Workshops as Catalysts for the Standardization of Robotics Semantics

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Standardization in robotics semantics is increasingly recognized as a cornerstone for achieving interoperability, safety, and efficiency in autonomous systems. Unlike top-down approaches, robotics standards emerge through iterative dialog among diverse stakeholders, including industry practitioners, academic researchers, tool developers, and standards organizations. Scientific and technical workshops have served as key venues for building community alignment during the development of semantic standards for robotics. We provide a historical overview of workshops organized over the past decade, tracing their evolution from focused discussions on ontologies and knowledge representation to broader engagements addressing semantic maps, human–robot interaction, and their integration. Particular attention is given to the Joint Workshop on Ontologies, Semantic Maps and Autonomous Robotics Standardization (J-WOSMARS), held in 2025, which highlighted the pressing challenge of bridging perception-driven subsymbolic approaches with ontology-based symbolic knowledge representations. Lessons learned from these workshops underscore the importance of incremental, community-driven progress, in which standards serve as semantic anchors enabling interoperability across heterogeneous systems. Looking forward, we argue that continued workshop-based collaboration is essential to co-designing ontologies and semantic maps, aligning them with emerging technologies, such as foundation models, and ensuring that future robotic systems can seamlessly integrate perception, knowledge, and reasoning in scalable and ethically aligned ways.

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THE ROLE OF COMMUNITY ALIGNMENT IN ROBOTICS STANDARDS DEVELOPMENT

Open technical discussion is a foundational component of any successful standardization effort. In robotics, standards are rarely defined top down; instead, they emerge from continuous interaction among technology maturity, application requirements, and market interests. To be adopted and survive, standards are expected to address specific and real needs, avoiding excessive complexity. Hence, market uptake implicitly determines both the scope and the level of abstraction of a standard, influencing decisions regarding its main qualities (e.g., tradeoffs between flexibility and practicability or granularity and expressiveness). As a result, continuous technical dialog is essential to ensure that proposed standards remain aligned with real-world system constraints.

In this regard, it is crucial to ensure effective communication among all of the stakeholders involved in a standardization process, including industrial developers, academic researchers, tool providers, and standards organizations. Note that each group possesses different backgrounds and expertise, bringing to the table distinct perspectives and priorities. For instance, industrial experts tend to emphasize robustness, scalability, and cost-effectiveness, while academic fellows often focus on expressiveness, generality, and theoretical soundness. Without proper structured interaction, these different perspectives may lead to fragmented solutions and useless standards. This is a challenge that is more evident when standardizing the semantics of a domain and even more so if it is one as dynamic as the robotics domain. Note that shared concepts, definitions, and meanings must accurately reflect the collective understanding of the community to ensure long-term usability and acceptance. In this context, scientific and technical workshops may serve as an essential coordination mechanism, providing a focused environment in which assumptions can be challenged, requirements articulated, and design choices evaluated collectively.

BACKGROUND ON ONTOLOGIES, SEMANTIC MAPS, AND STANDARDIZATION EFFORTS

The rapid growth of applications involving close *interaction* and *communication* between robots and humans, across both research and industrial environments, has introduced new technical, legal, and ethical challenges. Indeed, well-established robotics standards typically target two complementary objectives: safety and efficiency. From a safety perspective, standardized representations and interfaces support certification, regulatory compliance, and predictable system behavior, particularly in safety-critical autonomous applications. From an efficiency standpoint, standards reduce engineering effort by enabling interoperability, reuse, and

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modular system design, thereby improving productivity across the development lifecycle.

In the context of standardizing the semantics of the robotics domain, these benefits are especially obvious since sound semantic representations enable reliable knowledge exchange, reasoning, and coordination among heterogeneous robotic components and platforms. Hence, standardized ontological formalisms and semantic map representations have emerged as foundational enablers for a future in which robots can reliably collaborate with, assist, and coexist alongside humans. Related to interaction, it is essential to create semantic maps that incorporate contextual and meaningful environmental information. Regarding communication, a vocabulary with clear and concise definitions (e.g., ontologies) is a sine qua non to enable information exchange (e.g., semantic map sharing, beliefs, plans, etc.) among heterogeneous groups of agents, including human and nonhuman actors (e.g., autonomous robots) [1]. In this regard, the development of standardized semantic maps and ontologies is expected to significantly facilitate robot certification processes and contribute to safe and ethically aligned system design.

Within the IEEE Standards Association, several past and ongoing initiatives directly address these challenges. IEEE 1872-2015 Standard Ontologies for Robotics and Automation established foundational concepts for structured knowledge representation in robotics [2]. More recently, the IEEE P1872 series has focused on ontology-based approaches for autonomous robotics, including the published IEEE 1872.2-2021 Standard for Autonomous Robotics (AuR) Ontology [3] and the ongoing IEEE P1872.3 Standard for Ontology Reasoning on Multiple Robots, both of which aim to support interoperable reasoning and coordination among autonomous systems, e.g., multiple robots. Those standards address topics such as 1) representation, reasoning, and behaviors for autonomy, 2) multiple autonomous robots and cloud robotics, 3) artificial intelligence and machine learning for autonomous robots, 4) affordances in human–robot interaction, and 5) trust and security for autonomous robotics. The same series has also addressed the ontology-based representation of robotic tasks, as specified in the IEEE 1872.1-2024 Standard for Robot Task Representation [4]. Currently, within the active project 1872.1.1, the working group is developing a guide for practical implementations of the standard. Complementing these efforts, the IEEE P3140 Working Group addresses semantic maps explicitly, with IEEE P3140.1 Standard for Semantic Maps for Autonomous Robots—Part 1: Use Cases and Requirements and IEEE P3140.2 Semantic Maps for Autonomous Robots—Part 2: Framework and Application Development Interface. Together, these standards reflect a growing recognition of the need for coherent, layered semantic frameworks and highlight the importance of coordinated community efforts to ensure their technical soundness and practical relevance.

BUILDING COMMUNITIES FOR ROBOTICS SEMANTICS STANDARDS DEVELOPMENT

Over more than a decade, members of several IEEE working groups have actively contributed to build and sustain communities around robotics standardization, with the explicit goal of enabling iterative feedback and long-term consensus building. Rather than treating standards development as a purely technical exercise, these efforts have recognized the importance of continuous interaction among stakeholders to ensure that emerging standards reflect both technological advances and real-world needs.

In recent years, this community-building strategy has been reinforced through a series of workshops organized at major IEEE Robotics and Automation (R&A) conferences. These workshops were explicitly designed to raise awareness of standardization activities, lower the barrier to participation, and provide an open forum for discussing challenges and opportunities in robotics semantics. Importantly, the focus of these workshops has evolved over time, adapting to the maturity of the field and to the needs identified during ongoing standardization efforts. Early workshops concentrated on well-defined topics, such as knowledge representation and ontologies, while later editions progressively broadened their scope to include semantic map generation and human–robot interaction studies. This evolution reflects the realization that effective standardization of robotics semantics cannot be addressed in isolation but requires input from multiple complementary research and application domains.

This trajectory can be illustrated through a sequence of workshops spanning more than 10 years, gathering approximately 400 people. The 2014 IEEE International Conference on Intelligent Robots and Systems (IROS) workshop "Standardized Knowledge Representation and Ontologies for Robotics and Automation" in Chicago, IL, USA, marked one of the earliest large-scale community gatherings on this topic, attracting approximately 60 participants. Subsequent events, such as the 2017 IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN) "Autonomous Robot Ontology Workshop" in Lisbon (20 attendees), fostered more focused technical discussions. The launch of the "Collaboratively Working Towards Ontology-Based Standards for Robotics and Automation (WOSRA)" workshop series at IEEE IROS 2018 in Madrid (70 attendees) represented a significant step toward explicitly aligning research outcomes with standardization goals. Indeed, some of the conversations that started at the workshop led to consequently more comprehensive online discussions and work, resulting in the publication of scientific articles that classify and analyze the state of the art on ontologies for autonomous robotics [5] and for Industry 4.0 [6]. Those publications became instrumental in selecting the scope of the standard IEEE 1872.2-2021. The second and third editions of WOSRA, held at the 2023 IEEE International Conference on Robotics & Automation (ICRA) in London (70 attendees) and IEEE ICRA 2024 in Yokohama (75 attendees), respectively, further consolidated the community and expanded participation across continents. Finally, the J-WOSMARS at

IEEE RO-MAN 2025 in Eindhoven, The Netherlands (40 attendees) reflected the increasing emphasis on integrating ontologies with semantic mapping and broader autonomy concerns. In parallel, a complementary initiative, the "Ontologies for Autonomous Robots Workshop series," was organized with the aim of discussing similar aspects from a foundational ontological perspective. Figure 1 provides an overview of the main organized workshops, illustrating the progressive evolution from focused discussions on knowledge representation toward broader, community-driven efforts addressing ontologies, semantic maps, and autonomous robotics standardization.

Across these events, workshops have proven to be an effective mechanism for connecting industry practitioners and academic researchers, enabling discussions on the current state of the art as well as on future research and standardization road maps. Their diversity, in terms of both participant backgrounds and technical perspectives, has been a key factor in their productivity. Beyond the events themselves, workshops have also served as entry points for growing working groups, with participants often continuing their engagement through follow-up meetings and formal standardization activities. In this way, workshops have not only facilitated technical exchange but have also played a central role in shaping shared visions, defining the current landscape, and outlining future directions for standards in robotics semantics.

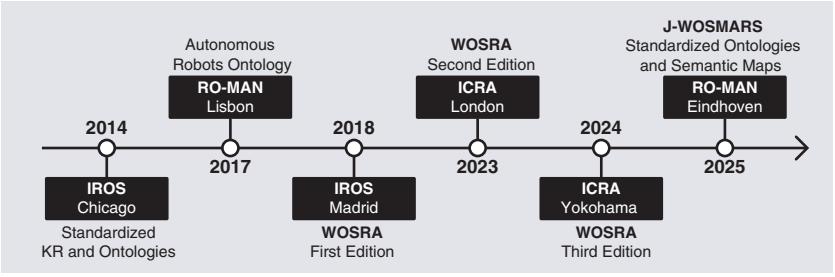

FIGURE 1. Timeline of a decade of efforts to systematically build communities for robotics semantics standards development. KR: knowledge representation.

FIGURE 2. Some of the attendees of the panel session at J-WOSMARS, held in Eindhoven, The Netherlands, in 2025 during the RO-MAN conference.

BRIDGING PERCEPTION AND KNOWLEDGE: INSIGHTS AND FUTURE DIRECTIONS

Our latest workshop, the first edition of J-WOSMARS, held at RO-MAN, August 2025, in Eindhoven (the Eindhoven University of Technology), brought together researchers and practitioners working on ontologies, semantic maps, and robotics standardization. The workshop was significantly insightful, probably because of its heterogeneity. It included a total of nine research talks by invited speakers plus some spotlight talks from submitted articles and IEEE standards working group chairs. The invited talks highlighted both the practical demands (e.g., real-world deployments and user-centric interfaces) and the methodological advances (e.g., context-aware planning, hybrid intelligence, and the "high-pain, high-gain" reality of standardizing environment data). Spotlight contributions reinforced this direction through work on semantic interoperability via task/action/environment modeling, ontology-based ethical reasoning in care settings, and the need for a backbone ontology for multirobot collaboration.

Overall, the workshop highlighted the need for co-designed semantic maps and ontologies, with environment representations tightly coupled to task/action models to support autonomy. It also emphasized that human-centered autonomy often depends on explicit, structured knowledge to encode personalization, adaptation, and ethical constraints that extend beyond purely data-driven methods. In addition, there was broad agreement that progress in standardization should be incremental, beginning with a well-scoped core and expanding via modular extensions for domains, uncertainty, provenance, and interaction context.

During the final panel discussion, "Ontologies and Semantic Maps Standards for R&A" (see Figure 2), a common message emerged: interoperability is no longer optional. Panelists and audience highlighted that one of the central challenges in autonomous robotics remains the effective integration of robot perception and robot knowledge. In practical terms, this challenge

manifests in the need to bridge semantic mapping, largely driven by subsymbolic perception methods, such as deep learning, with ontology-based knowledge representations, which are inherently symbolic. This issue reflects a broader, long-standing challenge in artificial intelligence: reconciling data-driven, subsymbolic approaches that excel at perception with symbolic methods that support abstraction, reasoning, and explainability. While perception systems have reached remarkable levels of performance, their outputs often lack explicit semantic structure, whereas ontologies provide rich semantics but depend on reliable grounding in perceptual data.

Participants emphasized the critical role that standards can play in addressing this gap. Standardized representations, interfaces, and workflows are needed to ensure that the population of robot knowledge bases from perceptual inputs—and, conversely, the use of knowledge to guide perception—is possible in a reusable, interoperable, and harmonized manner. Without such standards, integration efforts risk becoming ad hoc, tightly coupled to specific platforms, and difficult to scale or certify. In this sense, standards do not prescribe specific algorithms but rather define common semantic anchors that enable diverse approaches to interoperate across systems, domains, and development communities.

The discussion also explored the emerging role of foundation models in this landscape. Foundation models were discussed as horizontal enablers, analogous in spirit to foundational ontologies, offering flexible and general-purpose capabilities that can be adapted to a wide range of domain-specific (vertical) tasks and knowledge structures. When appropriately aligned with standardized ontologies and semantic maps, foundation models have the potential to facilitate knowledge base population, semantic annotation, and cross-domain generalization. However, their effective use in robotics depends on clear semantic interfaces and shared conceptual frameworks, reinforcing the need for continued standardization efforts.

A final key insight from the discussions was that the integration of perception and knowledge must be fundamentally bidirectional. Perception is shaped by existing knowledge and semantics, just as semantic representations are constrained and grounded by what can be perceived. Ontologies influence how sensory data are interpreted and categorized, while perceptual capabilities limit the semantics that can be meaningfully instantiated. When properly aligned, these two layers mutually enrich one another, leading to more robust, explainable, and adaptable robotic behavior. Bridging these two layers is critical to achieving consistent reasoning, interoperability, and reuse across robotic platforms and application domains. Looking forward, the community identified the need for continued dialog, experimentation, and standards development to support this coevolution, ensuring that future robotic systems can seamlessly combine perception, knowledge, and reasoning in a principled and scalable way.

CONCLUSION

Standardizing robotics semantics is not only a technical challenge; it is also a fundamentally community-driven process that relies on sustained dialog, shared understanding, and incremental consensus building. Over more than a decade, workshops have proven to be an effective mechanism for aligning diverse stakeholders, evolving the scope of discussion in response to technological maturity and translating research insights into concrete IEEE standardization efforts. The experience accumulated through initiatives such as WOSRA and, more recently, J-WOSMARS demonstrates that meaningful progress emerges when ontologies, semantic maps, and autonomy are addressed jointly rather than in isolation.

Looking ahead, the integration of symbolic and subsymbolic approaches, linking perception, knowledge, and reasoning, will remain a defining challenge for autonomous robotics. Standards can play a crucial role in this integration by providing stable semantic anchors that enable interoperability, reuse, certification, and ethical system design while remaining flexible enough to accommodate emerging technologies, such as foundation models. Continued workshop-based collaboration will be essential to refine these standards, expand them through modular extensions, and ensure that they reflect the evolving needs of both industry and academia. Finally, fostering shared semantics through open, inclusive community processes is key to enabling scalable, trustworthy, and human-centered robotic systems.

In this spirit, we invite readers to join our community at the second edition of the Joint Workshop on Ontologies, Semantic Maps and Autonomous Robotics Standardization (J-WOSMARS), to be held in June 2026 during ICRA in Vienna. Further details about the workshop program and participation can be found on the workshop website: https://wosra.github.io/j-wosmars/.

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