



Evaluation of Mathematics, ICT and Technology (EVALMIT) 2023–2024

Self-assessment for research groups

Date of dispatch: 19 September 2023

Deadline for submission: 31 January 2024

Institution (name and short name): University of Oslo (UiO)

Administrative unit (name and short name): Department of Informatics (IFI)

Research group (name and short name): Analytical Solutions and Reasoning (ASR)

Date: 23 January 2023

Contact person: Martin Giese

Contact details (email): martingi@ifi.uio.no

Content

1. Organisation and strategy	3
1.1 Research group's organisation	3
1.2 Research group's strategy	5
1.3 Relevance to the institutions	6
1.4 Research group's resources	7
1.5 Research group's infrastructures	7
1.6 Research group's cooperations	8
2. Research quality	9
2.1 Research group's scientific quality	9
2.2 Research group's societal contribution	20
3. Challenges and opportunities	22

1. Organisation and strategy

1.1 Research group's organisation

Describe the establishment and the development of the research group, including its leadership (e.g. centralised or distributed etc.), researcher roles (e.g. technical staff, PhD, post docs, junior positions, senior positions or other researcher positions), the group's role in researcher training, mobility and how research is organised (e.g. core funding organisation versus project based organisation etc.).

With a staff of more than 400, The UiO Department of Informatics (IFI) is a “powerhouse” for informatics training and research in Northern Europe. It is the largest such unit in Norway and the one with the strongest international rankings. Around a comprehensive core in computer science, IFI interprets informatics in substantial breadth: from microelectronics or signal processing, to participatory design or digital innovation. In 2023, IFI hosts five BSc and eight MSc study programmes, with close to 2500 students. The department is organized in four thematic sections, each of which comprising 2–5 research groups. Our group, «Analytical Systems and Reasoning» (ASR), is part of the section for Programming.

Over the reporting period, ASR has encompassed several distinct groups of researchers with quite separate research focus, and this report will attempt to take this into account. In its beginnings, the ASR group concentrated on topics in logic, reasoning, and **semantic technologies**. For much of the duration of the SIRIUS centre, starting in 2016, several researchers in **formal methods** joined ASR from the PSY group. These researchers are now once more in the PSY group, and their contributions will be reported there. At the end of the period, ASR was joined by the team of Thomas Plagemann and Vera Goebel, working in **distributed multimedia systems** (DMMS), whose contributions will also be reported here.

The original ASR group formed around Prof. Arild Waaler, with a focus on logic, reasoning, semantic technologies, and applications in industry. The group coordinated the EU FP7 project Optique during 2012–2016. This was followed by RCN funding for the centre for research-based innovation (SFI) SIRIUS 2015–2023. Prof. Martin Giese took over as research group manager, while Waaler lead SIRIUS which financed many of the researchers working in the area of semantic technologies. From the start of SIRIUS, there was an interest in the data management aspects of what became known as data science, but also interfacing between semantic technologies and other aspects of data science like machine learning. The combination of data management with machine learning was also characteristic of the DMMS group which ultimately lead to the merging of the groups, and recently the establishment of the Integreat SFF. Much of the workforce of this research focus has consisted of temporary staff, supplemented over time by some “permanent conditional on external funding” researcher positions. Recently, two permanent employees (adjunct professors) joined the group, both with a focus that fits the Integreat SFF.

Another development has revolved around the concept of semantic digital twins. Based on the RCN funded PeTWIN project, this has led to a collaboration between the semantics team and that PSY group focusing on formal methods. Towards the end of the reporting period, the increasing interest in industrial digital twins and asset modelling has led to Arild Waaler moving to the PSY group, so some of these activities will be reported by the PSY group.

The distributed multimedia group **DMMS** was managed by Thomas Plagemann and the members of externally funded projects (EU and RCN) formed the research group together with the permanent senior researchers. Each junior member (i.e., PhD and PostDoc) was supervised/mentored by two senior members. Furthermore, the DMMS group attracted many Master students that did their Thesis in the DMMS group and were supervised by a senior and a junior group member. The research focus evolved from the overlapping area of networking/distributed systems and data management with focus on multimedia to mobile sensor-based systems, data stream processing and medical applications of sensor-based systems.

Table 1. List of number of personnel by categories

	Position by category	No. of researcher per category	Share of women per category (%)	No. of researchers who are part of multiple (other) research groups at the admin unit	No. of temporary positions
No. of Personnel by position	Professor (1013)	3	33%	0	0
	Associate Professor (1011)	3	33%	0	0
	Senior Lecturer (1198)	1	0%	0	0
	Researcher (1108)	1	0%	0	1
	Researcher (1109)	5	20%	0	4
	Postdoctoral Fellow (1352)	4	25%	0	4
	Doctoral Research Fellow (1017)	11	18%	0	11
	Adjunct Professor (1013)	3	0%	0	3
	Adjunct Associate professor (1011)	6	0%	0	6
	Adjunct Senior Lecturer (1198)	1	100%	0	1

1.2 Research group's strategy

a) Describe the research group's main goals, objectives, and strategies to obtain these (e.g. funding, plans for recruitment, internationalisation etc. within the period 2012-2022).

Strategy – Semantic Technologies

The main objective has been to shape a group at the forefront of European research in theoretical aspects of semantic technologies, in order to 1) ensure continued funding and 2) become an attractive group for talented researchers to apply to. To achieve this, the group capitalized on the academic network and industrial connections built during the Optique project and continued to apply for large projects with industry collaboration.

This resulted in a centre for research-based innovation as well as participation in several further EU projects. The advent of data science around 2017 was realized as an opportunity, and the group presented data access and ontology reasoning as part of data science and explored the combination of data science and machine learning with semantics in SIRIUS. This led to inclusion in many of the University's data science initiatives (DataScience MSc programme, dScience centre, Integreat SFF). Towards the end of the reporting period, the group has attracted two highly talented researchers into permanent positions.

Strategy – DMMS group

Reaching international recognition through publications, participation in international networks (e.g., COST), active engagement in ACM and its conferences and journals to be (1) attractive as potential project partner (e.g., EU) and (2) for recruitment. The goal of having a larger number of PhDs and PostDocs in the group was targeted through continuous follow-up of open funding opportunities and proposal writing of senior members. To improve recruitment of local candidates for PhD positions the group had two central courses at the Master level and attracted through interesting projects many students to do the Master Thesis in the DMMS group. These in turn contributed actively to the ongoing research projects in the group and several of the best Master students joined the group as PhD candidates.

b) Please describe the benchmark of the research group. The benchmark for the research group should be written by the administrative unit in collaboration with the research group. The benchmark can be a reference to an academic level of performance (national or international) or to the group's contributions to other institutional or sectoral purposes.

The group has concentrated on:

- Excellence in research, with results published at the most recognized venues in their field.
- Relevance of results to project partners in industry:
 - In many cases, particularly in SIRIUS, the relevance of results to projects partners, and the engagement of partners in the research, has had higher priority than e.g. the number of academic publications.
- Relevance to the department's strategic focus, including in particular:
 - Applications in Healthcare in the CESAR and BigMed projects
 - The increasing focus on machine learning and data science over the reporting period

c) Describe the research group contribution to education (master's degree and/or PhD).

The ASR group is responsible for the following MSc and PhD level courses. The courses with a 5000 code are for advanced master students and PhD students, while the 4000 course are mostly intended for first year master students.

- IN4000 – Operating Systems (20 credits)
- IN4020 – Database Systems
- IN4060 – Semantic Technologies
- IN4070 – Logic
- IN-STK5000 – Adaptive methods for data-based decision making
- IN5040 – Advanced Database Systems for Big Data
- IN5070 – The future internet protocols
- IN5580 – Computability theory
- IN5800 – Declarative Data Engineering

Many of the courses reflect the group's tradition in logic, reasoning, and information management. Prof. Giese has been a member of the programme council of the Data Science master program (a joint programme with the Institute of Mathematics) since 2019. IN-STK5000 is a mandatory course for all data science MSc students. Prof. Giese has also been a member of the programme council of the BSc and MSc programmes in Programming and Software Engineering, to which most of the students of these courses belong.

d) Describe the support the host institution provides to the research group (i.e., research infrastructure, access to databases, administrative support etc.).

The department of informatics has provided general administrative support, like financial management of projects. The MATNAT faculty has an EU team which provided invaluable help in attracting and realizing the EU project Optique.

The research in the DMMS group was systems oriented and the group maintained and managed a lab with their own research infrastructure. This was necessary, because the research required full control over HW and SW (e.g., root access) which is not possible on general infrastructure. To properly integrate the lab in the University network received some support from systems administration.

1.3 Relevance to the institutions

Describe the role of the research group within the organisation. Consider the group's contribution towards the institutional strategies and objectives and relate the group's benchmark to these.

The ASR group has been visible by attracting significant external funding through Optique and SIRIUS. The group has played a leading role in the institute's orientation towards data science. The group was the initial contact point with the institute of mathematics in establishing the Data Science master programme and is responsible for the mandatory computer science course for first year Data Science master students.

1.4 Research group's resources

Describe the funding portfolio of the research group the last five years (2018–2022).

During 2018–2022, the group has received considerable external funding. For the semantic technology part of the group, most of this came from the 8 year SIRIUS centre for research-based innovation. Many of the group's PhD students were funded from the centre, but also many researchers and postdoctoral fellows. This was complemented by several other projects, including the PeTWIN project in collaboration with the University of Rio Grande do Sul in Brasil.

For the distributed multimedia part of the group, the most important external project was CESAR (2016–2021) which started the line of research on monitoring sleep apnea. Towards the end of the reporting period, Thomas Plagemann and Vera Goebel attracted funding for an interdisciplinary («fellesløft») project that will last until 2027.

Table 2. Describe the sources of R&D funding for the research group in the period 2018-2022 (in KNOK).

	2018(kNOK)	2019(kNOK)	2020(kNOK)	2021(kNOK)	2022(kNOK)
Basic funding	6146	9769	12819	10506	9319
Funding from industry and other private sector sources					
Commissioned research for public sector					
Research Council of Norway	7118	10728	11751	14455	12739
Grant funding from other national sources					
International funding e.g. NIH, NSF, EU framework programmes					
Other					

1.5 Research group's infrastructures

Research infrastructures are facilities that provide resources and services for the research communities to conduct research and foster innovation in their fields. [These](#) include major equipment or sets of instruments, knowledge-related facilities such as collections, archives or scientific data infrastructures, computing systems communication networks. Include both internal and external infrastructures.

a) Describe which national infrastructures the research group manages or co-manages.

Open-source software: The ASR group maintains the following open-source software:

- OTTR: a language and tools for representing and instantiating RDF graphs and OWL ontology modeling patterns <https://ottr.xyz/>

- R2RML API: an API to parse and process mapping specifications in the W3C recommended Relational to RDF mapping language R2RML <https://github.com/R2RML-api/>
- SMOL: a language and runtime system for orchestrating digital twins that integrates semantic technologies for knowledge bases with dynamic configurations of data-driven and model-based analysis tools <https://smolang.org/>

b) Describe the most important research infrastructures used by the group.

- The distributed multimedia part of the group maintains a lab with its own “research infrastructure” since the experimental research work often requires system administrator credentials. The infrastructure comprises traditional higher-performance servers and GPU machines as well as more ubiquitous devices like RaspberryPis, smartphones, smart sensors, and physiological sensing devices.

1.6 Research group’s cooperations

Table 3. Reflect on the current interactions of the research group with other disciplines, non-academic stakeholders and the potential importance of these for the research (e.g. informing research questions, access to competence, data and infrastructure, broadening the perspectives, short/long-term relations).

Interdisciplinary (within and beyond the group)	DMMS has had a long-standing collaboration with the Oslo University Hospital (OUS) and Lovisenberg Diakonale Hospital on sleep-related breathing disorders. The semantic technology part of the group has also had interactions with OUS through the BigMed project on precision medicine. The group has had an increasing interest in intersections between our field and statistics and machine learning. This has led to intensive interaction with the statistics group at the Department of Mathematics, as well as the Oslo Center for Biostatistics and Epidemiology. Towards the end of the reporting period, we jointly applied for and were awarded the centre of excellence (SFF) Integreat.
Collaboration with other research sectors e.g. higher education, research institutes, health trusts and industry.	Much of the research of ASR in the reporting period revolves about industrial applications of logical methods and semantic technologies, e.g. the oil and gas industry in Optique and SIRIUS, monitoring of gas turbines in Optique. There has also been a joint PhD project with NIVA, the Norwegian Institute for Water Research, applying semantic technologies and machine learning to problems in ecotoxicology.
<u>Transdisciplinary</u> (including non-academic stakeholders)	ASR has collaborated with the group of Prof. Mara Abel at the Federal University of Rio Grande do Sul to establish activities in “digital geoscience.” The recently submitted PhD thesis of Yuanwei Qu explores the qualitative modelling of geological situations and processes by means of ontologies and object-oriented simulations.

2. Research quality

2.1 Research group's scientific quality

Describe the research profile of the group and the activities that contribute to the research group's scientific quality. Consider how the group's work contributes to the wider research within the group's field nationally and internationally.

At the beginning of the reporting period, ASR established itself as the leading Norwegian group in semantic technologies. Much of the research concentrated on making these technologies applicable in real-world industrial settings. Research topics spanned from the design of an ontology-based visual query system (OptiqueVQS), suitable for non-IT professionals with complex data access needs, to the template language OTTR that facilitates the generation of the large but repetitive semantic domain models typical of industrial applications, to theoretical foundations of semantic data integration.

Around 2016, it became clear that there is significant potential in considering data analytics, including machine learning, in combination with semantic data access and integration, and like many other groups internationally, ASR has embraced this new direction. Many of the more recent publications include aspects like ontology embeddings, supporting machine learning through formal domain knowledge, or the use of machine learning techniques on graph data. The group has also attracted two new permanent employees, Egor Kostylev and more recently Ana Ozaki, both of whom are interested in this intersection of research fields.

Another more recent direction (mostly in the PeTWIN project) was to combine semantic technologies with research in programming languages and co-simulation, as an underpinning of semantic digital twins. This novel combination has led to a series of publications at recognised venues within all of the mentioned fields.

The distributed multimedia part of the group has seen a similar development: over the reporting period, the focus has shifted from traditional topics in distributed processing, e.g. complex event processing, to the inclusion of machine learning at different stages of data processing. As part of this development, the group focused on medical applications, in particular the application of sensors and machine learning in monitoring sleep disorders. More recently the group has been extending this direction to the interdisciplinary RESPIRE project that includes ethical and legal aspects.

Publication list at the research group's website:

<https://www.mn.uio.no/ifi/english/about/strategy/evalmit/asr.html>

Table 4. List of projects

Instructions: Please select 5-10 projects you consider to be representative/the best of the work in the period 1 January 2012 – 31 December 2022. The list may include projects lead by other institutions nationally or internationally. Please delete tables that are not used.

Project 1: Optique – Scalable End-user Access to Big Data (2012–2016)	Project owner(s) (project leaders organisation)	University of Oslo
	Total budget and share allocated to research group	€ 13.8 million total budget € 3 million to ASR
	Objectives and outcomes (planned or actual) and link to website	Use semantic technologies to integrate industrial datasets in Statoil and Siemens, and provide access to non-IT end users. The time required for routine data access problems could be reduced from days to minutes. https://cordis.europa.eu/project/id/318338
Project 2: SIRIUS – Centre for Scalable Data Access (2015–2023)	Project owner(s) (project leaders organisation)	University of Oslo
	Total budget and share allocated to research group	kr 250 mill total budget
	Objectives and outcomes (planned or actual) and link to website	A broad range of research in formal methods, semantic technology, database integration, scalable computing, data science and industrial digital transformation, applied to beacon projects in subsurface, operations and engineering, but also health and ecology use cases. https://sirius-labs.no/

Project 3: PETWIN – Whole-field digital twins for production optimization and management (2020–2023)	Project owner(s) (project leaders organisation)	University of Oslo/Fed. Univ. of Rio Grande Do Sul, Brazil
	Total budget and share allocated to research group	Kr 28 million total budget Kr 14 million to ASR
	Objectives and outcomes (planned or actual) and link to website	Use of semantic technologies and ontology-based data integration to integrate disparate digital twins. The targeted use case is digital twins covering a variety of aspects of petroleum fields. https://www.petwin.org/
Project 4: Parrot – Privacy Engineering for Real-Time Analytics in Human-Centered Internet of Things (2020–2024)	Project owner(s) (project leaders organisation)	University of Oslo
	Total budget and share allocated to research group	Kr 16 million total, Kr 13.3 million to the DMMS group (now part of ASR)
	Objectives and outcomes (planned or actual) and link to website	The project develops privacy solutions for data stream processing systems that resolve the privacy-utility trade-off in a (semi-)automatic way during application development. https://www.mn.uio.no/ifi/english/research/projects/parrot/index.html
Project 5: CESAR – Using Complex Event Processing for Low-threshold and Non-intrusive Sleep Apnea Monitoring at Home (2016 – 2021)	Project owner(s) (project leaders organisation)	University of Oslo
	Total budget and share allocated to research group	Kr 9 million total, all to the DMMS group
	Objectives and outcomes (planned or actual) and link to website	The objective and outcome of CESAR was to identify tools and develop methods for low-cost sleep apnea screening at home in form of a simple respiration belt and ML analysis. https://www.mn.uio.no/ifi/english/research/projects/cesar/

Project 6: RESPIRE Responsible Explainable Machine Learning for Sleep-related Respiratory Disorders (2022–2027)	Project owner(s) (project leaders organisation)	University of Oslo
	Total budget and share allocated to research group	Total budget: 26.7 million NOK ASR: 7.4 million NOK
	Objectives and outcomes (planned or actual) and link to website	Development of explainable ML solutions for diagnosis and research on sleep-related disorders that safeguard the basic ethical principles and legal rights of stakeholders. https://www.mn.uio.no/ifi/forskning/prosjekter/respire/index.html
Project 7: Plooto – Product Passport through Twinning of Circular Value Chains (2022–2026)	Project owner(s) (project leaders organisation)	MAGGIOLI SPA, Italy
	Total budget and share allocated to research group	€ 7.6 million 50 person months to IFI
	Objectives and outcomes (planned or actual) and link to website	The project will develop a Circular and Resilient Information System (CRIS) to support manufacturers in waste reduction and end-to-end traceability of secondary raw materials through interconnected digital services. The system will be tested in three different circular supply chains.
Project 8: OntoCommons – Ontology-driven data documentation for Industry Commons (2020–2023)	Project owner(s) (project leaders organisation)	TU Wien, Austria
	Total budget and share allocated to research group	€ 4.3 million 36 PM to IFI
	Objectives and outcomes (planned or actual) and link to website	Standardisation of data exchange in the manufacturing sector and the material science field by means of ontologies.

Project 9: <i>BigMed – A big data medical solution for precision medicine /Project period (2016–2021)</i>	Project owner(s) (project leaders organisation)	Oslo University Hospital
	Total budget and share allocated to research group	60 MNOK, 2.3 MNOK to ASR
	Objectives and outcomes (planned or actual) and link to website	Overcoming (amongst others) information management challenges on the way to Precision Medicine https://bigmed.no/

Table 5. Research group's contribution to publications

Instructions: Please select 5-15 publications from the last 5 years (2018-2022) with emphasis on recent publications where group members have a significant role. **If the publication is not openly available, it should be submitted as a pdf file attached to the self-assessment.** We invite you to refer to the Contributor Roles Taxonomy in your description: <https://credit.niso.org/>.

Cf. Table 1. List of personnel by categories: Research groups up to 15 group members: 5 publications. Research groups up to 30 group members: 10 publications. Research groups above 30 group members: 15 publications.

Please delete tables that are not used.

Publication 1: <i>CARE: coherent actionable recourse based on sound counterfactual explanations.</i> <i>International Journal of Data Science and Analytics (JDSA), 2022.</i> https://doi.org/10.1007/s41060-022-00365-6	Authors (Please highlight group members)	Peyman Rasouli, Ingrid Chieh Yu
	Short description	A modular explanation framework for generating counterfactual explanations and actionable recourse. The framework considers validity, soundness and coherency that are important for explanation generation and user-defined global and local constraints to facilitate personalized recourse.
	Research group's contribution	Both authors are members of the group. The paper reports on Rasouli's PhD project.

Publication 2: <i>My Health Sensor, My Classifier - Adapting a Trained Classifier to Unlabeled End-User Data. ACM Transactions on Computing for Healthcare (HEALTH), 2022.</i> https://dl.acm.org/doi/10.1145/3559767	Authors (Please highlight group members)	Konstantinos Nikolaidis, Stein Kristiansen, Thomas Peter Plagemann, Vera Hermine Goebel, Knut Liestøl, Mohan Kankanhalli, Gunn Marit Traaen, Britt Øverland, Harriet Akre, Lars Aakerøy, Sigurd Loe Steinshamn
	Short description	Unattended sleep monitoring at home with low-cost sensors and Machine Learning to detect sleep apnea faces the problem that patient characteristics, lack of sufficient training data, and other factors can imply a domain shift between training and end-user data and reduced task performance. This work presents an unsupervised domain adaptation (UDA) solution with the constraint that labeled source data are not directly available. Instead, a classifier trained on the source data is provided. The solution iteratively labels target data sub-regions based on classifier beliefs, and trains new classifiers from the expanding dataset.
	Research group's contribution	Data pre-processing, data curation, development of UDA solution, design of experiments, implementation of experiments including classifier training, tuning, and testing, analysis of the results, writing major parts of the paper, and funding.
Publication 3: <i>Interactive Inverse Reinforcement Learning for Cooperative Games. Proceedings of Machine Learning Research (PMLR) 2022.</i> https://proceedings.mlr.press/v162/buning22a/	Authors (Please highlight group members)	Thomas Kleine Büning, Anne-Marie George, Christos Dimitrakakis
	Short description	We study how an autonomous agent can learn to cooperate with a potentially irrational human partner without access to the reward signal. We model this problem as a two-player Stackelberg game and propose algorithms that infer the unknown reward function from repeated interactions with the human partner.
	Research group's contribution	All authors are members of ASR.

Publication 4: The complexity and expressive power of limit Datalog. Journal of the ACM 69 (1), 6:1-6:83, 2021. DOI 10.1145/3495009	Authors	M Kaminski, Egor Kostylev , B Cuenca Grau, B Motik, I Horrocks
	Short description	We introduce and thoroughly study a logical language called limit Datalog. This language extends the classic database query language Datalog with arithmetic functions over integers and is motivated by declarative data analysis. On the one hand, it is powerful enough to naturally capture many important data analytic tasks. On the other hand, it possesses good computational properties, thus allowing efficient implementations.
	Research group's contribution	Egor Kostylev of ASR and Mark Kaminski were the main authors, with equal contribution to the work.
Publication 5: <i>Never Mind the Semantic Gap: Modular, Lazy and Safe Loading of RDF Data.</i> <i>Extended Semantic Web Conference 2022</i> DOI 10.1007/978-3-031-06981-9_12	Authors	Eduard Kamburjan, Vidar Norstein Klungre, and Martin Giese
	Short description	We discuss the “semantic gap” between class hierarchies in ontological modelling and in OO programming. We advocate embracing this gap rather than unifying both views, and propose a method for loading RDF data into an object oriented system. Best research paper award at ESWC 2022.
	Research group's contribution	The entire work was done in ASR, in the frame of the PeTWIN project.
Publication 6: <i>Order preserving hierarchical agglomerative clustering. Machine Learning. 2021.</i> https://doi.org/10.1007/s10994-021-06125-0	Authors (Please highlight group members)	Daniel Rygh Bakkelund
	Short description	The classical clustering problem is investigated in the setting where data points have an associated partial ordering, and the aim is to preserve this ordering while clustering. An important application is to cluster pieces of machinery by similarity, where the ordering reflects the part-of relationship between the pieces.
	Research group's contribution	The research was performed during the author’s PhD fellowship in the group.

Publication 7: <i>Learning realistic patterns from visually unrealistic stimuli: Generalization and data anonymization.</i> <i>The journal of artificial intelligence research.</i> 2021. https://dl.acm.org/doi/10.1613/jair.1.13252	Authors (Please highlight group members)	Konstantinos Nikolaidis, Stein Kristiansen, Thomas Peter Plagemann, Vera Hermine Goebel, Knut Liestøl, Mohan Kankanhalli, Gunn Marit Traaen, Britt Øverland, Harriet Akre, Lars Aakerøy, Sigurd Loe Steinshamn
	Short description	Privacy regulations often prohibit sharing of data from medical studies, which can lead to insufficient training data for Machine Learning applications. This work investigates a simple yet unconventional approach for anonymized data synthesis to enable third parties to benefit from such anonymized data. We explore the feasibility of learning implicitly from visually unrealistic, task-relevant stimuli, which are synthesized by exciting the neurons of a trained deep neural network. As such, neuronal excitation can be used to generate synthetic stimuli. The stimuli data is used to train new classification models. Furthermore, we extend this framework to inhibit representations that are associated with specific individuals. We use in the empirical evaluation sleep monitoring data from both an open and a large closed clinical study to detect sleep apnea, and Electroencephalogram sleep stage classification data.
	Research group's contribution	Data pre-processing, data curation, development of UDA solution, design of experiments, implementation of experiments including classifier training, tuning, and testing, analysis of the results, writing major parts of the paper, and funding.
Publication 8: <i>OWL2Vec*: embedding of OWL ontologies.</i> <i>Machine Learning.</i> 2021. https://doi.org/10.1007/s10994-021-05997-6	Authors (Please highlight group members)	Jiaoyan Chen, Pan Hu, Ernesto Jimenez-Ruiz, Ole Magnus Holter, Denvar Antonyrajah & Ian Horrocks
	Short description	This is groundbreaking work about a vector space embedding of the concepts in an ontology, it has received over 130 citations.
	Research group's contribution	The work is based on Holter's MSc thesis, supervised by Jimenes-Ruiz in the ASR group

Publication 9: <i>Machine Learning for Sleep Apnea Detection with Unattended Sleep Monitoring at Home. ACM Transactions on Computing for Healthcare (HEALTH). ISSN 2691-1957. 2(2). doi: 10.1145/3433987</i>	Authors (Please highlight group members)	Kristiansen S, Nikolaidis K, Plagemann T, Goebel V , Traaen GM, Øverland B, Aakerøy L, Hunt E, Loennechen JP, Steinshamn S, Bendz C, Anfinssen OG, Gullestad L, Akre H
	Short description	We investigate the use of supervised machine learning to automate the analysis of polygraphy data from the A3 study containing >7,400 hours of sleep monitoring data from 579 patients. We conduct a systematic comparative study of classification performance and resource use with different combinations of 27 classifiers and four sleep signals.
	Research group's contribution	Data pre-processing, data curation, design of experiments, implementation of experiments including classifier training, tuning, and testing, analysis of the results, and writing major parts of the paper.
Publication 10: <i>Improving the Accuracy of Timing in Scalable WSN Simulations with Communication Software Execution Models. Computer Networks. 2021. https://doi.org/10.1016/j.comnet.2021.107855</i>	Authors (Please highlight group members)	Espen Volnes, Stein Kristiansen, Thomas Peter Plagemann
	Short description	The core problem addressed in this work is that general-purpose network simulation does not include the delays that occur within WSN nodes, and therefore, the results are inaccurate. To overcome this problem, we create a communication software execution model of TelosB that accounts for its <u>temporal behavior</u> to enable more accurate WSN simulations in the ns-3 simulator. A challenge is to create a tracing framework for TinyOS that can be used to accurately and reliably trace the behavior of a very resource-constrained system.
	Research group's contribution	All work for this paper was performed by the DMMS group members.

Publication 11: <i>The logical expressiveness of graph neural networks. Conference on Learning Representations (ICLR 2020), 2020.</i> https://openreview.net/forum?id=r1IZ7AEKvB	Authors (Please highlight group members)	P Barceló, Egor Kostylev , M Monet, J Pérez, JL Reutter, JP Silva
	Short description	We establish fundamental relationships between variants of graph neural networks (GNNs) and several logic-based formalisms. Here, GNNs are a family of modern neural architectures, which are successful in many applications dealing with graph-shaped data. In turn, logics, including FOC2 and ALCIQ, are classic AI formalisms popular in, for example, Knowledge Representation and the Semantic Web.
	Research group's contribution	
Publication 12: <i>A scalable semantic framework for IoT healthcare applications. Journal of Ambient Intelligence and Humanized Computing, J Ambient Intell Human Comput</i> 14 , 4883–4901 (2023). https://doi.org/10.1007/s12652-020-02136-2	Authors (Please highlight group members)	Rita Zgheib, Stein Kristiansen , Emmanuel Conchon, Thomas Peter Plagemann , Vera Hermine Goebel , Rémi Bastide
	Short description	Semantic reasoning over activities of daily living (ADL) can discover anomalies, diseases, and epidemics. However, semantic reasoning is computationally expensive and therefore unusable for real-time monitoring in large scale applications. To overcome this limitation, this paper proposes a new scalable semantic framework based on several semantic reasoning techniques that are distributed over a semantic middleware. To reduce the number of events to process during the semantic reasoning, a complex event processing (CEP) engine is used to detect abnormal events in ADL and to generate the associated symptom indicators.
	Research group's contribution	All major activities were basically shared equally between the research group members and the other co-authors.

Publication 13: <i>Qualitatively correct bintrees: an efficient representation of qualitative spatial information. Geoinformatica. 2019.</i>	Authors	Leif Harald Karlsen, Martin Giese
	Short description	Most data structures for the efficient storage and access to spatial information rely on numerical coordinates. This work presents indexing data structures to capture qualitative information like adjacency, overlap, containment, etc.
	Research group's contribution	The entire work was done in ASR, in the frame of Karlsen's PhD thesis
Publication 14: <i>Mobile Distributed Complex Event Processing - Ubi Sumus? Quo Vadimus? Mobile Big Data. 2018. https://doi.org/10.1007/978-3-319-67925-9_7</i>	Authors	Fabrice Starks, Vera Hermine Goebel, Stein Kristiansen, Thomas Peter Plagemann
	Short description	Complex Event Processing (CEP) is a technology to detect complex (or composite) events in data streams and has been successfully applied in high volume and high velocity applications like stock market analysis. However, these application domains faced only the challenge of high performance, while the Internet of Things and Mobile Big Data introduce a new set of challenges caused by mobility. We explain these challenges and give an overview on how they are solved respectively how far state-of-the-art research has advanced to be useful to solve Mobile Big Data problems.
	Research group's contribution	All work for this paper was performed by the DMMS group members.
Publication 15: <i>Practical Ontology Pattern Instantiation, Discovery, and Maintenance with Reasonable Ontology Templates. Intl. Semantic Web Conference ISWC 2018. https://doi.org/10.1007/978-3-030-00671-6_28</i>	Authors	Martin Georg Skjæveland, Daniel Lupp, Leif Harald Karlsen, Henrik Forssell
	Short description	The paper presents the OTTR template language, a macro language for ontologies and knowledge graphs that has since received considerable attention and use.
	Research group's contribution	OTTR was and still is developed in the ASR group by the team around Martin Skjæveland.

Table 6. Please add a list with the research group's monographs/scientific books. Max 10 listed: title, first three authors et al and link to webpage (if any). Please delete lines which are not used.

1	Roger Antonsen – Logiske Metoder. https://logiskemetoder.no/
---	---

2.2 Research group's societal contribution

Describe the societal impact of the group's research. Consider contribution to education, economic, societal and cultural development in Norway and internationally.

The ASR group has been disseminating the idea of semantic technologies as a means of data management, data access, and data integration in industry and public sector for more than a decade. Members of the group have been giving presentations and courses to representatives of the Norwegian energy industry, the Norwegian national broadcasting service NRK, the consulting company Cap Gemini, the bank DNB, the engineering software division of DNB, and others. The group's course on semantic technologies (IN3060/IN4060, previously INF3580/INF4580) has been given each year since 2010.

Over the years, groups working with semantic technologies have sprung up in consulting companies like Acando Norway and Cap Gemini, but also the Norwegian Digitalisation Agency (Digdir) and the oil field service company Aibel Norway. Many of the central people in these initiatives have their education from the ASR group and its predecessors at IFI.

Table 7. The research group's societal contribution, including user-oriented publications, products (including patents, software or process innovations

Instructions: Please select 5–10 of your most important user-oriented publications or other products from the last 5–10 years with emphasis on recent publications/products. For each item, please use the following formatting: Please delete lines which are not used.

No.	Name of publication/product	Date of publication/product	Link to the document
1	SMOL open source software		https://smolang.org/
2	OTTR open source software		https://ottr.xyz/
3	Titan article «Søvnapné kan avsløres av en sensor koblet til mobilen» (sleep apnea can be detected by a sensor connected to the mobile phone)	8. March 2021	https://www.titan.uio.no/teknologi/2021/sovnape-kan-avsløres-av-en-sensor-koblet-til-mobilen.html
4	Healthtalk podcast «Kunstig intelligens finner farlig søvnsykdom» (AI detects dangerous sleeping disorder)	10. March 2020	https://www.healthtalk.no/cpap-garmin-garmin-health/kunstig-intelligens-finner-farlig-sovnsykdom/117529
	Titan article «SIRIUS digitaliserer norsk olje- og gassindustri» (SIRIUS digitalises Norwegian oil & gas industry)	17. March 2019	https://www.titan.uio.no/blogg/tidligere-bloggere/kristin-vinje/2019/sirius-digitaliserer-norsk-olje-og-gassindustri.html
5	Titan article «Datamengden eksploderer – SIRIUS finner dataene og kobler dem» (The amount of data explodes – SIRIUS finds the data and connects it)	16. May 2016	https://www.titan.uio.no/innovasjon/2016/datamengden-eksploderer-sirius-finner-dataene-og-kobler-dem.html

3. Challenges and opportunities

Information about the strengths and weaknesses of the research group is obtained through the questions above. In this chapter, please reflect on what might be the challenges and opportunities for developing and strengthening the research and the position of the group.

One of the strengths of the semantic technology part of the group also constitutes one of the main challenges: over the years, several of the researchers have acquired quite deep knowledge of industrial hydrocarbon exploration and production, spanning from aspects of geoscience to asset management. As part of the green shift in the energy industry, this detailed knowledge about the application area is losing its importance. On the other hand, the increasing digitalisation of all industries, the health sector, finance, media, etc. provides ample opportunities for the application of our methods on different domains. Associating with the Energy@UiO effort may be valuable. The difficult question is which application area to concentrate on, since impact depends on specialisation, but specialisation requires investment.

Another challenge lies in the fact that traditional research fields like information management, database theory, distributed databases, formal logic, reasoning, etc., that some of the senior researchers of the group have established themselves in are not currently *en vogue*. This is offset by the novel possibilities offered by a combination of these disciplines with data science and machine learning, which also is a focus point of the faculty of Mathematics and Natural Sciences. This combination is being investigated by many other groups internationally, but we believe that the combination with statistical methods in the frame of Integreat can lead to a distinctive new research profile in the years to come. Moreover the close interaction with the language technology group LTG of IFI holds great potential.

Having successfully coordinated the Optique FP7 project and the SIRIUS centre, and having recently been awarded the integreat centre and the RESPIRE project makes the group a highly attractive partner for further centre and EU funding and will lead to invitations into project consortia. Many excellent opportunities will arise from this, but the group will again need to choose which of these to concentrate on to avoid further loss of focus in our research.

Finally, the composition of the group from the semantic technology part and the distributed multimedia part is still to be felt clearly. Joint research crossing these two subgroups will have great potential but requires an investment of time and energy.