



Human-centric algebraic machine learning

Exploitation and Outlook Plan - M54

Deliverable D8.9

WP8 - Dissemination, Exploitation and
Collaboration



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Consortium



ALGEBRAIC AI



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E-mail: alma@eprosima.com
Consortium: **Proyectos y Sistemas de Mantenimiento SL (eProsima) (EPROS)**, Spain
Champalimaud Foundation (CF), Portugal
ALGEBRAIC AI (ALG), Spain
German Research Center for Artificial Intelligence (DFKI), Germany
Inria (Inria), France
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Technical Research Centre of Finland (VTT), Finland
Carlos III University (UC3M), Spain

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Executive summary

Algebraic Machine Learning (AML) is a novel machine-learning technique based on algebraic representations of data. Unlike statistical learning, AML algorithms are robust regarding the statistical properties of the data and are parameter-free. AML systems can retain what they learn, including sociocultural ethical practices for human–artificial intelligence systems. The EU-funded ALMA project aims to study the mathematical properties of AML and to leverage them to develop a new generation of interactive human-centric machine learning systems. These systems are intended to minimize bias to facilitate trust while better enabling distributed collaborative learning.

This deliverable—*Deliverable D8.9 - Exploitation and Outlook Plan - M54*—details the comprehensive strategy for exploiting the outcomes of the ALMA project. It outlines a joint exploitation plan agreed upon by all consortium partners, ensuring that the innovative benefits of AML and its integration platform (AML-IP) are maximized across various sectors, including robotics, healthcare, and beyond. EPROS, as project coordinator and leader of WP8, will ensure coordinated efforts across the consortium while individual partners tailor their exploitation strategies to their specific strengths, target audiences, and market opportunities.

Key elements of the exploitation plan include:

- Establishing AML as a novel and explainable machine learning paradigm that challenges the limitations of deep learning and other traditional methods.
- Deploying AML-IP, an open-source communications framework that seamlessly integrates AML into established ecosystems like ROS 2 and FIWARE, thereby facilitating real-world applications.
- Addressing potential barriers to adoption through the development of user-friendly tools and comprehensive documentation that lower the entry threshold for developers and industry stakeholders.
- Outlining individual partner strategies—ranging from theoretical advancements and academic publications to hardware acceleration and industry-specific applications—each designed to generate tangible impact and broaden AML’s reach.

In summary, the exploitation plan sets a clear path toward translating groundbreaking AML research into practical, market-ready solutions that foster innovation, enhance data security, and promote a transparent and collaborative approach to artificial intelligence.

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Acronyms

AI	Artificial Intelligence.
AML	Algebraic Machine Learning.
AML-DL	Algebraic Machine Learning - Description Language.
AML-IP	Algebraic Machine Learning - Integrating Platform.
CPU	Central Processing Unit.
DL	Deep Learning.
DNN	Deep Neural Network.
DQN	Deep Q-learning Neural Networks.
GA	Grant Agreement.
HCI	Human-Computer Interaction.
HW	Hardware.
LAN	Local Area Network.
ML	Machine Learning.
OEM	Original Equipment Manufacturer.
SEO	Search Engine Optimization.
SVM	Support Vector Machines.
SW	Software.
SWOT	Strengths, Weaknesses, Opportunities, and Threats.
URL	Uniform Resource Locator.

1 General exploitation plan

1.1 Project's mission and vision

Nowadays, the use of machine learning techniques is widespread in a multitude of sectors such as automotive, manufacturing, construction, marketing, etc. However, in many situations the machine learning algorithms utilized do not allow introspection when checking what the machine is actually learning, its learning state or how it learns. This is the black box phenomenon that is so common in neural networks by which the user no longer has control over what the machine is learning with the purpose of solving complex problems that a human cannot tackle.

AML is proposed as a new learning paradigm that builds on Abstract Algebra and Model Theory. Unlike other popular ML algorithms, AML is not a statistical method, but produces generalized models from embedded semantics of data in discrete algebraic structures.

Moreover, AML has the potential to seamlessly integrate unstructured and complex information contained in training data, with a formal representation of human knowledge and requirements. It also makes use of internal representations based on discrete sets and graphs, offering a good starting point for generating human understandable descriptions of what, why and how has been learned.

The mission of the ALMA project is to provide a new ML paradigm easily understandable by users, eliminating the black box phenomenon of current algorithms and bringing this new paradigm closer to end users through an integration platform that allows exploiting AML in a wide variety of use cases.

1.2 Knowledge, data and IPR Management

To gain comprehensive insights into how knowledge, data, and intellectual property are managed within the ALMA project, we invite you to explore the ALMA project website ¹. Specifically, you can find detailed information in the *Publications* section, under *Public Deliverables*. There, you will find the D8.11 Data Management Plan - Final M48 deliverable, which serves as a cornerstone for understanding our data management strategy.

The Data Management Plan specifies:

- The data that is open to the public.
- The types of data generated by the project.
- The methods for exploiting and providing access to the data for verification and re-use.
- Strategies for curating and preserving the data.

1.3 Target customers and stakeholders

The main customers of AML and Algebraic Machine Learning - Integrating Platform (AML-IP) are presented in the following list:

- AI Researcher and research institutes/departments
- Artificial Intelligence (AI) consulting companies
- Companies specializing in Machine Learning (ML) applications

¹<https://alma-ai.eu>

- Hardware acceleration Original Equipment Manufacturers (OEMs)
- AI engineers
- Software developers

Also, the relevance of this project to the AI research community should be noted, being AML the core element of the ALMA project.

Also please refer to the *D8.3 - Report on Communication and Dissemination M48* deliverable for more information on the target audience and the activities carried out to engage this group.

1.4 Strategic approach to materialize the vision

To materialize a reality in which AML is used to solve large real-life problems, it is necessary to provide a user-friendly library, as well as an infrastructure that exploits the capabilities and advantages of AML. In addition, it is required that the user's interaction with AML keeps complexity to the minimum to engage the developer community and facilitate its incorporation into target communities such as ROS 2 or FIWARE.

In addition, an effort is required to build an AML ecosystem through well-defined standards and community building efforts. These efforts in particular will be the basis for the project to achieve the visibility and influence required for it to be adopted by a larger number of users and developers worldwide.

The keys to the success of the project lie in the development of the key results shown in Table 2:

Key result	Type	Contribution
AML	Brand	Novel ML paradigm based on Complex Algebraic Model Theory
AML-DL	Open source specification	Specification for encoding algebraic rules describing a problem in an embedding understandable by the AML engine.
AML-IP	Open source platform	Platform that exploits the capabilities of AML and allows it to be integrated into ROS 2 ² systems and FIWARE-compliant environments.
AML Open Source Tools	Open source tools	Tools that enable end-users to address ML problems using AML.

Table 2: Key result of materializing the vision

The activities corresponding to the realization of the ALMA project vision in order to achieve the key results appearing in Table 1 are based on the following fundamental principles:

- Commercial exploitation, with special focus on the European market.
- Alignment with activities that are being developed in related fields of research in the European Union, whether other projects of the Horizon 2020³ programme or new projects of the NextGener-

³<https://ec.europa.eu/programmes/horizon2020/en/home>

ationEU⁴ programme.

- Acceptance of the results by the international community.

1.4.1 ALMA Project website

The ALMA project will maintain an owned website in order to have an openly accessible space where partners will showcase every new accomplishment achieved as the project progresses. The URL of this webpage is the following: <https://alma-ai.eu/>

One of the main strategies of the ALMA exploitation plan is to maintain up-to-date the Search Engine Optimization (SEO) of this website. These are the actions that have already taken place to pursue this goal:

- The website is indexed in Google
- Uniform Resource Locator (URL) is SEO optimized
- ALT attribute implemented in all images.
- HTML Headers (H1, H2, H3) are SEO optimized.
- Meta-description implemented.
- Robots.txt file implemented, which prevents Google Crawler from accessing (and exposing) internal URLs of the website.
- The website has Google Analytics implemented as a tool to get feedback from and improve the SEO.

1.4.2 Algebraic Machine Learning (AML)

AML, as a Novel ML paradigm based on Complex Algebraic Model Theory, aims to solve common problems of traditional ML technologies such as independence of statistical data, combination of formal knowledge and training data, distributed and collaborative learning, and human-understandable learning.

Testing and real-world applications of AML are being conducted by the project partners. Their practical implementations generate valuable feedback that not only drives improvements in AML but also facilitates its broader dissemination and adoption.

Barriers and risks of AML AML is founded on advanced mathematical theory, which necessitates a strong mathematical background for effective understanding and utilization. This requirement represents one of the primary entry barriers for developers and practitioners who lack extensive expertise in mathematics, limiting its immediate adoption by a broader community.

To address this challenge, the project has prioritized the development of a suite of user-friendly tools. Key innovations such as AML-DL, AML-IP, the AML Dashboard, and other open-source utilities have been introduced to simplify the interaction with AML. These tools are specifically designed to lower the steep learning curve by providing accessible interfaces, clear documentation, and practical guidance for newcomers, ultimately facilitating easier experimentation and application of AML.

⁴https://europa.eu/next-generation-eu/index_en

Furthermore, all project partners are actively integrating AML into their research efforts. Currently, partners like DFKI and others are applying AML to solve real-world problems, which not only demonstrates its practical viability but also generates valuable feedback. This continuous loop of testing and refinement is expected to enhance the maturity of AML, paving the way for wider community engagement and adoption in the near future.

Input from users Current AML users are consortium member partners who have the knowledge necessary for the application of AML to specific problems.

Roles of the partners Since the whole project focuses on AML, all partners have a fundamental role to play in relation to this key outcome.

- CF and ALG are in charge of the development of the mathematical foundations of AML,
- DFKI researches world, cultural and ethical models that can be embedded in AML,
- Inria explores new paradigms and models of human interaction with AML,
- TUK develops a prototype for AML acceleration,
- EPROS develops the AML integration platform,
- UC3M applies AML to real-world use cases in robotics,
- VTT explores potential for AML world models to encompass cultural and ethical issues in interactive human-centric machine learning systems.
- FIWARE is in charge of providing compatibility of the integration platform with its product ecosystem.

1.4.3 Algebraic Machine Learning - Description Language (AML-DL)

The Algebraic Machine Learning - Description Language (AML-DL) is a specification that dictates the patterns for describing a problem so that a subsequent embedding of the problem can be generated and understood by the AML engine. This is still under development and is intended to be improved throughout the ALMA project.

Barriers and risks of AML-DL The main risk of AML-DL is the problem that a user requires the mathematical knowledge to be able to write a problem in AML-DL format correctly. This can be a major entry barrier for new AML users who do not have a mathematical background, such as software developers or AI experts.

This risk is mitigated with the development of open source tools for working with AML and the AML-IP.

Input from users At present, AML-DL is mainly tested and evaluated within the consortium, with its usage focused on internal testing and refinement. Consortium partners, equipped with the necessary mathematical expertise, are actively utilizing AML-DL to model and describe problems for subsequent embedding by the AML engine. Their inputs and feedback—derived from practical, real-world use cases—are invaluable in identifying potential issues and areas for improvement. This internal feedback loop has been critical to refining the AML-DL specification during the project execution.

Roles of the partners In this case, ALG and CF are the developers of the specification and the partners responsible for disseminating the knowledge to the rest of the partners so that they can define actual problems using the specification.

1.4.4 Algebraic Machine Learning - Integrating Platform (AML-IP)

The integration platform aims to exploit the benefits of AML such as collaborative learning, model-parallelizable learning on computational nodes working on smaller problems in parallel, and integration of AML into robotic systems (ROS 2) and the FIWARE ecosystem, as it is defined in *section 2.6 AML-IP integration with external frameworks* of the deliverable *D6.4 AML-IP implementation - Final M48*. AML also entails some benefits over state-of-the-art ML paradigms regarding confidentiality and data security. This is achieved thanks to the ability of AML to generate better models being agnostic of the dataset. More detailed information on this matter may be found in deliverable *D6.4 AML-IP implementation - Final M48*.

Barriers and risks of AML-IP The AML-IP is a completely new concept in which the user is provided with a platform that allows to connect all their own AML nodes, or even connect with other users working on the same problem in order to obtain a final ML model without suffering any bias.

There may be a reluctance on the end-users to start using AML and this would be the main barrier to the use of the AML-IP. That is why the integration platform intends to start by solving the problems of deployment and communication of conventional ML techniques in order to engage the user and subsequently offer new possibilities for this platform besides AML.

The risk associated with the initial reluctance to adopt AML-IP has been effectively mitigated through the development of the AML Dashboard ⁵. This tool provides a user-friendly interface that simplifies the deployment and testing of AML models. Designed specifically for developers and researchers, the AML Dashboard offers an intuitive and guided environment to configure, connect, and monitor AML nodes, thereby easing the transition from conventional ML systems. By streamlining these processes, the Dashboard not only reduces the technical barriers to entry but also fosters collaborative learning and innovation within the AML ecosystem.

Input from users This integration platform has already been presented to the ROS 2 community and to the ROS 2 TSC⁶, who have given feedback taking into account the current ROS 2 systems and AI user needs within the ROS 2 ecosystem.

Roles of the partners The AML-IP will be fully developed by EPROS taking into account the needs and advantages of AML to be exploited, and which are provided by ALG and CF.

1.4.5 AML Open Source Tools

In an effort to make AML more accessible and less daunting for newcomers, a collection of open-source tools has been developed. These tools are intended to mitigate the AML learning curve. EPROS has produced two tools: the DDS Monitor and the DDS Router. The DDS Monitor serves as a resource for debugging AML networks, helping users identify and rectify issues. The DDS Router enables users to communicate with AML networks across various Local Area Networks (LANs) enhancing connectivity and accessibility. These tools can be used by a wider and non-experienced community.

Barriers and risks of the open source tools AML Toolkit is a set of software tools that allow users to develop, train, and deploy Algebraic Machine Learning (AML) models. These tools are designed to be used by researchers, developers, and industry professionals who want to implement AML models in their

⁵<https://aml-tools.readthedocs.io/en/latest/rst/amldashboard/specification/amldashboard.html>

⁶<https://discourse.ros.org/t/ros-2-tsc-meeting-minutes-12-16-2021/23541>

applications. AML Toolkit aims to provide users, developers, and researchers with the documentation, guides, and examples needed to start working with AML.

These tools cover the entire process of developing AML applications, from data collection and preprocessing to generating embeddings for problem description, validating those embeddings, training the model using an AML engine, performing inference using the resulting AML model, and validating the results.

Since these tools are open source, they allow the community of developers, researchers and mathematicians to contribute and apply their knowledge in their development in order to make them more robust and easily adopted.

Input from users Key components of the tool suite, such as the DDS Router—a critical element of AML-IP—have already been developed and released. Several customers have had the opportunity to test these tools, and they are now actively deployed in production environments.

Roles of the partners These tools have been developed by ALG, authors of AML, together with EPROS, with great knowledge in the field of open source software and the possibility to reach a large community such as ROS 2.

1.5 Competition and SWOT analysis

AML is a novel ML paradigm that aims to break into a collapsed market and industry of ML solutions such as:

- supervised learning techniques like neural networks, Support Vector Machines (SVM), decision trees, etc.;
- unsupervised learning like k-means clustering and association rules; and
- semi-supervised learning.

However, AML presents great benefits and strengths that none of the aforementioned technologies exhibit. Exploiting these strengths will allow AML to find a niche in the market for collaborative learning applications or applications that require understanding of the learning process.

The following Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis was presented in *Section 2.2.1.1 Exploitation* of the ALMA Grant Agreement (GA) 952091.

- Strengths
 - Innovative ML paradigm based on simple, demonstrable and elegant mathematical principles.
 - Radically new capabilities (reduced dependence on training data statistics, capability to combine formal knowledge and training data and distributed learning).
 - Auditable and certifiable knowledge representation.
 - Experienced partners.
 - Compatible with widely extended and well established frameworks as ROS 2 and FIWARE.
 - Open source licences.
- Weaknesses
 - AML still has to demonstrate that it is practical for resolving large, real-life problems.
 - Advanced skills required in mathematics and programming make finding core developers hard.

- A high performance engine to compete with neural network GPU implementations is still missing.
- Unforeseeable risks inherent to new technologies.
- Opportunities
 - Many new potential and emerging markets.
 - No competitors with the same technology.
 - Good platform for researchers.
 - Increased investments in AI research and development by the EU.
 - Good channels for dissemination and exploitation including the large ROS 2 and FIWARE communities.
- Threats
 - A competing technology (Deep Learning (DL)) supported by strong competitors such as Google.
 - Commoditization of ML methods (and accompanying libraries) based on Deep Neural Network (DNN), for example TensorFlow⁷ or PyTorch⁸.

As stipulated in the GA, the previous SWOT analysis has been reviewed by the consortium and some significant changes have been applied. The opinions and feedback received by each of the partners in the multiple meetings of the ALMA project have been taken into account, resulting in the following new SWOT analysis (**bold text** indicates additions while ~~crossed-out text~~ denote deletions):

- Strengths
 - Innovative ML paradigm based on simple, demonstrable and elegant mathematical principles.
 - Radically new capabilities (reduced dependence on training data statistics, capability to combine formal knowledge and training data and distributed learning).
 - ~~Auditable and certifiable~~ **Human understandable** knowledge representation.
 - Experienced partners.
 - Compatible with widely extended and well established frameworks as ROS 2 and FIWARE.
 - Open source licences.
 - **Enhanced privacy and security of user data.**
- Weaknesses
 - AML still has to demonstrate that it is practical for resolving large, real life problems.
 - Advanced skills required in mathematics and programming make finding core developers hard.
 - A high performance engine to compete with neural network GPU implementations is still missing.

⁷<https://www.tensorflow.org/>

⁸<https://pytorch.org/>

- Unforeseeable risks inherent to new technologies.
- Opportunities
 - Many new potential and emerging markets.
 - No competitors with the same technology.
 - Good platform for researchers.
 - Increased investments in AI EU research and development.
 - Good channels for dissemination and exploitation including a large ROS 2 and FIWARE communities.
 - **Application of Human-Computer Interaction (HCI) paradigms and methodologies for AI systems.**
 - **Embedding knowledge of world models, culture and ethics.**
- Threats
 - A competing technology (DL) supported by strong competitors such as Google.
 - Commoditization of ML methods (and accompanying libraries) based on DNN, for example TensorFlow or PyTorch.
 - **Vendor lock-in: low acceptance of AML by companies that cannot change to other ML vendors without incurring significant cost.**

1.6 Unique Selling Propositions (USPs)

ALMA offers a unique value proposition in the AI sector, and more specifically in the field of ML, by proposing a new machine learning paradigm based on the Theory of Abstract Model Algebra. This new ML paradigm referred to as AML offers benefits such as: *a)* reduced dependency on statistics in training data, *b)* combination of formal knowledge and training data, *c)* distributed and parallelizable learning, *d)* collaborative learning independent of the original training data, *e)* enhanced security of user data, *f)* greater mathematical transparency, *g)* understandable and traceable learning process for the user. This is enhanced by the presence in the ALMA consortium of experienced partners in the AI industry that allow for the exploitation of all the aforementioned benefits. Moreover, the presence of experienced partners in the robotics business guarantees the compatibility of AML with ROS 2 systems, as well as other members that have elaborated use cases and applications of AML to demonstrate how to use AML in cases of greater applicability.

1.7 Communication and dissemination strategy - revision of actions and priorities

Besides the materialization of the vision, the main dissemination and communication activities conducted during the lifetime of the ALMA project are included, as they constitute part of the exploitation strategies.

1.7.1 Target communities and working groups

Table 3 shows the list of target communities as well as the partners in charge of raising awareness of the project results among these communities.

Target community	Partner(s) involved
ROS 2 TSC	EPROS
ROS / ROS 2 community	EPROS
Open Robotics Foundation	EPROS
FIWARE	FF
OMG	EPROS
International Data Spaces Association	FF
Finnish Center for AI	VTT/DFKI
Finnish AI Accelerator	VTT/DFKI
Computer Science community	ALG/CF/DFKI
Mathematics researchers	ALG/CF
ROS 2 Hardware Accelerator WG	TUK
ROS 2 AI Integration WG	EPROS

Table 3: ALMA target communities and partners responsible for raising awareness

1.7.2 Project activities

Project communication and dissemination activities are detailed in *Deliverable D8.3 – Report on Communication and Dissemination M48* of the ALMA project. The primary focus has been on publishing research papers and actively participating in scientific events to effectively disseminate the project's objectives and results.

2 Individual exploitation plan

This section describes the individual exploitation plan of each of the ALMA consortium members, as well as the target audience, expected results and impact of each of them.

It is worth mentioning that according to *Section 2.2.1 Dissemination and exploitation of results* of the ALMA GA 952091, “while an individual Exploitation will be developed by each partner, the main exploitation effort will be carried by the two SMEs involved in the ALMA project, EPROS and ALG”.

2.1 eProsima (EPROS)

Exploitation plan The exploitation strategy pursued by eProsima is designed to enhance the company’s competitiveness and footprint in the robotics industry. This is achieved not only by providing a robust communication middleware for robots but also by delivering advanced solutions that enable the integration of Algebraic Machine Learning (AML) into robots developed with the ROS 2 framework.

By leveraging the inherent compatibility of AML-IP with the ROS 2 ecosystem—thanks in large part to the use of Fast DDS as the communication backbone—eProsima effectively reaches and engages a vast community of robotics developers. The strategy includes hands-on workshops, detailed tutorials, and comprehensive documentation, as well as active involvement in the ROS 2 AI Integration Working Group led by eProsima, all of which facilitate the adoption of AML in the robotics sector.

Moreover, eProsima capitalizes on its proven experience in exploiting open-source software by following a commercially successful model based on consultancy and freemium services. In actual production environments, the company is already putting into practice essential tools such as the DDS Router and DDS Monitor—along with other key Fast DDS enhancements—to support the AML-IP. These tools, deployed in customer sites, not only optimize data communication and network scalability but also provide real-time debugging and monitoring capabilities that are critical for maintaining robust, distributed AML applications. This commitment to open source software and open standards, exemplified by contributions to bodies like the OMG, underpins eProsima’s holistic approach to the exploitation of AML-IP.

Target group / audience / stakeholders These tools are designed for developers and engineers working on robotics and distributed systems. They are especially useful for those using ROS 2 and looking to integrate AML into their projects. Also, the DDS Router connects different parts of a network smoothly, the DDS Monitor helps debug the system to quickly spot and fix issues, and Fast DDS improvements ensure that data flows reliably and quickly. In short, these tools are aimed at professionals who need robust communication, monitoring, and debugging to build efficient, real-world robotics applications.

Expected results / impact eProsima has proven experience in exploiting open-source software by following a commercially successful model based on consultancy and freemium services. In actual production environments, the company is already putting into practice essential tools such as the DDS Router and DDS Monitor—along with other key Fast DDS enhancements—to support the AML-IP. These tools, deployed in customer sites, not only optimize data communication and network scalability but also provide real-time debugging and monitoring capabilities that are critical for maintaining robust, distributed AML applications. This commitment to open-source software and open standards, exemplified by contributions to bodies like the OMG, demonstrates eProsima’s approach to the exploitation of AML-IP and the tools developed within the project.

2.2 Champalimaud Foundation (CF)

Exploitation plan Champalimaud's deliverables correspond to the development of the mathematics of Algebraic Machine Learning, the application to practical cases like medical images and the publication of these results. They are interested in testing how Universal Algebra can be a different mathematical foundation of Machine Learning, and scientific applications.

With these results, Champalimaud will train several researchers with expertise in this new technology and will be able to apply for other grants.

Target group / audience / stakeholders Champalimaud has set as their target researchers in ML and more broadly in Computer Science and Mathematics interested in learning problems. They believe their technology can be the basis for a highly transparent learning framework, and expect other researchers to make use of it.

Expected results / impact Champalimaud's immediate results consist of the publication of arXiv reports and journal manuscripts with proofs and illustrations of AML. They expect that these results will pave the way for a second stage in which the new technology is applied to different problems. Within their lab, it will be tested in Neurobiology and Genetics, for example. They also expect that the mathematical results and the specific application will show the community of scientists and engineers what are the advantages of the new technology, especially in transparency and understandability of the model.

2.3 Algebraic AI (ALG)

Exploitation plan The goals of the Algebraic AI exploitation plan are:

- Provide solid theoretical foundations for AML. A foundations manuscript on AML [1], a thorough study of Finite Atomized Semilattices [2], a paper on Semantic embeddings on Semilattices [3], a work on Infinite Atomized Semilattices [4], and a fifth article on machine learning using algebraic models (in progress).
- Create awareness of AML among scientists and engineers. Organisation of a conference on alternative AI methods: ALTAI25 (sites.google.com/view/altai25). Release of tools for training of AML models and their exploration.
- Develop an AML engine for scientific and industrial applications, and to complement the publication of articles. Release an open AML engine in February 2025.
- Design hardware to compute AML models more efficiently. They expect to sell hardware accelerators in the mid-term.
- Engage in an aggressive campaign to popularize AML. Efforts have already started with the publication of papers, organisation of the conference ALTAI25, and the release to the public of an open AML engine.
- Develop an open network for distributed computation of AML. Unlike neural networks, AML models can be efficiently trained in parallel. They plan to leverage this unique capability of AML by creating a world-wide decentralized network that will allow for the collaborative training of AML models. They expect to sell usage tokens, software, hardware and consultancy to the network users.

Target group / audience / stakeholders Algebraic AI's main target group is Machine Learning scientists and engineers.

Expected results / impact Algebraic AI have the ambitious goal of bringing AML to a state of development sufficient to replace Deep Learning in a number of real practical applications.

2.4 German Research Center for Artificial Intelligence (DFKI)

Exploitation plan DFKI is in charge of modeling use cases of real-world problems with AML, focusing on connecting activity monitoring sensors with the AML computational engine. Furthermore, they aim to represent complex human concepts in AML. The goal is to exploit these research results through Human-AML co-creation of complex domain models.

Target group / audience / stakeholders The target audience of DFKI are AI researchers and developers of AI applications.

Expected results / impact The expected results are:

- Represent basic ethical ideas with AML.
- Define world models in terms of ecosystem culture and ethics.
- Human-AML co-learning of cultural pluralism and cultural hybridization.
- Embed complex human concepts in a language understandable to the AML interpreter.

If these objectives are met, it would be of high benefit for the exploitation of AML as a new ML technology that aims to solve problems not achievable by traditional ML technologies.

2.5 Inria (Inria)

Exploitation plan Inria's goal is to include AML models in creative interactive software for gesture applications to allow end-users to train and apply AML models to their needs.

Target group / audience / stakeholders Inria expects to reach *a)* the general public, as the gesture applications will be designed for them, to enable exploration and adaptation of AML models to individual needs and *b)* the creative professionals, as the system will include personalized gesture recordings, which can be extended, compared and adapted by a creative audience.

Expected results / impact The expected results are running software applications using AML enabling it to be trained and applied by end-users. With that, we aim to make the AML pipeline accessible to the public. Finally, we aim to develop a set of tools to extend the functionality of the pipeline in the future, such as making it easy to compare AML to other models or define AML model training in more detail.

2.6 RPTU Kaiserslautern-Landau (former TUK)

Exploitation plan RPTU plans to release the current version of Hardware (HW)/Software (SW) accelerator architecture and corresponding HW implementation to ALG in order to speed-up the processing of AML in their environment. For the final version, detailed validation and testing will be done in close collaboration with ALG. Further, the outcomes and results of these hardware developments creating new designs will be used to train students and foster new machine learning paradigm changes. In terms of scientific exploitation, we aim to publish several papers in scientific journals or conferences.

Target group / audience / stakeholders ALG is the company that will benefit the most from RPTU developments, designs, and optimizations. By achieving both HW and SW acceleration algorithms for the AML computation engine, the target audience of ALG can be more easily engaged to incorporate AML in their projects.

Expected results / impact RPTU expects performance speed-ups as compared to a standard CPU of 10-15x at a minimum of 5x energy efficiency improvement. This will have a large impact on the scaling possibilities and potential of AML.

2.7 FIWARE Foundation e.V. (FF)

Exploitation plan FIWARE's exploitation plan aims at achieving compatibility between AML-IP and the products present in their ecosystem, paying special attention to the Context Broker. In this way, AML and AML-IP can be exploited by the FIWARE community.

Moreover, as with EPROS, FIWARE is highly experienced in exploiting Open Source products and technologies by providing freemium services and contributing to the dissemination and exploitation of open products and standards.

Target group / audience / stakeholders FIWARE's main target audience is their own community, with a special consideration for the FIWARE community dedicated to the development of AI technologies.

Expected results / impact AML-IP is expected to be compatible with the FIWARE ecosystem, thus enabling the exploitation of AML by FIWARE users.

2.8 Technical Research Centre of Finland (VTT)

Exploitation plan VTT work in ALMA is focused in WP5 (Learning world models, ethics and culture with AML). VTT's work is focused on world models encompassing cultural and ethical considerations. VTT aims for an exploitation at three levels: basic, use-inspired, and applied. At the basic research level, VTT will publish in natural science journals. At the use-inspired research level, VTT will publish in bridging scientific journals. At the applied research level, VTT aims to publish in applied science journals as soon as results from the application of AML become available towards the end of the project.

Target group / audience / stakeholders In accordance with the tasks present in WP5, VTT's work will be directed to communities with interest in Artificial Intelligence that are working at the intersection of natural science, social science, and action science. These can include Finnish Center for AI⁹ and Finnish AI Accelerator¹⁰.

Expected results / impact Increasing awareness and application of the world models construct to better enable shared interpretation of cultural and ethical issues in human-artificial intelligence systems implementations. Increasing awareness of AML in the context of communities working at the intersection of natural science, social science and action science.

⁹<https://fcai.fi/>

¹⁰<https://faia.fi/>

2.9 Carlos III University (UC3M)

Exploitation plan UC3M's research on robot planning and control will showcase valid use cases and comparisons using AML applied to humanoid robots. All results will be published in renowned scientific journals and conferences.

Target group / audience / stakeholders UC3M's target audience is composed of ML researchers as well as software and hardware developers in the robotics industry to include AML as the primary ML technology to be included in their developed robots.

Expected results / impact The impact that UC3M expects to have is that developers and researchers will be able to learn from the application of AML to the humanoid robot use case and thus achieve the spread of AML to more scenarios and use cases in the industry.

3 Current results of the individual exploitation plan

This section provides an overview of the current results and progress of each ALMA consortium member.

3.1 eProsima (EPROS)

Results eProsima's contributions to the ALMA project are showcased through the development of essential tools and enhancements to Fast DDS. These achievements include:

- **DDS Router**¹¹: the DDS Router facilitates distributed topologies by seamlessly connecting distributed DDS networks. It serves as a component for optimizing data communication, enhancing efficiency, and ensuring scalability.
- **DDS Monitor**¹²: eProsima has designed the DDS Monitor, a graphical desktop application. This tool simplifies the process of debugging and provides real-time monitoring capabilities for DDS networks, offering significant advantages in terms of development and maintenance.
- **Fast DDS Enhancements**: The commitment to optimize Fast DDS, combined with bug-fixing and functionality enhancements, has resulted in significant improvements. These refinements result in superior system performance and an increase in overall reliability.
- **AML-IP**¹³: eProsima, supported by Algebraic AI, has developed the AML-IP, a communications framework in charge of data exchange between Algebraic Machine Learning (AML) nodes through local or remote networks. It is designed to allow non-expert users to create and manage a cluster of AML nodes to exploit the distributed and concurrent learning capabilities of AML. The first beta release of AML-IP¹⁴ is now available in its corresponding public repository on GitHub. It comes with associated documentation, tutorials and use cases to ease the entry of new users into the development of distributed ML applications. In addition, the compatibility of this tool with the ROS 2 framework allows this community to facilitate its use in their projects. To further enhance usability, AML-IP nodes have been incorporated into AML-Dashboard¹⁵, streamlining interaction and accessibility.

Uses eProsima's customers have already demonstrated commercial success using these tools in a variety of use cases and conditions. Their feedback and results underline the practical applicability of these solutions.

On the other hand, the expansion of AML-IP into the open-source community is growing. In this context, we can draw on the precedent set by Fast DDS, eProsima's flagship product, which has successfully navigated its way into the open-source ecosystem.

¹¹<https://github.com/eProsima/DDS-Router>

¹²<https://github.com/eProsima/Fast-DDS-monitor>

¹³<https://github.com/eProsima/AML-IP>

¹⁴<https://github.com/eProsima/AML-IP/releases/tag/v0.1.0>

¹⁵<https://github.com/eProsima-Private/AML-Dashboard>

3.2 Champalimaud Foundation (CF)

Results As a member of the ALMA project, the Champalimaud Foundation focuses on the research and development of the fundamental theory behind AML, as well as on its application to healthcare use cases. Champalimaud Foundation's main contributions can be summarized as follows:

- **Publications:** Four manuscripts on AML theory have been submitted to peer-reviewed journals on Machine Learning and Algebra.
- **Image classification in healthcare:** The Champalimaud Foundation has researched how to efficiently embed non-quantized, color images in algebras. These methods have been used to classify medical images in the MEDMNIST dataset as well as in other datasets like MNIST and CIFAR.
- **Human Interaction:** Human interaction has been studied with the user selecting out a part of an input example and then the algebraic model is a subset of the complete model. The two models are then compared to see if the user selected a region of the example is as good, better or worse than the complete input.

Uses Champalimaud Foundation's users are ALMA members, the readers of the manuscripts sent for publication and members of the CS, ML and Mathematics community attending dissemination events.

3.3 Algebraic AI (ALG)

Results Algebraic AI's mission is to develop software and hardware to compute AML models. In addition to the development of tools, the company devotes a comparable amount of effort to basic research. Algebraic AI is engaged in the research of both, the machine learning and the algebraic aspects of AML. The company collaborates and supports the work of every member of the ALMA project, providing tools, processing data and giving advice. Algebraic AI's contribution includes:

- **AML engines:** Significant progress has been made to better compute AML models. Discrete engines were improved and developed into an engine capable of using real-valued data. An improved version of the discrete engine was shared with EPROS and DFKI. The new real-valued compatible engine was shared with DFKI, INRIA, CF and UC3M;
- **Development and promotion of the mathematics underlying AML:** Three manuscripts have been submitted to peer-reviewed mathematics journals.
- **AMLDDL specification and tools:** The specification for the AML Description Language has been written and updated to include the handling of real-valued data. AMLDDL is used to describe datasets in algebraic terms. Interpreters for the specification were also integrated with the engines. Tools to help understand the consistency of the embeddings with visualization and debugging have also been developed.
- **Reinforcement learning alternative:** A new algorithm was discovered to play games and tackle robotics problems using an AML-based alternative to reinforcement learning. Engines were modified to better support the computation of this algorithm. The algorithm is currently in use by UC3M.
- **AML accelerator:** Algebraic AI supported the research and development of a hardware prototype for AML algorithm acceleration in collaboration with TUK.
- **Distributed Learning:** development of techniques and software for federated learning of AML models, using a variety of approaches, including FastDDS (EPROS). The final goal is providing the computational cores for the AML-IP nodes.

- **AML-IP:** Close collaboration between Algebraic AI and eProxima to develop AML-IP Nodes capable of collaborative training (Collaborative Node), distributed training (Computing Node and Main Node) and data transformation (Mediation Node).

Uses Algebraic AI's algorithms and tools are used by Champalimaud Foundation, DFKI, INRIA, UC3M, VTT, and eProxima. Collaboration has sparked new approaches to problems and algorithms.

3.4 German Research Center for Artificial Intelligence (DFKI)

1. We have explored representing basic ethical ideas in terms of ecosystems of culture and ethics in AML in our deliverables in cooperation with VTT.
2. We have investigated how to apply AML for both gesture typing in our deliverables with INRIA. This also included an online exploration of training personalised gestures that users can train using their webcam.
3. We have explored representing complex human concepts in a language understandable to the AML interpreter. This work started by focusing on representing activity recognition as an algebraic problem. Moreover, we have worked on problems not yet fully achievable by traditional ML technologies, such as continual learning, where we have compared probabilistic models with algebraic approaches.

3.5 Inria (Inria)

Inria's goal is to include AML models in creative interactive software for creative applications. We developed three different demos to show how AML can be applied to creative and professional use cases. We also developed an interactive AML pipeline for training and comparing AML models by end and professional users.

In particular, our contributions in this are:

1. We showed in a demo how to collect, train and apply AML models for gesture exploration of music in our AML Dashboard.
2. Developed an AML training pipeline allowing users:
 - (a) to define and train an AML model with personalized gestures
 - (b) to compare AML to existing ML approaches in the web
 - (c) use AML results for creative exploration of sound patterns
3. Provide means to interactively train AML models
4. Provide means for developers to better specify the training process in collaboration with eProxima (AML Dashboard V2)
5. Provide software examples to apply AML to different exploratory and creative use cases

3.6 RPTU Kaiserslautern-Landau (former TUK)

RPTU tasks in the ALMA project are analyzing the algorithmic characteristics of AML and designing a high-performance AML hardware accelerator in WP3. RPTU contributions to the ALMA project include:

- Extraction of AML computation flow, including data flow, kernel operations, memory requirements, and appropriate hardware platform for implementation.

- Designing high throughput and energy-efficient hardware accelerator for heterogeneous computing platforms.
- Deployment of hardware accelerator and developing software stack to offload AML task to hardware accelerator.

The results show 8x performance and 3x power consumption improvements compared to a standard CPU both using multi-threaded HW. This is very promising as it offers scaling and faster acceleration.

This AML hardware accelerator will be exploited together with Algebraic AI that supports the research and development of a hardware prototype for AML algorithm acceleration.

3.7 Technical Research Centre of Finland (VTT)

Overview. As stated in the project summary, ALMA is concerned with interactive human-centric machine learning systems. VTT's work in ALMA is focused in WP5 (Learning world models, ethics and culture with AML). In particular, VTT's work is focused on world models encompassing cultural and ethical considerations. There are three types of world models in interactive human-centric machine learning systems: the world models of individual people, of machine learning, and of human organizations. VTT aims for exploitation at basic, use-inspired, and applied levels.

Publications. At the basic research level, in ALMA, VTT has published in natural science journals to address gaps in world models research. VTT has published a scientific journal paper concerned with human-embodied psychomotor world models for predictive processing in the natural science journal *Entropy* (in the *Entropy and Biology* section). This paper has been selected as an Editor's Choice paper. Also, VTT has published a paper in the journal *Behavioral Sciences* about ethical interactions between human embodied functioning and artificial intelligence systems in changing environments. In addition, VTT has published a commentary paper in the scientific journal *Behavioral and Brain Sciences* about challenges in defining and representing where world model internal states end and where external states in the world begin. At the use-inspired research level, VTT has published a paper in the scientific journal *Systems* about machine learning world models in human-artificial intelligence systems. These four papers are referred to and cited in the WP5 deliverables that VTT has contributed to. At the applied research level, VTT has taken the lead and is the lead author of four papers with consortium partners. These papers build upon VTT's earlier project papers and include some of the content from WP5 deliverables that VTT has contributed to. One paper is in the scientific journal, *Informatics*, and three papers are in the scientific journal, *Machine Learning and Knowledge Extraction*. There are two papers with DFKI, one paper with UC3M, and one paper with ALG.

Contributions. Through project deliverables and scientific journal papers, VTT has made the nine contributions listed below to addressing the challenge of including cultural and ethical world models in interactive human-centric machine learning systems.

Basic Research Level. 1) Explaining that there are three types of world models in interactive human-centric machine learning systems: the psychomotor world models of individual people, machine learning world models, and the documented world models of human organizations. 2) Explaining that world models are situated in ever-changing behavioral ethics ecologies in which different types of individual people and different types of human organizations seek to survive in situations involving machine learning applications ranging from road traffic signals to functional disorder diagnoses. 3) Explaining that boundaries between human psychomotor world models and behavioral ethics ecologies can be immediately apparent in some situations but intractably indeterminate in other situations.

Use-inspired Research Level 4) Explaining that human survival first principles influence the formulation and application of human organization's machine learning world models. Hence, different human organization's machine learning world models, although all within the scope of current socio-cultural norms,

can be in opposition to each other as different human organizations strive to survive in competitive environments.

Applied Research Level. 5) Establishing a simple to complex range of use case scenarios for interactive human-centric ML systems involving world models encompassing cultural and ethical considerations. These range from the locally simple to the locally complex as follows: road traffic systems – food access landscapes – functional disorder diagnoses. 6) Explaining how human ethical requirements can be represented in AML models, but how human psychomotor world models can generate inferences that decisions informed by outputs from ML models are not ethical decisions. 7) Explaining how AML has potential to reduce loopholes in interactions between human organizations, artificial intelligence, and individual people by core AML algorithms checking that the human-defined constraints are maintained in the subsequent relationships between inputs and outputs that are learned during training. 8) Explaining that although AML is transparent, the cognitive load involved in interpreting AML needs to be reduced to reduce the potential that people refer more to their existing psychomotor world models than to new information that is produced through AML implementations. 9) Explaining how to reduce the cognitive load of AML inputs and AML outputs, while balancing the accuracy and complexity of machine learning models, through using diagrammatic semilattices that are linked to algebraic semilattices at the core of AML.

Future. VTT will draw upon its expertise gained during the ALMA project to apply world models encompassing culture and ethics in interactive human-centric machine learning systems, including those using AML.

3.8 Carlos III University (UC3M)

Publications: UC3M has published two scientific papers [5] and [6] in the Cognitive Systems Research Journal, one of the as a part of a Special Part of special issue on Psychologically Inspired Cognitive Systems, Edited by Félix Francisco Ramos Corchado, Alexei V. Samsonovich in which we explore the transfer of human emotions to robot motions and in the generation and control of robot movements involving for human-like sketching. In both we tried to set the test bed for a future comparison of the probabilistic models used (such as Deep Q-learning Neural Networks (DQN)) with algebraic approaches. A great effort has been done to update the TEO humanoid robot to prepare the robot/simulator for the ROS2 communications infrastructure for the interconnection of middlewares under development at ALMA. After this ROS2 migration of the TEO's Humanoid robot SW architecture, still some work has to be done for testing and debugging reliability of our robotics platform to get it ready for the AML engine. UC3M aims to publish new results in applied robotics journals as soon as results from the application of AML continuous engine become available. Additionally, we have presented related works ROS2 enabled control modes with TEO and collaborative robots in National conference "Jornadas de Automática" for two consecutive years [7], [8], [9] and [10] and participate in a Workshop in the ICRA2023, one the best international robotics conference, presenting the work related with the ALMA project [11].

Reinforcement learning alternative: In close collaboration with Algebraic AI a new algorithm was discovered to play games and tackle robotics problems using an AML -based alternative to reinforcement learning. Their engines were modified to better support the computation of this algorithm. The algorithm is currently in use by UC3M in its discrete form.

UC3M has released and open-sourced its work under a common repository: <https://github.com/roboticslab-uc3m/gymnasium-alma>. This repository contains our code and results and will serve as a platform for future updates and findings. Since the AML engine does not have an explicit reward function, we have incorporated it implicitly through new problem formulations, leveraging the available discrete version of the AML engine.

UC3M's members of the ALMA project are active users of the AML engine. Our feedback has also

looped back into steering research in proper directions and prioritizing some lines of research, such as the discretization strategies to deal with continuous real spaces.

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