR as a researcher on topics related to statistics, data science, and machine learning.

Azzeddine Bakdi, BigInsight Postdoc until 2021, now Battery Analyst in Corvus Energy:

The BigInsight section of sensor systems matched my research interests, covering both theoretical development and industrial applications of data analysis.

It was useful for networking with partners from universities and industries. Learning more about new data analysis methods and their successful applications. It was fruitful to publish some research papers.

I completed my Postdoc on 2021 at BigInsight, since then I have worked at Corvus Energy Norway. I plan to continue working within the fields of digitalization and electrification/ decarbonization of maritime systems.

EMPLOYMENT OF PHD CANDIDATES (NUMBER)

	By centre company	By other companies	By public organisations	By university	By research institute	Outside Norway	Other	Total
Funded by BigInsight	-	5	-	3	5	1	-	14
Affiliated with BigInsight	-	-	1	3	-	8	-	12
Total	-	5	1	6	5	9	-	26

COMMUNICATION / POPULAR DISSEMINATION OF KNOWLEDGE

The centre has been very successful in generating national and international attention. Both the interesting mix of big and important partners and the fact that BigInsight was seen as the first AI centre in Norway caught the interest of many companies, public administration and non-scientific conferences, especially in Norway and in the Nordic countries.

From the introduction of the innovation objective "Explaining AI", the centre became and still is a key player in the public debate in Norway on the blessings and pitfalls of artificial intelligence. This was done through popular science opinion pieces in Norwegian media, talks, podcasts and panel discussions in non-scientific conferences.

BigInsight's groundbreaking COVID-19 research guided the Norwegian Institute of Public Health and the Norwegian Government efforts and plans during the pandemic. The Norwegian media (NRK, Aftenposten, TV2, Klassekampen, Morgenbladet, Finansavisen, DN, and more) have given great attention to our work, and we have learned, also the hard way, how to communicate to the public. Our results have really helped decision makers, so that we can proudly affirm that it is also thanks to BigInsight that Norway succeeded to control the virus rather well. In 2021 the centre and its host organised a panel debate at Arendalsuka – an annual Norwegian political festival – on "What we can learn from the COVID pandemic: How do we handle uncertainty and openness?" with the head of BigInsight, the head of the Norwegian Institute of Public Health, a journalist from Norway's leading newspaper Aftenposten, a journalist from Norway's public broadcaster NRK and a research scientist from the centre.

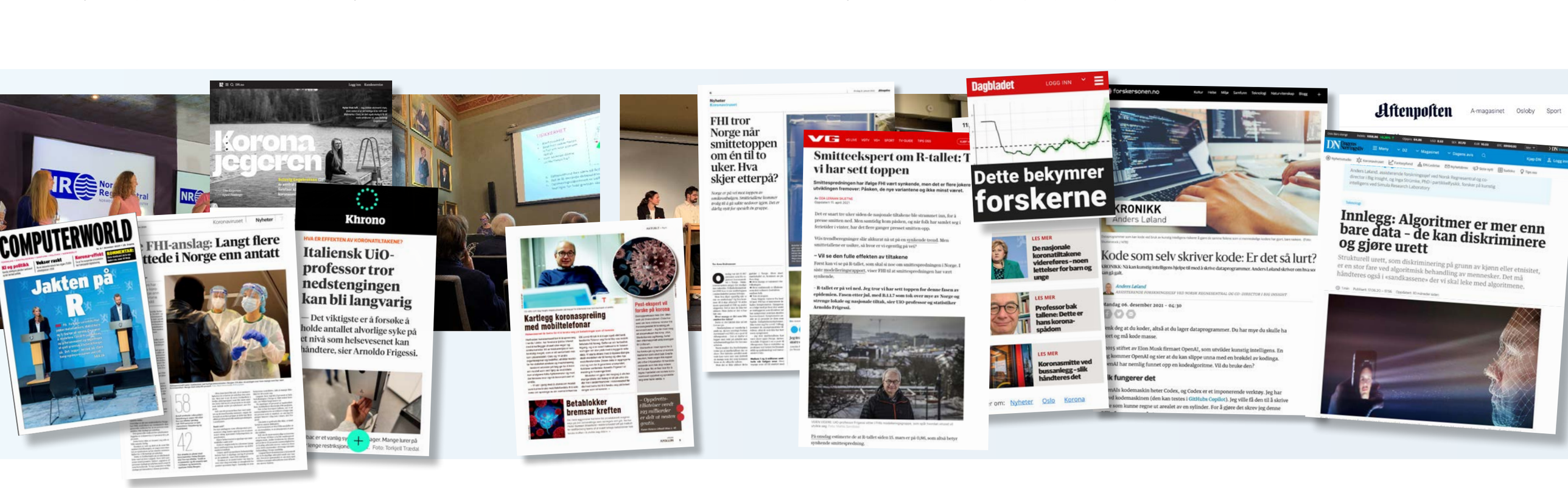
BigInsight has shared knowledge from the centre's results in a range of ways, including podcasts, radio and tv appearances, seminars, conferences and more.

Screenshot from nrk.no. Anders Løland discussing the threat of super intelligence at "Dagsnytt 18", a daily news magazine from Norwegian radio and tv.

Data Science Day has been an annual event at the University of Oslo since 2017, and was initiated by BigInsight, SIRIUS (a sister SFI) and DataScience/dScience at the University of Oslo. Data Science Day is an event for everyone, whether you are familiar with data science practices, or you are simply curious what data science is all about. Each year it gathered several hundred participants, and the topics have included *Social aspects of AI: Privacy, Fairness and Safety* by Christos Dimitrakakis (UiO), *On the use of Bayesian methods in machine learning* by Geir Storvik (UiO and BigInsight), *AI Explainability from the ground up* by Morgan Briggs (The Alan Turing Institute), and *Learning without seeing – catching the evolution of bacteria through the statistical looking-glass* by Professor Jukka Corander (UiO and BigInsight).

In 2024, two important workshops were organised to convey the centre's results and experiences beyond the research community and look to future prospects:

- *The 1st Oslo Invitational Workshop on Model-Agnostic Explainable AI*
- *National seminar on machine learning for AML (anti-money laundering) for Norwegian banks*



EFFECTS OF CENTRE FOR THE HOST INSTITUTION AND RESEARCH PARTNERS

The two main research partners in BigInsight are UiO and the host institution NR.

NR holds a strong national position within statistical modelling, machine learning, image analysis, artificial intelligence and specific areas within information technology. Leveraging our more than 70 years of historical and institutional experience, today the research institute develops new and employs state of the art methods, algorithms and computational systems to provide insight and knowledge from data, whether labelled statistical modelling and inference, machine learning or artificial intelligence. NR's primary mission is to conduct valuable and highly relevant research in close partnership with Norwegian industry and society. Although all of NR's services are rooted in robust research, NR's purpose differs from the universities. The institute's objective is to have comprehensive and state-of-the-art knowledge in methodology and theory, to be able to provide innovative solutions to complex and challenging problems. While NR tailors solutions and systems for each client, the researchers often draw on generic methodologies which are developed for and used across partners and sectors.

NR's strategy is based on the institute's purpose clause, the current scientific status and the market position. NR's strategical ambitions are:

1. NR shall consolidate and fortify the position as a sought-after and leading contract research institute in the institute's research areas and secure a substantial volume of direct commissions across the entirety of NR's organisation.
2. NR shall be an attractive partner and project leader in research projects that are funded wholly or partially by public research grants and deliver valuable and internationally leading research results.
3. NR shall be an internationally recognised research environment with a publication rate and quality on par with or surpassing comparable institutes.
4. NR shall be prominent in public discourse and be a clear communicator of NR's insights and research.
5. NR shall operate in a financially responsible manner, and balance profitability with attaining its social mission. NR shall grow in accordance with the market to consolidate and strengthen the position in core areas.
6. NR shall dominate the recruitment market and attract the best candidates within the institute's disciplines. NR will provide support that fosters desirable and exciting development for each individual and that motivates employees to take on ambitious challenges.
7. NR shall collaborate with the University of Oslo (UiO) and other research institutions to collectively produce optimal, internationally recognised research.
8. NR shall continue to develop and maintain efficient support systems that reinforce its core activities.

BigInsight has been crucial in fulfilling these ambitions. NR's scientific level has increased further during the life span of BigInsight. NR is proud of the important new innovations which have been made and implemented at the user partners. Not at least, solutions based om methodological challenges in BigInsight have been transferred and tailored to numerous of NR's partners and clients not participating in BigInsight. With BigInsight as a basis, both scientifically and financially, NR has been able to take higher risks in attracting new, talented young researchers, who have developed the necessary skills to fulfil NR's role also in the future.

BigInsight has had similar impact at UiO, securing a basis of knowledge and science at a high level. The substantial number of PhDs has increased the scientific capacity. In addition, the close connection to industry and user partners is important for the further development of UiO, and this cooperation has created a vital, motivating environment.

NR and UiO have cooperated for decades, and BigInsight has further strengthened this collaboration. Together, this environment of statistical modelling and machine learning has a strong international reputation. One important result is the establishment of the Centre of Excellence "Integrate", which has BigInsight as one of its core pillars.

BigInsight can be seen as the first Norwegian AI-centre. One direct effect of BigInsight is the prominent role the researchers in statistical modelling and machine learning now play within the Norwegian AI society. Hence, as a legacy of BigInsight, NR and UiO have taken a common initiative to establish a new AI-centre TRUST, which, if funded, will become extremely important for the development of responsible and trustworthy AI in Norway in the years to come.

EFFECTS OF CENTRE FOR THE COMPANY PARTNERS, PUBLIC PARTNERS AND SOCIETY AT LARGE

The effects of BigInsight are substantial and impressive. Although detailed measuring of innovation and value creation from research is notoriously difficult, even if we only consider BigInsight's contributions during the COVID-19 pandemic, the value for the society at large is very high. During the COVID-19 pandemic, NIPH and partners from NR, UiO and Telenor provided situational awareness, short-term forecasting and scenario modelling, supporting the Norwegian government and local health authorities in managing the pandemic. The success of this joint work during a global health crisis underscored the importance of having an established collaborative network in place before emergencies arise – which we call *Research as Preparedness*.

BigInsight has for nine years been building competence and capacity which will be beneficial to all partners and for Norway at large. The AI revolution comes both with great opportunities and uncertainties: in what way will the bank and telecom sectors change if Google and Facebook start offering personalised bank, insurance and telecom products based on huge amounts of personal data? BigInsights's partners must prepare for an unclear future and a new level of competition. Our large commercial partners ABB, DNB, DNV-GL, Gjensidige, Hydro and Telenor may increase their markets substantially if they succeed in being in front of the new competition, while a lack of adapting may result in rapid loss of markets, with large economic consequences. BigInsight has been important because we have been testing new avenues of business, in depth, scientifically. Additionally, the capacity and knowledge being built through BigInsight can be seen as even more strategically important and long lasting than tests, pilots and proof-of-concepts performed.

Our public partners, the Cancer Registry of Norway, NAV, NIPH, Skatteetaten, OUS, SSB, have been and are moving very rapidly in the lane of digitalisation, creating data sources of potentially enormous impact. BigInsight has accompanied them in this journey, by exploring radically new possibilities. The societal benefit can be huge, in terms of economical savings, more fair and efficient services, better public health, patient safety and treatment.

Innovations based on BigInsight's research include Improved transaction-based alarms for AML (Anti Money Laundering) · Mortgage default prediction with convolutional neural networks · sentiment models for insurance fraud detection · Improved risk premiums for water damage insurance through spatial modelling · Shapley explanations for predictive models to support welfare administration · Quantile regression, copula coupling and error dressing for wind farm production and price forecasting · Advancement of model for control of VAT returns · Bayesian semi-parametric modelling tool for in-vitro drug combination experiments · Individual treatment prediction against breast cancer · Phenotypic deconvolution of cancer drug screens · Dynamic Slate Recommendation with Gated Recurrent Units and Thompson Sampling · Anomaly detection for large ship engines · Large Language Models for Chat Response Generation.

BigInsight has been one of the very few arenas where private and public actors exchange AI knowledge and share research. This also leads to progress and provides benefits to Norway as a whole. BigInsight's work and competence building are of course also relevant for other industries, sectors and businesses. Our work is open – we have produced open publications and open software[2] – and our young students and researchers will take their experiences further. NR's contracted research will give advantages to their clients. As all the partners of BigInsight are large companies or public partners, startups have not been a focus, but via NR startups like SoundSensing and FundingPartner now use methods for anomaly/changepoint detection and explainable artificial intelligence that have been developed in BigInsight.

2 See **https://www.biginsight.no/software** for a list of available open software.

The most important effects of BigInsight

What has been most important for the centre's user partners along the lines of what was asked at the midterm evaluation? This varies somewhat from partner to partner. All partners have had a keen interest in the development of new or improved processes or services, building up a strengthened knowledge base, improved access to competent personnel and research institutions, and recruitment of qualified personnel. Some partners that also make use of NR's contracted research have pointed out the importance of strengthening NR's competence and foundation is in their interest as well as in NR's interest.

Possibly somewhat unexpectedly, many of the partners really appreciated the informal exchange of knowledge and ideas between private and public actors, and the improved network it gave. From the annual BigInsight day, hosted by the user partners, to the weekly BigInsight lunches as well as other informal or organised meetings across the centre set the stage for this.

telenor | Skatteetaten | DNB | NIPH Norwegian Institute of Public Health | BigInsight | nav | UiO : University of Oslo

2016 | 2017 | 2018 | 2019 | 2020/2021 | 2022 | 2023

From the annual BigInsight days, hosted by the partners.

Success stories

Here we present some results considered particularly important for the user partners. All the stories presented in "Highlights of scientific results" earlier in this report are also success stories not only academically, but also for many of the user partners, and some of them will be embellished in the following. Of those that are not elaborated upon here, "Explainable AI taking feature dependence into account" was for example instrumental to NAV's efforts in securing responsible AI supporting Norwegian welfare services.

Benefits for the maritime industry

In BigInsight, we have worked with statistical and machine learning research motivated by problems and data from the maritime industry, especially connected to new approaches to safety surveillance, condition monitoring and performance monitoring of vessels or equipment based on large arrays of sensors. Examples of impact at DNV and ABB include research on new methods for automatic detection of developing faults or anomalies based on sensor and ship log data, which has been implemented in these two partner companies. In an interview with ABB researcher Morten Stakkeland – "Avoids ship disasters with advanced statistics", he comments on the impact of the collaboration[3]:

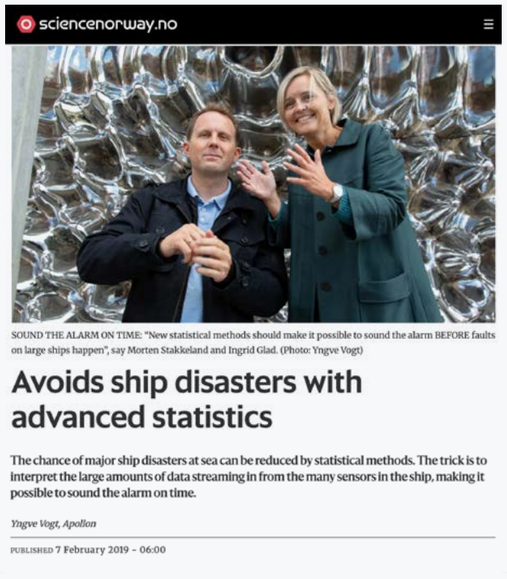
> –One company that has adopted this new way of thinking is the international industrial group ABB. They work closely with statisticians at the University of Oslo to enable shipping companies to save millions on more optimal operations and improve ship safety." – Instead of sending inspectors on board ships, we can rather use statistical methods to monitor all the data for changes, such as when the engine is about to overheat or break down. This automatic data monitoring should be able to provide warnings about incidents before they happen, says Morten Stakkeland.

The interview also comments on work we have performed on battery health monitoring (for example for electric vessels). Through development of monitoring methods based on sensor data, the electric vessels don´t have to be taken out of operation for battery controls. In the interview it is stated that:

– This is lost uptime. We look at how it is possible to use statistics to evaluate the batteries. This will save shipowners a lot of money, says Morten Stakkeland. One of the big points is maintenance only when needed, rather than at fixed intervals.

– Shipowners could potentially save millions of kroner per ship, Stakkeland points out.

Another example of both economic and safety critical impact is a system for autonomous shipping, which has been implemented and is in operation/development at DNV in Trondheim.


sciencenorway.no

SOUND THE ALARM ON TIME: "New statistical methods should make it possible to sound the alarm BEFORE faults on large ships happen", say Morten Stakkeland and Ingrid Glad. (Photo: Yngve Vogt)

Avoids ship disasters with advanced statistics

The chance of major ship disasters at sea can be reduced by statistical methods. The trick is to interpret the large amounts of data streaming in from the many sensors in the ship, making it possible to sound the alarm on time.

Yngve Vogt, Apollon

PUBLISHED 7 February 2019 - 06:00

3 https://www.sciencenorway.no/forskningno-norway-statistics/avoids-ship-disasters-with-advanced-statistics/1553406

The COVID-19 story

BigInsight's greatest achievement and societal impact was the modelling of COVID-19 during the pandemic in Norway. Basic research is like insurance: You never know when you need it but having it can save the day. As described already in this report in "Modelling COVID-19 in Norway – the scientific story", BigInsight's real-time research played an instrumental role during the pandemic.

What was our impact? The impact of BigInsight's research was during the whole pandemic (2020-2022) and continues today in terms of preparedness for future pandemics. We were part of the NIPH pandemic management during the whole period, with responsibility for all modelling and predictions. The groups included about 15 researchers, including system and data engineers and epidemiologists, in addition to us. We were responsible for all methodology and algorithms, including weekly runs.

Typically, our week started Monday at 8 in the morning, when we froze the current data and started running our models, with results ready on Wednesday morning, when the report was prepared and submitted at 12:00. The modelling group had a meeting on Monday at 8:00 to decide what algorithms to run, on Wednesday to discuss results and on Friday to critically discuss and decide about needed improvements and planning the specialised reports, with hard work all week long, often including weekends: week after week, taking turns during vacations. In addition, we were responsible for communication with the public and media on all modelling and prediction. Meetings were also organised with health authorities that used our results and regularly with all the Nordic health authorities.

Our results reached immediately the health authorities and the government. The R number was used in the public discourse, including uncertainties in estimating it. We

- Engbretsen, Frigessi and Kenth Engo-Monsen from Telenor took a temporary break from their ongoing projects to concentrate fully on this work, together with a larger team at the Norwegian Institute of Public Health led by Professor Birgitte De Blasio (left).

experienced several times to hear the minister or the health directors to cite from our reports during press conferences on national TV, just few hours after publication.

It is difficult to quantify the impact of our results. We dare to say that the beneficiary is the whole Norwegian population, in terms of lives saved, reduced hospitalisation and illness, and increased economic benefits. Norway as a country has been able to manage the pandemics well, citing from the national Coronavirus Commission: "The country's population and its authorities have handled the pandemic well overall. Norway has had one of Europe's lowest mortality rates, least restrictive infection control regimes and smallest declines in economic activity." One reason for this is the timeliness with which the national and the local governments have introduced interventions, to prevent the spread to explode. Our estimates and predictions were making this possible.

To give evidence of the importance of our work, we cite (our translations) from the report of the Coronavirus Commission, "Evaluering av pandemihåndteringen – Rapport fra Koronautvalget, 29. april 2022, for å gjennomgå og trekke lærdom fra koronapandemien i Norge"[4], see section 12.3.5 on "Matematisk infeksjonsmodellering":

> "The situational understanding included mathematical modelling to estimate the disease burden of the epidemic in the coming weeks. Mathematical infection modelling was part of a comprehensive knowledge base, and NIPH's professional advice was always provided based on a holistic assessment. – By quantifying health loss and the burden of measures, the [modelling] group could highlight the societal consequences of reducing imported infections, differentiating measures geographically, or illustrating how characteristics of the virus variant influenced the choice of strategy. – Throughout the pandemic, projections of infection numbers, hospitalizations, and sick leave were crucial parts of the government's decision-making basis. The committee believes that such projections have clear utility as decision-making tools and should, therefore, be used in future crises."

Section 12.3.5 of the report in also includes two statements, here translated: Prime Minister Jonas Gahr Støre described his relationship with the models and that these results were useful in "challenging decision-makers to consider what to do with hospital capacity … that must be scaled up if [the predictions would] materialize."

In addition, we believe that a further impact of our work, of more long term and educational type, is the increased understanding by the general population of uncertainty quantification of predictions. We think that recognising the presence of uncertainty in decision making, can more generally help to increase the trust in government and politics – important in our current world.

Mistakes we did in the COVID period also made an impact, not only our correct results: We failed to explain well enough the assumptions of our three-week ahead predictions. These were such that we predicted the number of new COVID hospitalisations, given that no new intervention would be implemented, and given that the population would continue to have the same mobility. Aftenposten, the main Norwegian newspaper, found that our predictions were pessimistic when the spread was increasing, and this was the main news on 15 June 2021. The reason for this difference was that when our predictions were alarming, then governments often would introduce additional restrictions and people would naturally behave more carefully, thus leading to less hospitalisations than predicted. We tried to explain this, but it was difficult.

Weekly reports for Situational awareness and forecasting for Norway were published from 14.4.2020 until 25 May 2023[5]. The NIPH also published a weekly report which always included a summary of our results, which then were seen in a global perspective[6].

During the pandemic, we gave many online presentations, including for the Alan Turing Institute in London and at the University of Helsinki. On the BigInsight Celebration Day in 2023, Camilla Stoltenberg, director of NIPH, wholeheartedly thanked BigInsight for the work during the COVID times[7].

4 https://www.regjeringen.no/contentassets/b1dace9390054c85a5a87c7bbf1bc384/no/pdfs/nou202320230016000dddpdfs.pdf

5 https://www.fhi.no/ss/korona/koronavirus/koronavirus-modellering/

6 https://www.fhi.no/publ/statusrapporter/luftveisinfeksjoner/#alle-ukerapporter-2020-2023

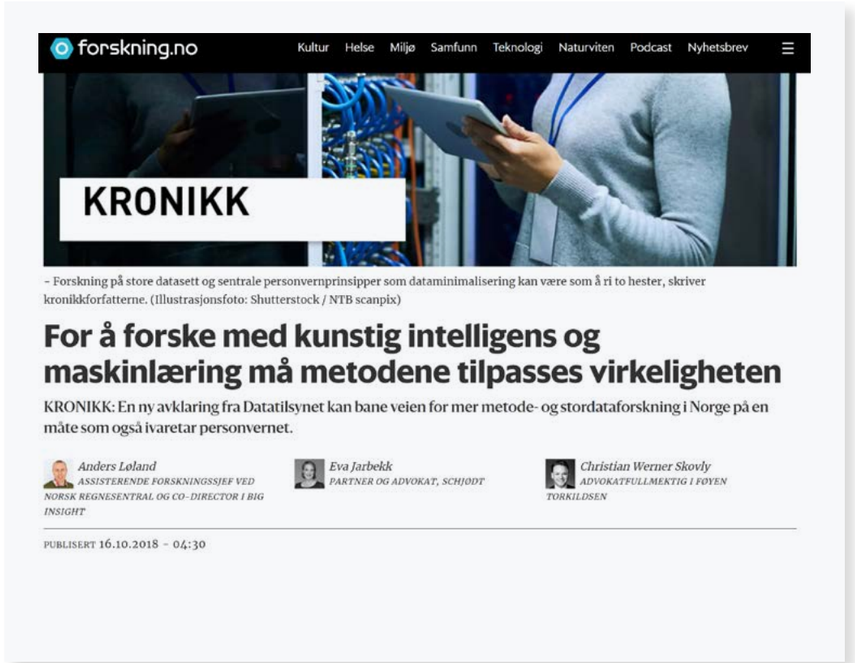
7 https://www.biginsight.no/news/2023/11/21/biginsight-celebration-day-was-fun

First in Norway to request authorization from the Norwegian Data Protection Authority for Machine Learning research on personal data

Quite early in the centre's lifetime – and before the introduction of the GDPR (General Data Protection Regulation) – BigInsight was planning to do methodological research on machine learning methods for detection of social welfare fraud and tax evasion. This involved applying for a data processing permit from The Norwegian Data Protection Authority (NDPA). In NDPA's first response, development of methodology was not seen as a scientific purpose and of general interest and benefit for the society. However, after a thorough complaint filed by BigInsight/NR, NDPA agreed that development of methodology has a scientific purpose and is of general interest. We believe this principal decision has been very important for all AI research in Norway since this decision.

Facsimile from forskning.no, Norway's independent, online science newspaper, October 16, 2018[8].

8 https://www.forskning.no/kronikk-om-forskning-teknologi/for-a-forske-med-kunstig-intelligens-og-maskinlaering-ma-metodene-tilpasses-virkeligheten/1249590



forskning.no Kultur Helse Miljø Samfunn Teknologi Naturviten Podcast Nyhetsbrev

KRONIKK

– Forskning på store datasett og sentrale personvernprinsipper som dataminimalisering kan være som å ri to hester, skriver kronikkforfatterne. (Illustrasjonsfoto: Shutterstock / NTB scanpix)

For å forske med kunstig intelligens og maskinlæring må metodene tilpasses virkeligheten

KRONIKK: En ny avklaring fra Datatilsynet kan bane veien for mer metode- og stordataforskning i Norge på en måte som også ivaretar personvernet.

Anders Løland ASSISTERENDE FORSKNINGSSJEF VED NORSK REGNESENTRAL OG CO-DIRECTOR I BIG INSIGHT

Eva Jarbekk PARTNER OG ADVOKAT, SCHJØDT

Christian Werner Skovly ADVOKATFULLMEKTIG I FØYEN TORKILDSEN

PUBLISERT 16.10.2018 - 04:30

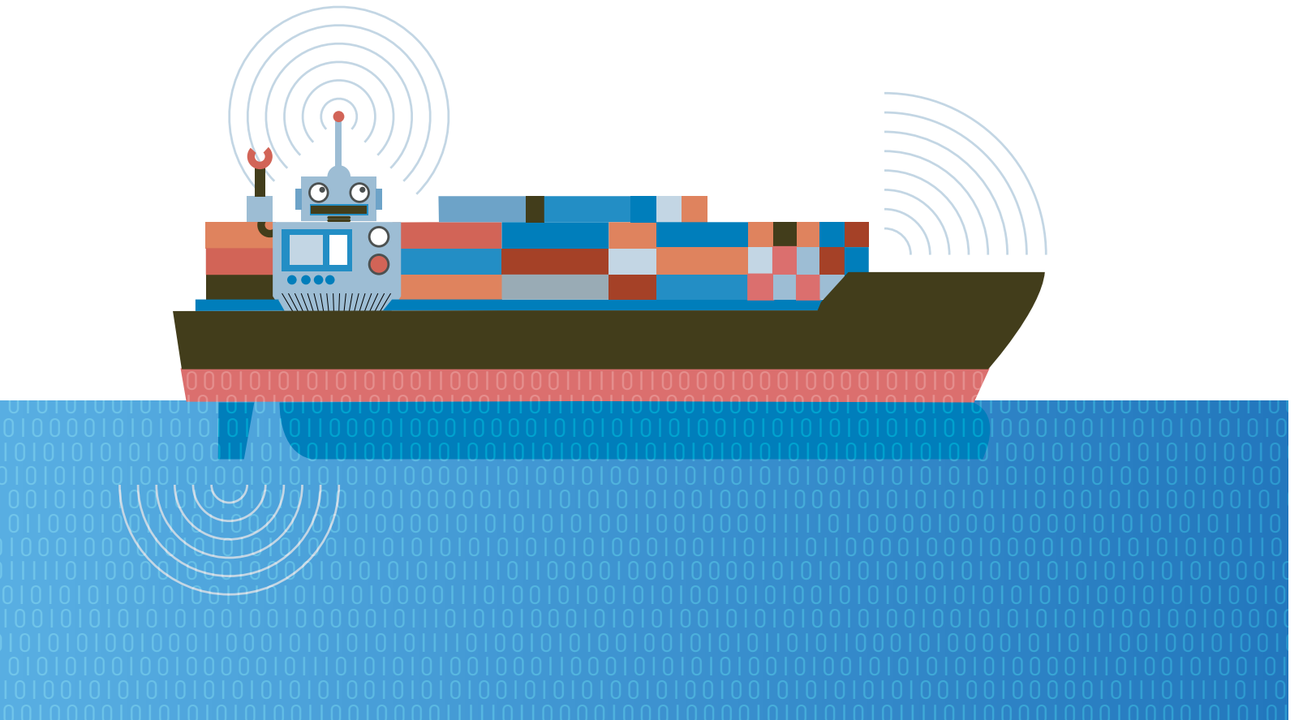
Exchange of personnel between the partners

To link our research with the innovation priorities of our partners, BigInsight employed three researchers from three of our partners (DNV, ABB, SSB) at UiO. This turned out to be a very important move. These three partners were the ones we had least pre-BigInsight collaborative experience with and involving them more closely to our research was very beneficial. With all three partners, we have produced important research-based innovation, we published strong papers, we trained three PhD students and in one case, we organised a course on Survey sampling and statistical demography, for master and PhD students, given for the first time in Oslo. In general, several of our PhD students seconded at our partners, mostly for shorter time periods, but a few for several months, when it was important to get really acquainted with data, systems and approaches of the partner.

Patents, commercialisation and new business activity

BigInsight has not been directly involved in any patents, and no startup companies has been started as a direct consequence of BigInsight, but BigInsight has been important for startup companies in two ways:

1. PhD students and master students from BigInsight have started to work in startup companies after completing their degrees.
2. Several startup companies, connected to Norway's largest incubator, StartupLab, which is situated at the Blindern campus, are partly based on methods from BigInsight's innovation objective Sensor systems. These companies are partly funded by the Research Council through the Innovation Project for the Industrial Sector scheme.



Feedback from some active company or public partners

In the following, three user partners present – in their own words – their experience from being a partner and how they have benefitted from affiliation with the centre.

DNB – Norway's largest financial services group

DNB are among the founding partners of the SFI BigInsight and have appreciated the journey and the success of the centre. The centre has been an important contributor to DNBs increased maturity in utilizing machine learning and data driven approaches for decision-making. BigInsight has also been a clear and knowledgeable voice in the hype surrounding Data, ML & AI – giving sound advice and clear recommendations.

To highlight some major achievements, I would like to highlight two concrete achievements and one important generic topic. Last thing first – BigInsight have been an important contributor to explainable AI. In DNB, being able to explain our models is instrumental and regulated by law. Based on knowledge acquired from BigInsight and partly related to their research [Shapley values] we have utilized some of these techniques in some of our internal models. This is valuable both to comply with the regulations but also to ease the adoption of these models internally by making the models understandable for our employees.

A concrete achievement was the development of the risk model based on transactions [«Predicting mortgage default using convolutional neural networks», 2018]. This showcased that our data had an untapped potential for risk calculations, providing value to our customers thru improved risk models for secured loans. The insight is partly implemented in our risk models today.

The second achievement I would like to highlight is the work on Anti Money Laundering. Banks have become one of the cornerstones in fighting financial crime and together with BigInsight we did some of our initial steps to combine large datasets, Machine learning techniques and domain knowledge to radically improve our models and approach [«Detecting money laundering transactions with machine learning», 2020].

Gjensidige – a leading general insurance company in the Nordic region

Gjensidige has been a partner of BigInsight since the beginning. In our opinion BigInsight has been a successful venture delivering value on several areas. The main value proposition is of course the research results both directly applicable but also generating insights fuelling our own research and solutions. The most obvious examples are the different climate scenarios, geographic scoring models, and prediction of claims with weather data. This is particularly important for Gjensidige as the EU taxonomy requires the insurance sector to "properly reflect climate risk" in its pricing.

But we have also taken big steps when it comes to increased automation of our risk modelling processes by leveraging machine learning without necessarily going the traditional black-box route, but rather exploring so called glassbox methods. BigInsight has been a highly valuable sparring partner and helped us avoid several pitfalls. Yet another area where results from BigInsight are being used is models on sentiment and language used in improving process-routing and fraud filters.

The Partnership-model and the network created by BigInsight has been another area driving value in Gjensidige. Together with the different partners we have had a large number of reference visits, speakers on internal summits, experience sharing sessions, presentations, and workshops on everything from tool usage, (agile) organisation of R&D and tech teams, data governance, AI guidelines and governance models. This is something we could leverage even more.

Furthermore, collaborating closely with NR has increased our internal competence in an efficient an agile manner and given us a strong recruitment pool. The collaboration also contributes strongly to our employer brand and is highly valued by candidates when we are recruiting.

A key success factor has been the long-term commitment from both SFI and partners, yielding a strong understanding in NR and BigInsight of the partners needs and an ability to anticipate and plan for demands from a rapidly changing future. Examples are the focus on Machine learning and the inclusion of Explainable AI as a separate research objective. To further build on this, Gjensidige fully onboarded BigInsight scientists on our systems allowing even closer collaboration and improving business understanding among the scientists leading to easier-to-adopt solutions for us.

The combination of the eight-year horizon and the SFI-funding ties Gjensidige to the competence hub in NR. For a commercial, listed company focusing on quarterly results, this drives value, lasting improvements, and robust solutions.

NIPH – the Norwegian Institute of Public Health

The infectious disease modelling unit, Division of Infection Control at the Norwegian Institute of Public Health (NIPH), has been an active partner in BigInsight since the start.

Participation in BigInsight has been critical to our research and provided fruitful scientific contacts and knowledge exchange, both towards forefront scientific research environments within academia but also towards public and private research organisations contributing real-world problems, data and practical implementation skills. The annual scientific meetings have been an important venue for networking and for our younger researchers, providing them with opportunities to present their work.

BigInsight and NIPH have co-financed a PhD modelling project (Solveig Engebretsen) in collaboration with Telenor, UiO, and NIPH. This constellation was very fruitful as the partners could use their cross-disciplinary network to get access to data and local expertise. For example, we collaborated on modelling the geographical spread of seasonal influenza in Bangladesh. NIPH has contacts with epidemiologists at the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B), providing access to vital health data. At the same time, Telenor facilitated access to Bangladesh mobile phone data through its subsidiary Grameenphone, which became the basis for an advanced modelling study addressing a global health challenge.

The most significant impact of the BigInsight partnership was the modelling work during the COVID-19 pandemic, where NIPH and partners from NR, UiO and Telenor provided situational awareness, short-term forecasting and scenario modelling, supporting the Norwegian government and local health authorities in managing the pandemic. The success of this joint work during a global health crisis underscored the importance of having an established collaborative network in place before emergencies arise.

Moreover, the collaboration during the COVID-19 pandemic has led to the development of promising long-term research initiatives. For instance, members of the COVID-19 modelling team now participate in a Nordic Pandemic Preparedness Modelling Network, collaborating with academic institutions and public health organisations across Nordic countries. In 2024, this network received funding from the Nordic Research Preparedness Initiative (NRPI) to conduct a hands-on pandemic modelling exercise workshop. This initiative will strengthen cross-border collaboration and improve preparedness for future pandemics, and the network has submitted applications to NordForsk to foster sustainable, long-term research relationships, instilling optimism about the future of our partnership.

Moving forward, integrating social and behavioural factors into infectious disease models is a key priority for NIPH, as it may improve model accuracy and enable the evaluation of real-time effects of large-scale social distancing measures. Novel data sources, such as credit card transaction data, can be used to gauge changes in behaviour. The established network with private sector partners, such as DNB, through BigInsight, can continue to be valuable for potential collaborations to drive future innovations in public health modelling.

FUTURE PROSPECTS

After the funding from the Research Council ceases, BigInsight has led to further and strengthened activities along avenues that cover both basic research and innovation:

Integreat – Centre of Excellence

Integreat is a Centre of Excellence funded by the Research Council of Norway of the University of Oslo, UiT the Arctic University of Norway and the Norwegian Computing Centre. Integreat will make machine learning more sustainable, accurate, trustworthy, and ethical. With world-leading researchers, young talents, and prominent international scientists, Integreat will contribute to shape the new field of knowledge-driven machine learning. The centre started in September in 2023 and will exist for ten years. Integreat would probably not be here without BigInsight.

Digital twins for personalized cancer therapies

The usefulness of mechanistic models to disentangle complex multiscale cancer processes, such as treatment response, has been widely acknowledged. However, a major barrier for multiscale models to predict treatment outcomes in individual patients lies in their initialization and parametrization, which needs to reflect individual cancer characteristics accurately. We have used multitype measurements acquired routinely on a single breast tumor, including histopathology, MRI, and molecular profiling, to personalize parts of a complex multiscale model of breast cancer treated with chemotherapeutic and antiangiogenic agents. The model accounts for drug pharmacokinetics and pharmacodynamics. We developed an open-source computer program that simulates cross-sections of tumors under 12-week therapy regimens and used it to individually reproduce and elucidate treatment outcomes of 4 patients. Two of the tumors did not respond to therapy, and model simulations were used to suggest alternative regimens with improved outcomes dependent on the tumor's individual characteristics. It was determined that more frequent and lower doses of chemotherapy reduce tumor burden in a low proliferative tumor while lower doses of antiangiogenic agents improve drug penetration in a poorly perfused tumor. Furthermore, using this model, we were able to correctly predict the outcome in another patient after 12 weeks of treatment. In summary, our model bridges multitype clinical data to shed light on individual treatment outcomes.

Anomaly detection and Explainable AI

Anomaly detection has become an important research field for both UiO and NR, being a core ingredient in future AI centres working with industrial data. At NR, anomaly detection methods are being further developed in contract research projects for companies such as ABB, Statkraft and Soundsensing. Similarly, having become internationally renowned in Explainable AI is of the uttermost importance for current both basic and contract research and future AI centres based on trust and a human-centric approach.

Future Research Centre for Artificial Intelligence

A large consortium around BigInsight has applied for a Research Centre for Artificial Intelligence, funded by The Research Council of Norway. This centre – called TRUST – will be approximately twice as big as BigInsight. The funding is to be decided in June 2025.

Professor Ingrid Glad, co-director at Integreat – Centre for Knowledge-driven Machine Learning. Photo: Integreat

CONCLUSIONS

Looking back, what has it meant to be a Research Centre as BigInsight, and what have learned? The strategy was to fulfil the vision of BigInsight; "[...] to develop methods, algorithms and computational tools in model based statistics and machine learning to solve innovation challenges at our partners and in science and society". After an initial series of rather broad workshops, involving all researchers and user partners, we organised the work into five (later six) innovation objectives, to ensure that the research was motivated by the innovation needs of the partners. Each innovation objective gave itself yearly objectives and deliverables, and were set up to:

- run projects which connect well, and not dedicated to a single partner, building on common challenges at a useful generic level, based on case studies, applications, examples and tests on data from partners,
- publish methodology and their new applications on international scientific journals,
- build research teams which included senior and junior staff from thezzz innovation and research partners, and have frequent meeting and close collaboration,
- guide the work towards value creation for the user partners.

Each innovation objective was led by a PI (principal investigator) and a co-PI, typically one from NR and one from UiO. On top of that, the director and the co-directors coordinated across the centre. The process of establishing the annual work plans was a bottom-up approach, from the partners in each innovation objective and up to the co-director level and finally the board.

Some of the innovation objectives' sub-projects lasted for years, while others lasted much shorter. Some sub-projects ended because of lack of data or that the methods we developed were not significantly better than state-of-the-art, and a few sub-projects should probably have been stopped earlier, but this is often easy to see in retrospect.

All the partners of BigInsight were represented in the Board, the highest organisational level of the centre, and there were two regular board meetings per year. The autumn meeting was dedicated to deciding next year's annual research plan and distribution of budget to each innovation objective, while the spring meeting discussed progress and strategy. As the partners by design of the centre were non-competitors, we experienced very open and fruitful discussions in the Board, which also helped keeping BigInsight in line with each partners' innovation strategies.

The bi-weekly, informal BigInsight lunches with a talk on a BigInsight-related topic, brought the centre together. The annual scientific meetings – the BigInsight Day – were key venues for networking, especially for our younger researchers, providing them with opportunities to present their work. Also, the BigInsight Career Day, and the annual DataScienceDay@UiO have been important recruiting arenas. However, a deep involvement in the innovation objectives, cooperating with researchers from NR, UiO and the user partners, is much more valuable than any annual workshop.

The annual scientific meetings and the BigInsight lunches as well as innovation objective specific workshops and informal meetings directly between several of the user partners were also crucial for communication and dissemination. Regarding popular science outreach, BigInsight was throughout the centre invited to speak at many national and international seminars and conferences, we contributed popular science opinion pieces in Norwegian media, and we were quite visible in the media during the COVID-19 pandemic, where we learned, also the hard way, how to communicate to the public in almost real time, in particular when the results or conclusions are uncertain.

Nine years (2015 – 2024) is a long time, and there is a delicate balance between sticking to the original research plan and adapting to the research front and the evolving innovation directions of the user partners. We are rather satisfied with the flexibility in the research plan. Here are three examples where we deviated from it:

1. Early on we took for granted that we would have to deal with massive data sets (big insight from big data!), which required mastering technologies like MapReduce and Hadoop. It turned out that what was big yesterday is not big today, and the improvement of statistical and machine learning software like Python and R made handling large data sets easier.
2. We quickly adapted to the rapidly changing research front, where Explainable AI and applying deep learning for new domains are two examples which were important both in terms of innovation and research.
3. When the COVID-19 pandemic hit us, BigInsight was ready and within a few weeks dedicated lots of its resources to this monumental challenge for Norway.

Appendix 1

LIST OF POST-DOCS, CANDIDATES FOR PHD AND MSC DEGREES DURING THE FULL PERIOD OF THE CENTRE

Postdoctoral researchers with financial support from the centre budget

NAME	M/F	NATIONALITY	SCIENTIFIC AREA	YEARS/PERIOD IN THE CENTRE	SCIENTIFIC TOPIC	MAIN CONTACT
Azzeddine Bakdi	M	Algeria	Sensor	2018-2021	Sensor systems	Ingrid K. Glad
Haakon C. Bakka	M	Norway	Fraud	2020-2022	Personalised fraud detection	Ingrid Hobæk Haff
Marta Crispino	F	Italy	Marketing	2017-2018	Personalised marketing	Valeria Vitelli
Annika Krutto	F	Estonia	Health	2020-2023	Personalised health and patient safety	Magne Thoresen
Alvaro Köhn- Luque	M	Spain	Health	2015-2017 Co-funding ERC Scientia Fellow 2016-2020, 2021-2024	Personalised health and patient safety	Arnoldo Frigessi
Pål Christie Ryalen	M	Norway	Health	4 months	Personalised health and patient safety	Kjetil Røysland

Postdoctoral researchers working on projects in the centre with financial support from other sources

NAME	M/F	NATIONALITY	SOURCE OF FUNDING	SCIENTIFIC AREA	YEARS/PERIOD IN THE CENTRE	SCIENTIFIC TOPIC	MAIN CONTACT
Tugba Akman	F	Turkey	Turkey Research Council	Health	2021-2022	Personalised health and patient safety	Alvaro Köhn Luque
Theophilus Quachie Asenso	M	Ghana	UiO	Health	2021-2023	Personalised health and patient safety	Manuela Zucknick
Youness Azimzade	M	Iran	UiO/EU	Health	2021-2023	Personalised health and patient safety	Arnoldo Frigessi
Fekadu Bayisa	M	Sweden	UiO	Health	2020-2022	Personalised health and patient safety	Manuela Zucknick
Hilde Kjelgaard Brustad	F	Norway	UiO	Health	2022-2024	Personalised health and patient safety	Arnoldo Frigessi
Louis Hat Hin Chan	M	China	NIPH	Health	2021-2023	Personalised health and patient safety	Birgitte F. De Blasio
Andrea Cremaschi	M	Italy	UiO/ NCMM	Health	2016-2018	Personalised health and patient safety	Arnoldo Frigessi
Erlend Ignacio Fleck Fossen	M	Norway	UiO	Health	2022-2024	Personalised health and patient safety	Arnoldo Frigessi

NAME	M/F	NATIONALITY	SOURCE OF FUNDING	SCIENTIFIC AREA	YEARS/PERIOD IN THE CENTRE	SCIENTIFIC TOPIC	MAIN CONTACT
Kristoffer Herland Hellton (20%)	M	Norway	UiO/NFR Focustat	Health	2015-2017	Personalised health and patient safety	Magne Thoresen
Gudmund Hermansen	M	Norway	UiO/NFR Focustat	Sensor	2016-2018	Sensor systems	Ingrid K. Glad
Neda Jalalil	F	Iran	NIPH	Health	2021-2022	Personalised health and patient safety	Arnoldo Frigessi
Fatih Kizilaslaw	M	Turkey	UiO	Health	2021-2023	Personalised health and patient safety	Valeria Vitelli
Alvaro Köhn- Luque	M	Spain	UiO	Health	2016-2021	Personalised health and patient safety	Arnoldo Frigessi
Richard Xiaoran Lai	M	UK	OUS/HSØ UiO	Health	2019-2022	Personalised health and patient safety	Arnoldo Frigessi
Christian Page	M	Norway	OUS/HSØ	Health	2016-2019	Personalised health and patient safety	Arnoldo Frigessi
Euloge Clovis Pagui	M	Italy	UiO	Health	2022-2024	Personalised health and patient safety	Arnoldo Frigessi
Henry Pesonen	M	Finland	UiO	Health	2019-2022	Personalised health and patient safety	Jukka Corander
Vincenzo Politi	M	Italy	UiO	Health	2021-2022	Personalised health and patient safety	Arnoldo Frigessi
Vandana Ravendran	F	India	UiO/OUS	Health	2020-2023	Personalised health and patient safety	Arnoldo Frigessi
Leonardo Santana	M	Brasil	UiO	Health	2020-2023	Personalised health and patient safety	Manuela Zucknick
Leonard Schmiester	M	Germany	UiO	Health	2021-2023	Personalised health and patient safety	Arnoldo Frigessi
Mauricio M. Soares	M	Brasil	UiO	Health	2020-2023	Personalised health and patient safety	Arnoldo Frigessi
Øystein Sørensen	M	Norway	UiO	Marketing	2018	Personalised marketing	Arnoldo Frigessi
Owen Thomas	M	UK	UiO	Health	2017-2019	Personalised health and patient safety	Jukka Corander
Valeria Vitelli	F	Italy	UiO / Kreft-foreningen NFR	Health, Marketing	2015-2017 2017-2020	Personalised health and patient safety Personalised marketing	Arnoldo Frigessi
George Zhi Zhao	M	China	OUS	Health	2021-2023	Personalised health and patient safety	Manuela Zucknick

PhD candidates who have completed with financial support from the centre budget

NAME	M/F	NATIONALITY	SCIENTIFIC AREA	YEARS/PERIOD IN THE CENTRE	THESIS TITLE	MAIN THESIS ADVISOR
Simon Boge Brant	M	Norway	Fraud	2018-2024	Selected topics in regression with a binary outcome: Fraud detection, and applications of copulas to logistic regression	Ingrid Hobæk Haff
Ingrid Dæhlen	F	Norway	Several	2021-2024	The best of the bad: Precise and robust estimation and model selection	Ingrid Hobæk Haff, Nils Lid Hjort

NAME	M/F	NATIONALITY	SCIENTIFIC AREA	YEARS/PERIOD IN THE CENTRE	THESIS TITLE	MAIN THESIS ADVISOR
Solveig Engebretsen	F	Norway	Health	2016-2019	Contributions to network science in public health	Birgitte F. de Blasio
Martin Jullum	M	Norway	Fraud	2015	New focused approaches to topics within model selection and approximate Bayesian inversion	Nils Lid Hjort
Lars Henry Berge Olsen	M	Norway	Explaining AI	2020-2024	What's in the Black Box? Improving the Shapley Value Explanation Methodology	Ingrid K. Glad, Martin Jullum, Kjersti Aas
Riccardo Parviero	M	Italy	Marketing	2018-2022	Statistical modelling of adoption processes on social graphs	Ida Scheel
Leiv Tore Salte Rønneberg	M	Norway	Health	2018-2021	Bayesian modelling of high-throughput drug combination screens: Accounting for uncertainty when searching for drug synergy	Manuela Zucknick
Clara Bertinelli Salucci	F	Italy	Sensor	2019-2023	Advancing data-driven diagnostics and prognostics for lithium-ion batteries: A focus on model interpretability and accuracy	Riccardo de Bin, Ingrid K. Glad
Martin Tveten	M	Norway	Sensor	2017-2021	Scalable change and anomaly detection in cross-correlated data	Ingrid K. Glad, Nils Lid Hjort
Chi Zhang	F	China	Health	2016-2020 (via center) 2020-2022 via NIPH)	Representation and utilization of hospital Electronic Health Records data	Magne Thoresen, Arnoldo Frigessi

PhD candidates who have completed with other financial support, but associated with the centre

NAME	M/F	NATIONALITY	SOURCE OF FUNDING	SCIENTIFIC AREA	YEARS IN THE CENTRE	THESIS TITLE	MAIN THESIS ADVISOR
Derbachew Asfaw	M	Ethiopia	UiO/ Norad	Marketing	2015-2020	Ranking Method and Inferences on the Admission Path of Students to University of Ethiopia	Arnoldo Frigessi
Denekew Belay	M	Ethiopia	UiO/ Norad	Health	2016-2017	Bayesian Hierarchical Models to Discover Structure in Malaria and Population Mortality Data	Arnoldo Frigessi
Andreas Brandsæter	M	Norway	DNV-GL, NFR Nærings PhD	Sensor	2015-2020	Data-driven methods for multiple sensor streams, with applications in the maritime industry	Ingrid K. Glad, Erik Vanem
Kristoffer Herland Hellton	M	Norway	Cancer Registry of Norway	Health	2015-2017	On high-dimensional principal component analysis in genomics: consistency and robustness	Magne Thoresen
Vinnie Ko	M	Dutch	UiO	Fraud	2016-2019	Model selection for copulas and model pruning for neural networks	Nils Lid Hjort, Ingrid Hobæk Haff

NAME	M/F	NATIONALITY	SOURCE OF FUNDING	SCIENTIFIC AREA	YEARS IN THE CENTRE	THESIS TITLE	MAIN THESIS ADVISOR
Håvard Kvamme	M	Norway	UiO	Marketing	2015-2019	Time-to-Event Prediction with Neural Networks	Ørnulf Borgan, Ida Scheel, Kjersti Aas
Richard Xiaoran Lai	M	UK	UiO	Health	2015-2019	Modelling, inference and simulation of personalised breast cancer treatment	Arnoldo Frigessi, Alvaro Köhn-Luque
Sylvia Qinghua Liu	F	China	UiO/MI Inno-vation	Health	2016-2021	Bayesian Preference Learning with the Mallows Model	Ida Scheel, Arnoldo Frigessi
Even Moa Myklebust	M	Norway	NFR	Health	2020-2025	Statistical modeling of cell population dynamics for personalized cancer medicine	Alvaro Köhn-Luque
Andreas Nakkerud	M	Norway	UiO Dep. Math.	Power	2016-2020	Integer Programming Approaches for Real-Time Traffic Management	Carlo Mannino, Ingrid K. Glad
Christian Rohrbeck	M	Norway	STORi UK	Methods	2016	Statistical methods for weather-related insurance claims	John Tawn, Arnoldo Frigessi
Negusse Sebro	M	Ethiopia	UiO/ Norad	Health	2017	Performance and progression of primary school pupils in Ethiopia: Markov and multilevel models for longitudinal and cross sectional studies	Arnoldo Frigessi
Anja Katrina Stein	F	Norway	STORi, Lancaster	Marketing	2019-2023	Sequential Inference with the Mallows Model	Arnoldo Frigessi
George Zhi Zhao	M	China	UiO IMB	Health	2016-2020	Multivariate structured penalized and Bayesian regressions for pharmaco-genomic screens	Manuela Zucknick
Celia Yinzhi Wang	F	China	UiO Dep. Math.	Fraud	2016-2019	Modelling extreme insurance claims via composite models and threshold selection methods	Ingrid Hobæk Haff
Emilie Eliseussen Ødegård	F	Norway	UiO/IMB	Health, Marketing	2019-2023	Rank-based Bayesian methods for high-dimensional data in transcriptomic analyses	Valeria Vitelli

PhD students with other financial support, but associated with the centre, who still are in the process of finishing studies

NAME	M/F	NATIONALITY	SOURCE OF FUNDING	SCIENTIFIC AREA	YEARS IN THE CENTRE	THESIS TOPIC	MAIN THESIS ADVISOR
Elisabeth Griesbauer	F	German	UiO	Health	2022-2025	Vine Copulas and Privacy	Arnoldo Frigessi, Ingrid Hobæk Haff
Per August Moen	M	Norway	dScience	Sensor	2021-2025	Changepoint and anomaly detection in high-dimensional data streams	Ingrid K. Glad, Martin Tveten

MSc candidates with thesis related to the centre research agenda and an advisor from the centre staff

YEAR/NAME	M/F	NATIONALITY	SCIENTIFIC AREA	YEAR(S) IN THE CENTRE	THESIS TITLE	MAIN THESIS ADVISOR
(2017) Daniel Piacek	M	Slovenia	Fraud	2016-2017	Detecting fraud using information from social networks	Ingrid Hobæk Haff
(2017) Jonas Fredrik Schenkel	M	Norway	Marketing	2016-2022	Collaborative Filtering for Implicit Feedback: Investigating how to improve NRK TV's recommender system by including context	Ida Scheel
(2017) Martin Tveten	M	Norway	Sensor	2016-2021	Multi-Stream Sequential Change Detection -- Using Sparsity and Dimension Reduction	Ingrid K. Glad
(2018) Kristin B. Bakka	F	Norway	Sensor (NTNU)	2017-2018	Changepoint model selection in Gaussian data by maximization of approximate Bayes Factors with the Pruned Exact Linear Time algorithm	Mette Langaas
(2018) Simon Boge Brant	M	Norway	Health	2017-2021	Dynamic survival prediction for high-dimensional data	Ørnulf Borgan
(2018) Tristan Hugh Curteis	M	UK	Health	2016-2018	Focussed Model Selection for Longitudinal Data	Ørnulf Borgan
(2019) Jenine Gaspar Corrales	F	Norway	Marketing	2017-2018	Analyzing and Predicting Demographics of NRK's Digital Users	Ida Scheel
(2019) Eirik Lødøen Halsteinslid	M	Norway	Fraud	2017-2019	Addressing collinearity and class imbalance in logistic regression for statistical fraud detection	Ingrid Hobæk Haff
(2019) Amirhossein Kazemi	M	Iran	Sensor (NTNU)	2018-2019	A Semi-Supervised Approach to the Application of Sensor-based Change-Point Detection for Failure Prediction in Industrial Instruments	Mette Langaas
(2019) Camilla Lingjærde	F	Norway	Health	2017-2019	Tailored Graphical Lasso for Data Integration in Gene Network Reconstruction	Ingrid K. Glad
(2019) Amanda Haugnes Rygg	F	Norway	Marketing	2017-2019	GLM and GAM modelling of life insurance data	Anders Rygh Swensen Ørnulf Borgan
(2019) Vegard Stikbakke	M	Norway	Health	2017-2019	A boosting algorithm to extend first-hitting-time models to a high-dimensional survival setting	Riccardo de Bin
(2020) Oda Johanne Kristensen	F	Norway	Marketing	2018-2020	Scalable Markov Chain Monte Carlo by subsampling methods	Geir Storvik
(2020) Vera Haugen Kvisgaard	F	Norway	Fraud	2019-2021	Can undersampling boost fraud detection? Combining undersampling with stochastic gradient boosting for high-dimensional prediction of rare events	Ingrid Hobæk Haff
(2020) Elyas Dawod Mohammed	M	Norway	Fraud (UiB)	2018-2020	Count time series with application to corporate defaults	Bård Støve
(2020) Alexander Njøs	M	Norway	Health	2020	Multiple imputation for Cox regression with sampled cohort data	Ørnulf Borgan
(2020) Lars Henry Berge Olsen	M	Norway	Explaining AI	2020-2024	Likelihood-Based Boosting Approximate Confidence Bands and Intervals for Generalized Additive Models	Riccardo de Bin

YEAR/NAME	M/F	NATIONALITY	SCIENTIFIC AREA	YEAR(S) IN THE CENTRE	THESIS TITLE	MAIN THESIS ADVISOR
(2020) Hanne Tresselt	F	Norway	Marketing	2020	Modelling Car Insurance Data with Individual Effects	Ørnulf Borgan
(2020) Fredrik Wollbraaten	M	Norway	Sensor	2020-2023	Parallel subsampling MCMC and the Perturbed Subset Parameter Approximation	Geir Storvik
(2021) Håkon Bliksås Carlsen	M	Norway	Fraud	2019-2022	Studying the application of semi-supervised learning for fraud detection	Ingrid Hobæk Haff
(2021) Bob Betuin Fjellheim	M	Norway	Marketing	2019-2021	Bayesian Plackett-Luce Models for Describing Consensus in Ranking Data - Review and applications to real data	Ida Scheel
(2021) He Gu	M	China	Sensor	2019-2021	Recurrent Neural Networks for predicting ship motor temperatures - aiming to help prevent motor overheating	Kristoffer Herland Hellton
(2021) Nicola Kaletka	F	Poland	Health	2019-2021	Effects of prior information on monotonicity directions in additive monotone regression	Ingrid K. Glad
(2021) Nicolay Bjørlo Kristensen	M	Norway	Sensor	2019-2021	Weakly Supervised Learning for Predictive Maintenance: An Extended Random Forest Approach using Imbalanced Event Data from Hybrid Ships	Azzeddine Bakdi
(2021) Anna Skovbæk Mortensen	F	Denmark	Fraud	2019-2021	Fraud detection using copula regression	Ingrid Hobæk Haff
(2021) Øystein Skauli	M	Norway	Marketing	2019-2021	Modelling Short Term Changes in User Interest for Online Marketplaces	Ida Scheel
(2021) Peder Nørving Viken	M	Norway	Sensor	2019-2021	Sequential Monte Carlo and twisted state space models; Twisting models to reduce variance	Geir Storvik
(2022) Erik Holst Aasland	M	Norway	Explaining AI (NTNU)	2021-2022	Shapley values for dependent features using divisive clustering	Kjersti Aas
(2022) Erik Lien Bolager	M	Norway	Marketing	2020-2022	Formalising Flows Introducing Affine Extended Transformations and Flow-Structures	Geir Storvik
(2022) Elisabeth Griesbauer	F	Germany	Health (TUM, Germany)	2022-2024	Vine Copula Based Synthetic Data Generation for Classification	Claudia Czado Ingrid Hobæk Haff Arnoldo Frigessi
(2022) Christian Alm Grindheim	M	Norway	Sensor	2020-2022	Methods for battery state of health estimation - Comparative study of machine learning methods	Ingrid K. Glad
(2022) Fredrik Johannessen	M	Norway	Fraud	2020-2022	Finding Money Launderers Using Heterogeneous Graph Neural Networks	Martin Jullum
(2022) Meghana Kamineni	F	USA Fulbright Scholar	Health	2021-2022	The effect of non-pharmaceutical interventions to control mobility during the Covid-19 pandemics	Arnoldo Frigessi
(2022) Anna Kejvalova	F	Czech Rep.	Sensor	2020-2022	Total least squares estimation of maritime battery capacity	Ingrid K. Glad
(2022) Shuijing Liao	F	China	Fraud	2020-2022	The application of penalized logistic regression for fraud detection. Studying measures of prediction performance for class imbalanced and high-dimensional data	Ingrid Hobæk Haff

YEAR/NAME	M/F	NATIONALITY	SCIENTIFIC AREA	YEAR(S) IN THE CENTRE	THESIS TITLE	MAIN THESIS ADVISOR
(2022) Martin Strøm Olsen	M	Norway	Sensor	2020-2022	Twisted targets in sequential Monte Carlo	Geir Storvik
(2022) Arne Rustad	M	Norway	Explaining AI (NTNU)	2021-2022	tabGAN: A Framework for Utilizing Tabular GAN for Data Synthesizing and Generation of Counterfactual Explanations	Kjersti Aas
(2022) Lars Einar Skaaret-Lund	M	Norway	Fraud	2020-2022	Improving latent binary Bayesian neural networks using the local reparametrization trick and normalizing flows	Geir Storvik
(2023) Heming Smedsrud Aldrin	M	Norway	Fraud	2022-2024	Portfolio management with vine copulas	Ingrid Hobæk Haff
(2023) Anders Kielland	M	Norway	Health	2021-2023	Integrating Biological Domain Knowledge in Machine Learning Models for Cancer Precision Medicine	Ingrid K. Glad
(2023) Haakon Muggerud	M	Norway	Marketing	2021-2023	Ranked-based Bayesian clustering and variable selection for high-dimensional data	Ida Scheel
(2023) Thomas Forest Mullally	M	Norway	Explaining AI (UiB)	2021-2023	Generative Adversarial Networks for Art Images	Bård Støve Sven Haadem
(2023) Ingvild Riiser	F	Norway	Explaining AI	2021-2023	Privacy and Utility Evaluation of Synthetic Data for Multi-State Time-to-Event Applications	Ingrid K. Glad
(2023) Leif Martin Sunde	M	Norway	Marketing	2021-2023	Spherical Priors for Bayesian Deep Learning	Geir Storvik
(2024) Hanne Gjemdal	F	Norway	Fraud	2022-2024	Fraud Detection Using Vine Copula Regression	Ingrid Hobæk Haff
(2024) S M Mamun Ar Rashid	M	India	Sensor	2022-2024	Sequential Monte Carlo in High Dimension	Geir Storvik
(2024) Eyvind Skretting	M	Norway	Sensor	2022-2024	Using Kalman Filters for Pressure Prediction and Leakage Estimation on Large LNG Transport Vessels	Morten Stakkeland

Appendix 2

LIST OF PUBLICATIONS

Aas, Kjersti. Pair-Copula Constructions for Financial Applications: A Review. Econometrics. Vol. 4(4). 2016.

Aas, Kjersti; Jullum, Martin; Løland, Anders. Explaining individual predictions when features are dependent: More accurate approximations to Shapley values. Artificial Intelligence. Vol. 298. 2021.

Aas, Kjersti; Nagler, Thomas; Jullum, Martin; Løland, Anders. Explaining predictive models using Shapley values and non-parametric vine copulas. Dependence Modeling. Vol. 9(1) pp 62-81. 2021.

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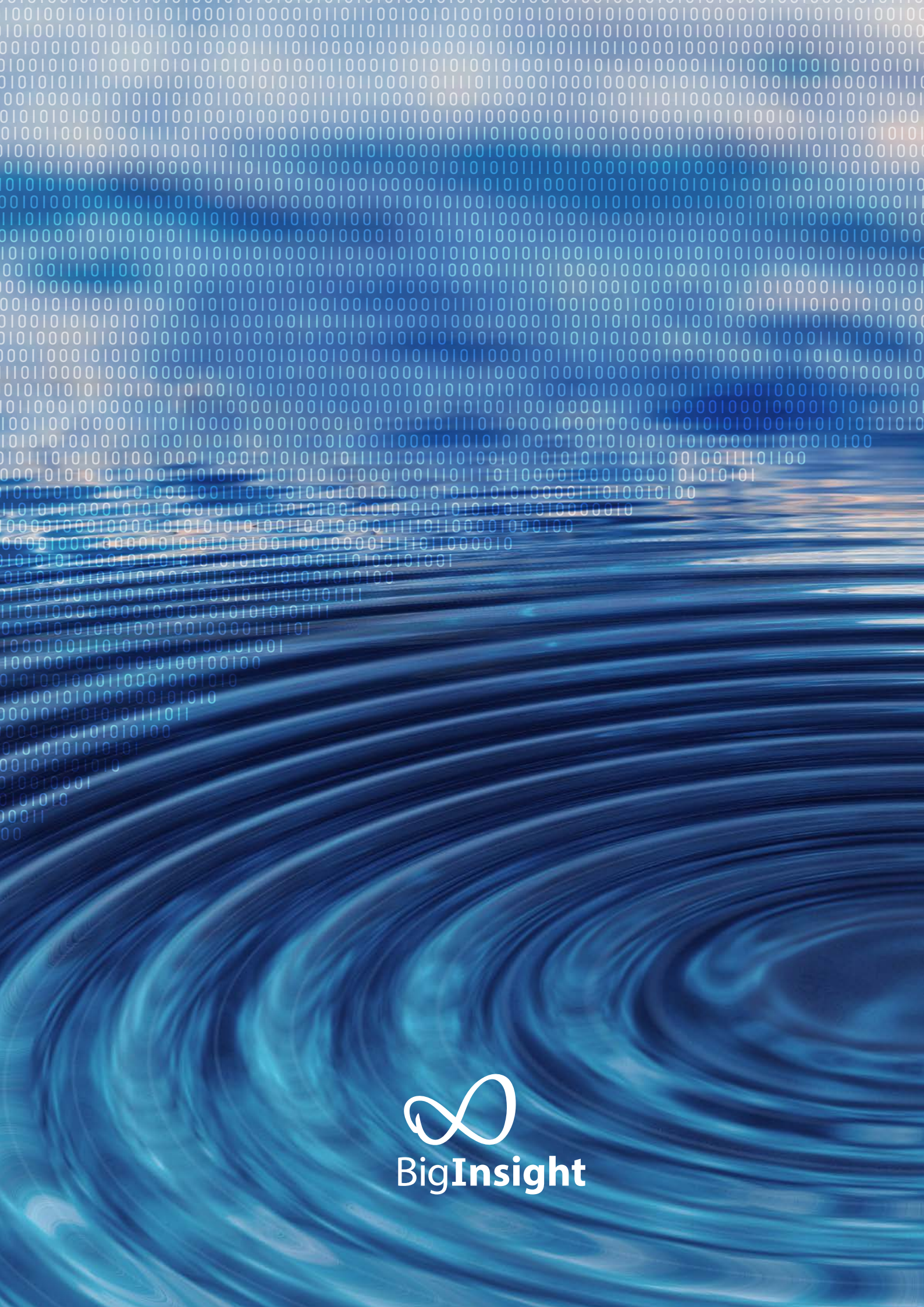
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