



Human-centric algebraic machine learning

Report on Collaboration - M54

Deliverable D8.6

WP8 - Dissemination, Exploitation and Collaboration



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Consortium



ALGEBRAIC AI



Chantalimaud
Foundation



German
Research Center
for Artificial
Intelligence



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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 report corresponds to *Deliverable D8.6 - Report on Collaboration - M54* of the ALMA project. Throughout its 48-month duration, ALMA has driven significant collaborative efforts both within its consortium and with external partners. Deliverable D8.5 encapsulates these extensive collaborations, detailing how rigorous theoretical research, advanced software and hardware tool development, and targeted engagement with key communities have collectively advanced the AML framework. Notably, the project’s research-intensive orientation—marked by high entry barriers for new adopters—has ensured that the contributions of each partner are deeply embedded in cutting-edge scientific inquiry and innovation. This document thus provides an integrated account of how collaborative research, strategic partnerships, and internal synergies have set the stage for AML’s future exploitation and potential integration into broader industrial and academic applications.

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Acronyms

AI	Artificial Intelligence.
AML	Algebraic Machine Learning.
HCI	Human-Computer Interaction.
ML	Machine Learning.
TSC	Technical Steering Committee.

1 Introduction

This document presents a comprehensive overview of the collaborative initiatives of the ALMA project. Recognizing that AML is a complex, research-driven technology with high entry barriers, the ALMA consortium has prioritized deep, focused collaborations to advance its theoretical foundations and practical implementations. The project has fostered a robust internal environment where regular bi-weekly meetings, joint research endeavours, and shared publication efforts have enabled partners to collectively overcome technical challenges and push the boundaries of what AML can achieve.

A strategic element of the project was its targeted engagement with the ROS community. Although the inherent sophistication of AML has naturally limited its immediate adoption by the broader ROS developer base, dedicated channels—such as ROS Discourse, the ROS 2 Technical Steering Committee, and the AI Integration Working Group—have been employed to introduce ROS practitioners to AML’s potential. This collaboration has primarily served to gather expert feedback and disseminate research findings, highlighting AML’s current focus on advanced research applications rather than widespread operational use.

Externally, partnerships with interdisciplinary research groups, EU projects, and academic institutions have further enriched the project. These collaborations have provided critical insights and validation for AML’s capabilities, ensuring that the technology not only advances theoretical innovation but also aligns with real-world needs. As the project concludes, the collective outcomes of these collaborative efforts—spanning innovative algorithm design, sophisticated tool development, and specialized hardware acceleration—achieve a well-founded foundation for future exploitation and broader adoption of AML in diverse application domains.

2 Research collaborations

2.1 Karl Friston's extended research group

VTT has been collaborating with Karl Friston's extended research group. This research group includes participants with a wide range of expertise including neuroscience, social science, and computer science. The multi-disciplinary group presents and discusses the latest work in addressing profound challenges in biosocial-technical systems.

The goal of this collaboration is to stay up-to-date with the latest applications of computer science based on first principles, which have been discovered through natural science research in, for example, theoretical biology. In particular, in relation to the latest developments in the world models construct.

The benefit resulting from their advice and revision of VTT's research is to have high-level expert feedback on VTT's work during its development. Of particular relevance to VTT's work in WP5 is this research group's interest in world models. This interest encompasses human-embodied psychomotor world models, organizational world models, and machine-learning world models. World models are internal models of self in the world, and a major topic is how boundaries between internal states and the external world can best be defined. A major related topic is how exchanges between internal states and external states can be represented. VTT's participation has included presentation, as well as participation in question and answer sessions with Professor Friston.

2.2 Center for Hybrid Intelligence

The Center for Hybrid Intelligence¹ is an interdisciplinary research team exploring digital interfaces that facilitate collaboration between humans and algorithms.

Inria has participated in a Round Table organized by the Center for Hybrid Intelligence, collaborating with Aarhus University professor Jacob Sherson.

2.3 Hybrid Human Artificial Intelligence (HHAI)

In June 2022, the first International Conference on Hybrid Human-Artificial Intelligence² took place in Amsterdam. This Conference is dedicated to the study of Artificial Intelligence systems that cooperate synergistically, proactively, and purposefully with humans, amplifying instead of replacing human intelligence.

Inria was invited to this event, where they gave a talk on the subject of *Reimagining the Future of Interaction: Towards Human-Computer Partnerships*, with a focus on explainability and controllability of Machine Learning (ML) approaches.

This public speech in an Artificial Intelligence (AI) and ML friendly scenario helped AML to take the first steps into the Human-Computer Interaction (HCI) community.

¹<https://hybridintelligence.eu/>

²<https://www.humane-ai.eu/event/the-first-international-conference-on-hybrid-human-artificial-intelligence-hhai/>

3 Collaboration with ROS community

Collaboration with the ROS community was designed to introduce ROS developers to the innovative capabilities of AML, even though the project's strong research focus and the high entry barriers associated with AML have naturally limited widespread integration. The strategy to engage the ROS community was based on three main channels:

- ROS Discourse,
- the ROS 2 Technical Steering Committee (TSC),
- and the AI Integration Working Group.

Each channel played a role in sharing developments, gathering feedback, and promoting discussions around AML, outside of the context of its research-centric orientation.

3.1 ROS Discourse

ROS Discourse provided a dynamic forum where users could exchange use cases, news, and progress updates, rather than engaging in detailed technical troubleshooting. In this environment, eProsima maintained its presence by posting updates on the progress of AML-IP, the platform developed to facilitate AML integration. Although initial expectations envisioned a rapid uptake by ROS developers, the reality was that the complexity and advanced nature of AML, which is still primarily targeted at research applications, resulted in a more measured engagement from the community. Nonetheless, key tools such as the DDS Monitor for debugging and the DDS Router—the core components of AML-IP—have gradually attracted attention. Their design on the versatile Fast DDS framework allows these tools to address a wide range of tasks, which has slowly encouraged interest from ROS users.

3.2 ROS 2 Technical Steering Committee (TSC)

The ROS 2 Technical Steering Committee (TSC)³ is the organism comprising representatives of companies, organisations, and ROS 2 community in charge of setting the guidelines for the development of ROS 2. These organisations are committed to collaborating in the development of ROS 2, and have the responsibility to define the direction of the project.

Within the ROS 2 Technical Steering Committee (TSC), eProsima's active membership has been crucial. The TSC, which comprises representatives from leading organizations within the ROS ecosystem, sets the strategic direction for ROS 2 development. Leveraging its position, eProsima has been able to promote AML at dedicated TSC meetings, ensuring that its innovations and roadmap receive due consideration. This direct engagement has also provided first-hand feedback from experienced industry experts, thereby guiding the evolution of AML in line with broader ROS 2 objectives.

3.3 AI Integration Working Group

The AI Integration Working Group, initiated by eProsima, further exemplifies the effort to bridge AML and ROS. The working group was proposed to cultivate a community of ROS users interested in integrating advanced ML technologies into their systems. Its discussions and activities have focused on demonstrating how AML and AML-IP can serve as viable alternatives to traditional machine learning methods. Although the sophisticated research component of AML has naturally limited immediate adoption by

³<https://docs.ros.org/en/rolling/Governance/ROS2-TSC-Charter.html>

new developers, the group has served as an important forum for exchanging insights and showcasing the potential benefits of this emerging paradigm. Detailed agendas, public meeting sessions, and continuous updates have been made available via eProxima's ROS Discourse posts ⁴, allowing interested stakeholders to follow the progress of these initiatives.

Overall, while direct collaboration with the ROS community has been more limited than initially anticipated, this approach reflects the project's priority on advancing high-level research in AML. The inherent complexity of the technology and the significant expertise required for its adoption mean that, at present, AML remains primarily a research-oriented tool. This careful, research-driven integration strategy is essential to ensure that, when AML and AML-IP eventually reach broader application, they are both robust and mature enough to meet the demanding needs of real-world ROS environments.

For a comprehensive overview of the group's topics and interactions, please refer to Figure 1.

⁴<https://discourse.ros.org/t/ros-2-ai-integration-working-group>

ROS 2 AI Integration Working Group

■ Next Generation ROS ros2, ai, working-group, neural-networks



L.Moreno

2 Jun '22

Hi all!

eProsima is glad to announce a new ROS 2 AI Integration Working Group

We will focus on enabling Machine Learning technologies for ROS 2, applying Artificial Intelligence to use cases in the new Vulcanexus framework.

Among the topics that we will discuss:

- Let's talk about Alma & Sustain Machine Learning By Raul Sanchez-Mateos
- Serving models to ROS 2 robots, with Vulcanexus environment by Javier Paris

Meet us on Tuesday the 28th of June at 18:00 CEST at this [Google Meet room](#)!

Find the full detail in the [Agenda here](#)!

Hope to see many of you there



14 ❤️ 🔗

created last reply 35 3.7k 7 49 27
Jun '22 Jul 5 replies views users likes links

(a) AI Integration Working Group first post



L.Moreno

Apr 21

Hi everyone,

Next week, ROS 2 Artificial Intelligence Integration Working Group meeting is here!

The [April 25, 2023 6:00 PM](#) will be the 6th AI IWG meeting. Register [here](#)!

Join us for the talk "Introduction to AI in Robotics" by Juan Carlos Gonzalez from UC3M

This is the agenda:

- Title: Introduction to AI in Robotics
- 1. A taxonomy of AI
- 2. Machine Learning
- 3. Robotics: From Expert Rules to End-to-End Learning
- 4. Conclusions and Resources

The meeting will be held in the usual [Google Meet room](#)!

Find the full detail in the [Agenda here](#)!

I hope to see many of you there.



1 ❤️ 🔗

(b) AI Integration Working Group - meeting #6

8 days later



L.Moreno

Jul 5

Hi everyone! 🌟

Exciting news! The video recording of our ROS 2 Artificial Intelligence Integration Working Group meeting is now available to watch! 📺

During our last AI IWG session in June 2023, we had Raúl Sánchez, who delivered a captivating talk on "Building Intelligent Distributed Systems in ROS 2: Exploring AML-IP for Cloud Model Serving to Edge Robots."

Take advantage of this valuable resource!



We thank you for your participation and engagement as we approach the summer break. We'll take some time off to recharge and prepare for the upcoming months. But don't worry, we'll be back in full swing in September 2023, ready to dive into more exciting topics and collaborations! Stay tuned, and mark your calendars for September's next AI IWG meeting. We can't wait to continue this incredible journey with you all!

Wishing you a fantastic summer filled with joy and relaxation! 🌴🌞

1 ❤️ 🔗

(c) AI Integration Working Group - meeting #7

Figure 1: ROS Discourse posts

4 Internal collaborations

The ALMA project's success is built on robust internal collaboration between all consortium partners. This section details how each partner has contributed through their expertise and joint efforts, enabling the development and integration of Algebraic Machine Learning (AML) techniques. The collaborative activities not only span the development of fundamental theories and numerical tools but also include practical implementations, hardware acceleration, and the design of user interfaces that support AML deployment across various use cases.

4.1 Overview of collaborative approach

The consortium has established a dynamic collaborative environment where partners engage regularly through bi-weekly meetings, shared research activities, and joint publications. The core collaborative areas include:

- **Theoretical and Mathematical Foundations:** Working jointly to develop AML's underlying algebraic models and numerical tools.
- **Software Development and Prototyping:** Coordinated efforts in designing, testing, and refining prototype software and hardware accelerators.
- **Integration and Validation:** Collaborative work on AML-IP, AML Dashboards, and other tools that ensure AML's integration into systems such as ROS 2.
- **Dissemination and Joint Publications:** Producing joint deliverables, journal articles, and conference presentations that reflect the integrated work of multiple partners.

4.2 Partners contributions and value added

Throughout the ALMA project, a range of activities has been executed that together have driven the advancement of Algebraic Machine Learning (AML) from theoretical conception to practical deployment. Fundamental research into the mathematical underpinnings of AML was a cornerstone of the project, with partners like ALG establishing robust algebraic models and innovative algorithms that have defined the AML paradigm. This theoretical groundwork provided the necessary framework to explore novel methods such as model splitting, recombination techniques, and alternative approaches to interactive learning.

Building on these foundations, significant efforts were devoted to the development of software and hardware tools that make AML accessible and scalable. eProxima, for instance, engineered critical components including the DDS Router and DDS Monitor, which optimize data communication and enable real-time debugging across distributed systems. These tools have been key components in the implementation of the AML-IP platform—a communications framework that integrates AML nodes within environments such as ROS 2. The collaborative work on AML-IP, which also involved contributions from ALG and was further refined through practical testing by partners like INRIA, has ensured that the AML technology can be deployed in complex scenarios.

In parallel, advancements in prototype software have been pursued to lower the entry barriers for new users. INRIA developed user-friendly applications and interactive dashboards that streamline the training and application of AML models, thereby expanding AML's reach beyond expert mathematicians to a broader audience of developers and end users. DFKI contributed by creating prototypes that embed ethical and cultural dimensions into AML, ensuring that the models not only perform efficiently but also maintain transparency and human-centrism. Their work has been essential in demonstrating how AML can represent complex human concepts in a comprehensible manner.

The project also recognized the need for specialized hardware to fully exploit the potential of AML. TUK focused on designing a hardware accelerator that significantly improves computational performance and energy efficiency, providing tangible benefits that facilitate the scaling of AML applications. These advancements in hardware complement the software developments, creating an integrated ecosystem that supports both rapid prototyping and eventual commercialization.

Further enriching the project, VTT's contributions have brought a unique perspective by incorporating cultural and ethical considerations into AML. Their research on world models has added layers of interpretability to the AML framework, ensuring that the technology remains not only efficient but also aligned with societal values. Similarly, UC3M has played a key role in standardizing the evaluation of AML techniques by developing open-source testbed prototypes and environments, which have become essential for benchmarking and further refining the technology in the robotics and AI research communities.

Collectively, the ALMA consortium has established a multifaceted and collaborative environment where theoretical innovation, practical tool development, and rigorous testing converge. Each partner's contributions, from theoretical models and software tools to hardware acceleration and ethical frameworks, have been instrumental in transforming AML into a robust and user-friendly machine-learning paradigm, poised to redefine the landscape of AI applications.

4.3 Conclusion

The internal collaboration among the ALMA consortium members has been instrumental in driving forward the development, testing, and validation of Algebraic Machine Learning. Through coordinated efforts across multiple domains—including theory, software, hardware, and user interface design—the consortium has built a strong foundation for the future exploitation and widespread adoption of AML. This section serves as proof of the synergistic impact of cross-partner collaboration in achieving groundbreaking advances in machine-learning.