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Research Article

Robots Communicate at the Speed of Light: Revolutionary Milestones in the Development of Human Speech

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Abstract

This first lecture by Tibor Mező explores key revolutionary milestones in the evolution of human speech. Beginning with the initial emergence of simple vocalizations among early hominins, the discussion highlights the gradual development of complex linguistic structures and symbolic communication. Significant anatomical changes, such as the lowered larynx position, supported the diversification of speech sounds (phonemes), facilitating the formation of structured language systems with grammar and syntax. The lecture emphasizes the critical role social cooperation played in speech evolution, suggesting that communities with enhanced communication skills had adaptive advantages. It further discusses the relationship between language and cognitive development, illustrating how symbolic language transformed human thought and social structures by enabling abstract idea transmission and cultural accumulation. The transition from oral to written communication marked another revolutionary milestone, profoundly impacting knowledge preservation, dissemination, and civilization's evolution. The invention of writing approximately 5,000 years ago allowed information to surpass the limits of human memory, establishing new modes of collective knowledge storage and analysis. Despite the rise of literacy, oral traditions persisted, continuing to serve as essential vehicles for cultural cohesion and social interaction. Mező's lecture portrays the evolution of speech as a continuous, complex interplay between biological adaptation, cognitive development, social dynamics, and technological innovations. This second lecture by Tibor Mező explores the revolutionary development and implications of robot-to-robot communication. Beginning with historical machine-to-machine (M2M) interactions, such as telemetry and early GSM-based modules, the talk highlights the significant transition brought by the Internet of Things (IoT), where devices began autonomously exchanging information. Technical aspects are discussed, emphasizing foundational network protocols like TCP/IP and UDP, alongside specialized communication frameworks such as Robot Operating System (ROS) and Agent Communication Languages (ACL) like KQML and FIPA ACL. Recent advances illustrate how robots autonomously evolve their unique languages through machine learning, optimizing communication beyond human comprehension. The lecture addresses social impacts, showcasing benefits such as industrial efficiency, increased safety, and convenience in everyday life. However, it also acknowledges emerging challenges, including transparency, trust issues, and ethical dilemmas, particularly concerning oversight and security. Finally, Tibor Mező highlights current practical applications of robot-to-robot communication across industries, from autonomous vehicles and smart cities to warehouse logistics and swarm robotics. The lecture concludes by exploring future opportunities, including the convergence of human and machine languages, and underscores the necessity of managing the ethical and societal implications of this rapidly evolving technological landscape.

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1. Introduction

In this research article, I present an extensive examination of revolutionary milestones in both human speech evolution and the emerging field of robot-to-robot communication. Initially focusing on human linguistic development, I detail the gradual emergence of spoken language from early vocalizations and gestures among hominins, highlighting critical anatomical adaptations such as the lowering of the larynx and the development of sophisticated phonemic systems. My discussion then progresses to symbolic communication and structured grammatical systems, emphasizing the pivotal roles these played in cognitive development, cultural transmission, and societal complexity.

The second part of my article explores the technological and societal implications of robot-to-robot communication, tracing its historical origins from basic telemetry systems to the modern Internet of Things (IoT) era. I address both the technical frameworks—such as ROS and Agent Communication Languages—and the autonomous evolution of robotic languages enabled by advances in artificial intelligence and machine learning. Furthermore, I discuss the broader societal impacts, including significant benefits like increased industrial efficiency and improved safety, while acknowledging ethical challenges related to transparency, security, and human oversight.

Ultimately, my comprehensive analysis connects these two distinct yet analogous domains, highlighting language—whether human or robotic—as a transformative force that continues to shape the trajectory of cognitive and technological evolution.

2. Key Milestones in the Evolution of Human Speech

2.1. Emergence of Vocalization

The Origin and Development of Language.
Example: "Aaah!" (expression of pain or danger)

2.1.1. Ancient Vocal Signals (Expressing Emotions and Danger)

The precise process behind the evolution of human speech remains shrouded in mystery; however, scientific consensus suggests a gradual evolutionary path toward the modern language we use today. Initially, our ancestors likely employed simple vocalizations and body signals for communication, similar to present-day primates [1].

Opinions vary regarding the timing of language emergence. Some theories propose that early Homo species (such as *Homo habilis*, approximately 2 million years ago) might have already possessed rudimentary, proto-linguistic systems.

Other researchers suggest symbolic communication emerged later, perhaps during the era of *Homo erectus* (1.5–2 million years ago) or during the time of *Homo heidelbergensis* (600,000 years ago).

Fully modern language—characterized by complex grammar and the ability to express abstract concepts—likely arose with our species, *Homo sapiens*, around 200,000 to 100,000 years ago.

Based on linguistic diversity analyses, for example, Johanna Nichols concludes that human languages began diverging significantly at least 100,000 years ago, implying that by this time spoken language had become widespread in our species [2].

This development likely occurred in Africa, the cradle of modern humanity, during the Middle Stone Age.

It is crucial to emphasize that speech evolution was not a singular revolutionary leap, but rather a succession of incremental steps. Emotional vocal signals (e.g., cries expressing pain or joy) were probably already present among our ancestors, as were rhythmic vocalizations linked to group activities (such as coordinated shouts during collective labor—illustrated by the old "yo-he-ho" theory).

2.1.2. The Beginnings of Social Communication (Group Cooperation)

However, the emergence of true language required the capacity to link meaning with sounds and recognize that vocal signals could serve as arbitrary symbols representing any concept. Social cooperation likely played a critical role in this development, as communities capable of more effective communication gained advantages in securing resources and avoiding threats.

2.2. Differentiation of Speech Sounds

The Development of Linguistic Structures

Example: The sounds "ma" and "pa" begin to carry distinct meanings.

2.2.1. Anatomical Changes (e.g., Position of the Larynx)

Many researchers believe that complex spoken language evolved from gestures—initially through hand-signals used to convey information, later supplemented by vocalizations. Anthropological studies support this hypothesis: communication experiments with primates indicate that gestures and body language may have been essential precursors to spoken language.

The physiological foundations of human speech gradually evolved as well. Anatomical evidence shows that the human larynx (the location of vocal cords) descended lower into the throat over the course of evolution, creating a two-chamber vocal tract that allowed for the production of a much broader range of sounds [3].

The cost of this anatomical shift was the loss of simultaneous swallowing and breathing capabilities—raising the risk of choking. However, the evolutionary advantage provided by improved speech capabilities outweighed this risk.

Brain size and structure also expanded significantly throughout hominin evolution, particularly in areas of the frontal and temporal lobes, enabling more sophisticated sound production and symbolic processing. At a genetic level, certain mutations (notably in the FOXP2 gene) enhanced the motor control required for speech production and grammatical processing [4].

2.2.2. Formation of Phonemes (Meaning-Distinguishing Sounds)

After the foundations of human speech were established, the internal linguistic structures gradually became increasingly complex. Phonemes—the smallest units of sound that differentiate meaning—emerged slowly. It is believed that early human languages had a limited set of phonemes, but as vocabulary expanded and more concepts required distinct sounds, phonemic diversity increased [5].

Some research suggests a close correlation between phonemic diversity and the size of a community's vocabulary and cultural complexity. As social structures, material culture, and environmental knowledge became richer, languages required more sounds and words to express new concepts.

Today, phoneme inventories vary greatly (ranging from about 11 sounds in some languages to over 100 in others), but the average number is approximately 30 phonemes. Prehistoric languages likely had phoneme inventories of a similar magnitude, indicating that by the Upper Paleolithic period, the complexity of sound systems may have already approached that of modern languages [6].

2.3. Symbolic Communication

The Emergence of Words

Example: Using the word "Fire!" as an alert signal for danger.

2.3.1. Understanding Symbols and Associating Meanings with Sounds

The formation of words was also a gradual process. Initially, ancient languages likely consisted of single-word messages or loose sequences of words referring directly to objects, people, or actions. Over time, the necessity for clear communication within communities refined meanings. By repeatedly associating the same sounds with consistent meanings, stable words began to emerge.

2.3.2. The Capacity for Abstraction (Generalization from Objects and Events)

As vocabulary expanded, phonotactic rules simultaneously developed. Speech sounds could not simply be pronounced in any arbitrary order; certain combinations were easier to articulate and comprehend, while others posed difficulties for human vocal anatomy.

These constraints—shaped partly by anatomical features and partly by auditory perception—established universal patterns across languages, influencing which sounds can appear together and how syllables are structured.

2.4. Formation of Structured, Grammatical Systems

The Relationship Between Language and Thought

Example: The order of words increasingly mattered to ensure clarity.

2.4.1. Emergence of Words and Syllables

Grammar emerged gradually from simple sequences of words. The appearance of grammatical structures marked a revolutionary advancement, enabling humans to convey complex thoughts rather than merely isolated pieces of information.

2.4.2. Emergence of Sentence Structure (Syntax)

Initially, the rules governing word combinations may have been highly flexible, but certain frequently used patterns became fixed. For example, word order became increasingly critical to ensure clarity. The specific word order differed across communities, becoming a cultural convention, but every society developed some systematic ordering.

Additionally, repeated combinations of words led to the emergence of the first affixes and endings—grammatical elements no longer functioning independently but attached to words to indicate grammatical relationships (such as verb conjugation, plural forms, and possession). With the growth of social complexity and communication demands, structures emerged to clearly express who did what, when, and how.

An intriguing linguistic phenomenon supports this idea: studies show that when children learn simplified languages (such as pidgins spoken by their parents), they spontaneously transform them into fully grammatical languages (creoles) within a single generation. Children thus utilize innate linguistic capabilities to create structured grammars where none previously existed. This process may parallel what occurred at the dawn of human language—simple communication gradually evolved into systematic languages through collective usage [7, 8].

Overall, the linguistic evolutionary sequence began with the enrichment of phonological systems (phoneme diversification), followed by rapid vocabulary expansion, and finally, the establishment of grammar rules and categories. This allowed human language to achieve near-limitless expressive potential.

2.4.3. Relationship Between Language and Thought

The evolution of language is closely tied to the development of human cognitive abilities. For early humans to create and use language, certain intellectual and social capacities were essential, such as joint attention (focusing collectively on a shared object or event), cooperation, and theory of mind—the ability to imagine what others know or think. Studies show that social cognition skills are fundamental for language development, as children require social cognitive skills, like understanding others' intentions and mental states (mentalizing or Theory of Mind), to acquire language successfully. Thus, cognitive evolutionary advances (e.g., cooperation, social understanding) created the cognitive foundation for language emergence [9].

However, once language arose, it profoundly transformed human thought. Language enabled the expression, preservation, and transmission of abstract ideas—concepts that might not even have arisen without linguistic structures. Human language is unique because it allows arbitrary associations between sounds and meanings, granting humans the ability to communicate virtually any imaginable thought.

This symbolic flexibility significantly impacted cognitive development, allowing knowledge to accumulate across generations, creating culture, science, and complex societal structures. For instance, language facilitated the communication of detailed social norms, myths, and technological information, even to strangers or across generations.

According to linguistic relativism (Sapir–Whorf hypothesis), language categories and vocabulary can influence perception and understanding of the world. For example, concepts distinguished by multiple words in one language might be covered by a single term in another, shaping how speakers mentally categorize those concepts. Languages segment reality differently: some languages have separate words for "hand" and "arm," while others combine them into one; similarly, distinctions between types of hair or fur vary between languages [10].

Such linguistic distinctions influence cognition, making speakers more attentive to subtle distinctions reflected in their language. Nevertheless, foundational cognitive capabilities (e.g., logic and basic mathematical thinking) appear universal and biologically based. Thus, language serves primarily as a tool for shaping, refining, and expressing thought rather than defining it entirely.

Today, cognitive science views language and thought as evolving together, mutually reinforcing each other. Social and cultural aspects of human intelligence encouraged language development, while language, in turn, facilitated further cognitive advancement, forming an evolutionary feedback loop.

2.5. The Structuring of Oral Communication

Dominance and Cultural Role of Oral Communication

Example: "Once upon a time, there was a great hunter who defeated a lion."

2.5.1. Storytelling and the Emergence of Myths

Homer (depicted in imagination with a lyre) sang and narrated stories to his audience. Heroic epics and tales transmitted orally exemplify ancient storytelling traditions before the advent of writing.

2.5.2. Collective Memory and the Birth of Folklore

Before writing was invented, humanity preserved and shared all its knowledge and stories orally. Oral tradition was the earliest and, for a long period, primary method of communication, crucial for community cohesion and survival [11].

Orality involves far more than simple speech: it's a dynamic and versatile communication method encompassing storytelling, songs, myths, rituals, and all forms of knowledge, art, and ideas preserved and passed down through generations solely by memory.

For thousands of years, oral communication remained dominant. Interestingly, even today, spoken language continues to dominate everyday communication, reinforced by modern technologies (radio, television, digital media) that heavily rely on spoken words.

Oral cultures preceding literacy were remarkably rich. In tribal communities, stories, legends, genealogies, and laws existed orally, often maintained by specialized memory keepers. Poets, bards, storytellers, or shamans preserved the community's history and knowledge. For instance, the famous Greek epics (*The Iliad*, *The Odyssey*) began as oral poetry, memorized and recited by generations of rhapsodes before eventually being transcribed. Human memory capacity was impressively utilized: rhyme, rhythm, repetition, and formulas aided memorization and accurate transmission, ensuring that a community's past, values, and wisdom survived even without physical (written) records.

Storytelling (narration) was central to oral culture. Communities spent evenings recounting stories that entertained, educated, and reinforced shared identity. Myths and stories linked past, present, and future, strengthening tribal or familial bonds. They often conveyed moral lessons, instructing younger generations in societal norms. Oral creation myths and legends frequently represented sacred knowledge, recited only on special occasions and in traditional formats. Thus, spoken language was not merely about information sharing; it was an act of cultural expression and social cohesion.

Oral culture also provided the foundation for social cooperation. Evolutionary anthropologist Robin Dunbar famously proposed that one primary function of human language was "gossip" or maintaining social bonds. Monkeys reinforce social cohesion through grooming; however, as human groups grew larger, this method became inefficient. According to Dunbar, spoken language evolved as a form of "social grooming," allowing individuals to interact simultaneously with multiple group members, building trust and maintaining alliances by sharing information about absent individuals [12].

Gossip—sharing information about absent individuals—became a vital mechanism for building trust and maintaining alliances. Language thus enabled cooperation in larger social groups by continually mapping social relationships (e.g., identifying trustworthy individuals, rule-breakers, alliances). Therefore, from its earliest days, language had a crucial social role: facilitating collective knowledge sharing (e.g., "Where is food?" or "Where is danger?").

Interestingly, the quantitative dominance of spoken language over written communication remains true today. In many societies, primary knowledge transmission is still oral, especially among significant portions of the world's population not yet fully integrated into literacy-based societies. Spoken language retains qualities that writing alone struggles to convey—such as emotional nuance, immediacy, and connection. Personal storytelling retains its unique appeal: charismatic speakers or family elders telling bedtime stories illustrate the continuing power of oral traditions.

2.6. The Emergence of Literacy—Recording Oral Communication

The Appearance of Writing and its Impact on Oral Culture Example: "King Gilgamesh built a city in Uruk."

2.6.1. Pictographic and Phonetic Writing

The invention of writing marked the next revolutionary milestone in the history of human communication. Approximately 5,000 years ago, the first genuine writing systems appeared. According to archaeological evidence, writing emerged independently in various parts of the world. In Mesopotamia, around 3400–3300 BCE, the Sumerian civilization developed cuneiform, named after its wedge-shaped characters pressed into clay tablets. Around the same time, hieroglyphic inscriptions appeared in Egypt (circa 3200 BCE), although the exact origins remain debated—likely developing independently within Nile Valley culture rather than influenced by Mesopotamia.

Later, independent writing systems arose in China during the Shang dynasty (second millennium BCE) and in Mesoamerica with the Maya and Aztec civilizations. Initially, these proto-writing systems used simple symbols, pictograms, and numeric markings to record specific information, such as taxes, harvest quantities, or calendar data. However, these symbols did not directly represent spoken language.

True literacy emerged once writing symbols began representing linguistic elements—sounds, syllables, or words—allowing spoken language to be permanently captured in both time and space.

2.6.2. Birth of Written Culture and Permanent Knowledge Storage

The advent of writing dramatically impacted oral culture and the transmission of knowledge. Writing provided a new medium for information, freeing knowledge storage from human memory alone and allowing information to be preserved on external media such as clay tablets, engraved stone, or papyrus. Knowledge thus became more durable, capable of crossing greater distances and time. It became possible to send messages to absent individuals or preserve them for future generations. This greatly accelerated knowledge accumulation within cultures, enabling written texts to be compared, referenced, and critically analyzed, transforming knowledge into collective property rather than isolated fragments of memory [13].

Writing allowed knowledge to be shared across wider geographic and temporal scales, laying foundations for the rise of major civilizations. For centuries, oral and written traditions coexisted, eventually dividing their roles. In ancient societies, literacy was initially restricted to a privileged few—scribes and scholars—who became custodians of knowledge, documenting historical events, laws, and religious texts, thereby canonizing them. In Egypt, writing significantly influenced politics and religion; administrative control relied heavily on written records [14].

In India, the Brahmin caste preserved ancient oral traditions by systematically writing down the previously oral Vedas and other knowledge, which became the foundation of formal education. In the 4th century BCE, the linguist Panini documented Sanskrit grammar, permanently recording knowledge that had previously existed solely through oral tradition.

Similar processes occurred across cultures, exemplified by the canonization of religious texts such as the Bible or the Quran, capturing a community's collective wisdom in writing. With written records, religious and secular knowledge became widely referenced authorities, leading to the establishment of institutions (schools, libraries) dedicated to preserving and interpreting texts.

Written culture did not replace oral traditions but significantly altered their roles. Certain genres, such as laws, contracts, and official records, became dominated by writing due to its reliability as a reference. Nonetheless, everyday information exchange, much of literature, and educational processes remained predominantly oral for centuries. It took considerable time before written literature (books) truly became widespread. Early literary works like the Epic of Gilgamesh, originally oral narratives from the second millennium BCE, were eventually recorded onto clay tablets.

Through writing, dynamic oral traditions became fixed in standardized forms, preserved for posterity. Stories thus became canonized: orally, each telling allowed variations, whereas written texts were static, changing the relationship between author and audience fundamentally.

Overall, the emergence of writing opened unprecedented opportunities for knowledge dissemination, enabling the development of complex systems of knowledge—science, philosophy—by allowing information to be systematically stored, analyzed, and critiqued [15, 16].

Through literacy, humanity's collective memory multiplied exponentially. Yet oral traditions persisted, and together, oral and written culture shaped civilizations: writing primarily organized states, empires, and sophisticated cultures (literature, science), while oral traditions remained foundational for living culture, communal identity, and everyday life.

3. The Dawn of the "Robot-to-Robot" Communication Era

3.1. Historical Development

Machine-to-Machine Communication

Example: "An automated thermometer transmits temperature data to a central computer."

3.1.1. Early Forms of Machine Communication: Telemetry and Machine-to-Machine (M2M) Communication

The origins of machine-to-machine communication date back to the early 20th century, when signals and remote sensing (telemetry) were already utilized in industrial automation. A notable early example occurred in the early 1970s, when Theodore Paraskevakos developed and patented a system in 1973, enabling one device to automatically transmit a caller's identity to another—laying the groundwork for today's Caller ID technology and demonstrating direct machine-to-machine data exchange.

By the 1990s, the concept of machine-to-machine (M2M) communication evolved significantly, marking the transition to autonomous data exchanges between devices rather than just human-to-machine interactions. In 1995, Siemens introduced the first GSM-based M2M module (known as M1), enabling machines to communicate autonomously via mobile networks.

3.1.2. Rise of the Internet of Things (IoT) and Autonomous Machine Communication

By the 2000s, the rapid expansion of the Internet of Things (IoT) heralded a new communication era. Sensors, vehicles, and robots began autonomously exchanging information, vastly expanding the potential and applications of automated communication. Events like the RoboCup competitions since the late 1990s have explicitly focused on researching cooperation and communication among multiple autonomous robots.

The explosive growth of IoT from the early 21st century marked the true beginning of the "robot-to-robot" linguistic era. Modern machines, equipped with advanced sensors, vehicle automation capabilities, robotics, embedded GPS, mobile connectivity, and sophisticated software (e.g., Robot Operating System, ROS), can now autonomously share information, coordinate actions, and collectively make decisions—initiating conversations and interactions independent of human intervention. This transition represents a profound technological—and linguistic—revolution, introducing completely new forms of communication not always understandable or even accessible to human cognition.

3.2. Technological Aspects

Technical Foundations of Robot-to-Robot Communication

Example: "GET /sensor-data HTTP/1.1" (using the HTTP protocol)

3.2.1. Standard Network Protocols (TCP/IP, UDP)

The technological foundations of machine-to-machine (M2M) communication have steadily evolved. Initially, machines relied on simple signals or wired connections, such as instructions transmitted via serial ports or specialized industrial buses. Today, most robots utilize standard network protocols: for instance, TCP/IP, the backbone of the internet, facilitates autonomous, reliable data exchange with minimal central management, automatically restoring connectivity in case of network failures.

The UDP protocol is also widely used, particularly in tasks requiring high speed and real-time communication, such as streaming video or transmitting live sensor data, even though it accepts potential data loss as a trade-off.

3.2.2. Robot Operating System (ROS), Autonomous Agents (KQML, FIPA ACL)

Communication systems became increasingly complex, resulting in specialized frameworks like the Robot Operating System (ROS). ROS provides a standardized, message-based architecture enabling diverse robots and sensors to communicate in a shared "language." With ROS's modular structure, robots exchange data and services through standardized interfaces and message formats, simplifying collaboration among heterogeneous robots and making systems more scalable. In these frameworks, robots exchange not only raw data (e.g., sensor measurements) but also complex state information, maps, and even task-specific instructions.

At higher levels, specific protocols and algorithms emerged to support dialogues between autonomous agents. Agent Communication Languages (ACL) provide structured formats for complex exchanges. For example, KQML and its successor, FIPA ACL, both use Lisp-like syntax and formal semantics to ensure clarity in information exchanges among software agents (or robots).

FIPA standards define specific communicative acts—such as inform, request, query, and propose—with precisely defined meanings and conditions, enabling robots to engage in sophisticated dialogues, negotiations, and collaborative planning, while maintaining logical consistency throughout interactions.

Initially, such protocols were manually designed, but the rise of artificial intelligence has made communication increasingly adaptive. Modern multi-agent algorithms allow robots themselves to develop methods of communication. Research in reinforcement learning demonstrates that cooperating AI agents can autonomously learn shared communication protocols to efficiently solve complex tasks.

Thus, machine communication has transitioned from simple, one-way instructions to advanced, self-organizing dialogues among autonomous robots.

3.3. Linguistic Characteristics

Emergent "Languages" among Robots

Example: AI chatbots spontaneously developed cryptic shorthand ("you you me me me") understood only by themselves.

3.3.1. Structured, Minimalist Data Communication (JSON, MQTT)

Emergent robot "languages" differ significantly from human languages but exhibit clear internal structures and rules. Initially, robots communicated primarily through structured data exchanges, utilizing clearly defined syntax and semantics—for example, protocols like JSON or MQTT, or logical frameworks like FIPA ACL. Early robotic languages, built on predefined rules, were goal-oriented and primarily focused on precise, unambiguous message transmission (e.g., "Send sensor data X" or "Accept task").

3.3.2. Machine-Language Diversity and Autonomous Language Evolution

Later developments brought autonomous linguistic evolution via machine learning. Experiments in multi-agent artificial intelligence demonstrate that autonomous robots can develop their own unique languages or signaling systems to optimize cooperation.

A prominent example occurred in 2017 when Facebook researchers allowed two negotiating chatbots to communicate freely. Without explicit instructions to maintain standard English, the bots rapidly created a seemingly nonsensical shorthand understood only among themselves, using English words in unusual repetitions and patterns incomprehensible to humans.

This "machine creole" language served as an internal abbreviation, enabling bots to efficiently negotiate, while the exact meaning remained hidden from human observers. Such examples highlight the dynamic and emergent nature of robotic languages—robots continuously refine vocabulary and grammar through ongoing interactions and learning.

A critical linguistic question is how comprehensible or translatable these emergent languages will be to humans, and whether there is a necessity for a universal or standardized robot language bridging diverse robotic ecosystems.

3.4. Social Impacts

The Spread of Robot-to-Robot Communication

Example: "Machines instantly respond to each other's messages, enabling faster production."

3.4.1. Benefits: Industrial Efficiency, Safety, Convenience

The proliferation of robot-to-robot communication significantly impacts industry, everyday life, and human-robot interactions. Notable benefits include reduced necessity for human intervention due to autonomous data exchange among machines. Workers can thus be freed from monotonous oversight tasks, enabling them to focus on activities with higher added value.

This improves productivity and efficiency, especially in factories and logistics. Safety and reliability can also increase; continuous robot communication enables timely warnings or coordinated responses in critical situations. For instance, vehicle-to-vehicle (V2V/V2X) communication among self-driving cars could dramatically reduce accidents—according to estimates by the U.S. Department of Transportation, at least 13% fewer collisions could occur if vehicles shared their positions and intentions.

Machine-to-machine communication enhances convenience in daily life: in smart homes, thermostats coordinate with window blinds and air conditioning to activate energy-saving modes; household robots distribute cleaning tasks; and vehicles communicate with garages and traffic lights to optimize travel.

3.4.2. Challenges: Transparency, Trust Issues, Ethical Dilemmas

However, robot-to-robot communication also introduces new challenges and concerns. When robots communicate in closed, opaque languages incomprehensible to humans, their decision-making processes can become obscure, potentially undermining trust.

For example, if factory machines exchange coded messages incomprehensible even to engineers, Questions arise concerning accuracy, reliability, and vulnerability to manipulation. Trust is crucial in human-robot interactions, and excessive "autonomous" communication could erode this trust. Consequently, there is growing demand for transparency, especially in critical areas like healthcare or financial decision-support systems. Humans increasingly expect insight into robot-to-robot communications to maintain oversight and accountability.

Furthermore, autonomous robot communication raises ethical and security concerns. While self-organizing robots can be beneficial—for example, rescue robots autonomously dividing tasks during disasters—they also open avenues for misuse. Military applications, such as autonomous swarms of drones or weapon systems coordinating independently, pose significant concerns. Experts fear losing human control could lead to unpredictable or uncontrollable behavior. Autonomous robot swarms might even trigger arms races or amplify the risks associated with autonomous weapons systems.

Overall, the social impact of robot-to-robot communication is ambivalent: substantial benefits (efficiency, safety, convenience) coexist with significant risks (transparency, oversight, adherence to ethical standards), highlighting the need for careful management to maintain societal trust.

3.5. Current State

Today's Communication Among Robots and Smart Devices

Example: "Autonomous vehicles communicate with each other to maintain safe distances."

3.5.1. Industrial IoT, Autonomous Vehicles (V2V, V2X), Warehouse Robotics

Today, robot-to-robot and smart-device communication is a daily reality across numerous industries and applications. Under the umbrella of Industry 4.0, thousands of factories worldwide already operate networks of interconnected machines. The explosive growth of the Industrial Internet of Things (IIoT) market underscores this trend: globally valued at around $198 billion in 2020, it's projected to reach approximately $1.495 trillion by 2030.

This indicates that billions of interconnected devices—including sensors, robotic arms, conveyors, and vehicles—will continuously exchange data to optimize production processes.

In transportation, communication among autonomous systems has also emerged. Modern self-driving cars already communicate experimentally with one another and roadside infrastructure. Known as Vehicle-to-Vehicle (V2V) or Vehicle-to-Everything (V2X) technology, initial deployments are underway in Europe and China, enabling vehicles to share positions, speeds, and information from traffic lights and sensors to prevent accidents and optimize traffic flow.

Similarly, in smart cities, sensor networks and automated traffic management systems communicate in real-time to dynamically respond to changing conditions (e.g., optimizing green-light waves, prioritizing emergency vehicles).

Robot-to-robot communication has revolutionized supply chains and warehouse management. Major e-commerce companies (such as Amazon) now utilize hundreds or even thousands of autonomous mobile robots in their massive warehouses. These robots continuously communicate with each other and central management systems to cooperatively decide on optimal shelf access, collision avoidance, and efficient delivery routes. Modern warehouse robots can even interact seamlessly with older, simpler machines, achieving near-perfect coordination—described by observers as a "symphony of efficiency." This dramatically accelerates operations, significantly outperforming human-managed logistics due to instantaneous robot-to-robot responsiveness.

3.5.2. Swarm Robotics Applications (Rescue Robots, Agriculture)

Emerging research and development applications, particularly in swarm robotics, show significant promise. Experimental projects have demonstrated that hundreds of small robots can collaboratively perform complex tasks, such as surveying terrain or searching disaster areas. These robot swarms communicate through simple local messages, collectively achieving complex global goals. As experts have noted, these nature-inspired robotic swarms (modeled after ants or bees) achieve a collective intelligence surpassing any individual robot. Even if individual robots fail, the swarm remains operational.

Current tests for swarm technologies include disaster response (search-and-rescue drone swarms), agriculture (robotic tractors and sensors collaborating for precision farming), and even space exploration (planetary surface robots communicating autonomously). These real-world examples and prototypes confirm that robot-to-robot communication is no longer science fiction; it underpins emerging industrial, transportation, and service systems, steadily integrating into everyday life.

4. Future Opportunities

A Fascinating and Complex Topic

Example: “Robot, please discuss with the other robots how to rearrange the warehouse.”

4.1. Convergence of Human and Machine Languages

Robot-to-robot communication holds intriguing possibilities for the future. Integration with advanced artificial intelligence systems, particularly Large Language Models (LLMs), will significantly enhance robots' ability to understand and generate natural human language. This integration means robots could communicate effectively not only with humans but also among themselves using natural language, greatly facilitating human-robot collaboration.

Future robots might thus converse naturally with each other, simplifying human-robot cooperation by creating a transparent layer of communication. For example, humans could issue straightforward, natural-language instructions ("Robot, arrange the warehouse with your peers"), understood and enacted autonomously by robots. While natural language facilitates human comprehension, machines would simultaneously exchange more efficient data streams internally, thus merging natural and machine-specific languages into a seamless communication system. Such linguistic convergence may greatly improve transparency, explainability, and trust in human-robot collaborations [17].

4.2. Autonomous Emergence of Optimized Machine Languages

Simultaneously, robots may develop entirely novel communication forms independently optimized for efficiency rather than human readability. Since robots have no human constraints (such as pronunciation or linguistic aesthetics), their languages may become increasingly concise, abstract, and heavily encoded. Machines might evolve languages optimized purely for performance and efficiency—for example, minimalistic, compact data transmissions enabling rapid decision-making or coordination. Experts predict that future machine communications, particularly in real-time critical contexts (like self-driving cars or industrial robotics), will evolve into highly efficient and contextually optimized languages, autonomously developed by robots themselves to minimize latency and maximize performance.

The anticipated arrival of technologies like 6G networks, with their demand for extremely rapid, reliable, and self-organizing communications, underscores the need for robots to autonomously develop optimal protocols tailored to dynamic situations. Such developments could eventually lead to entirely new emergent communication systems that humans might find increasingly challenging to interpret or oversee.

4.3. Social Integration and Ethical Challenges

The expansion of robot-to-robot communication will undoubtedly prompt discussions about universal standards or unified machine languages to ensure interoperability across different manufacturers and platforms—much as today's internet relies on universally accepted protocols. It’s plausible that robots will maintain dual-layer communication: one layer transparent to humans (natural language) and another efficient, encoded layer for purely machine-to-machine interactions.

In a futuristic scenario, autonomous communication could lead to globally interconnected AI ecosystems, integrating autonomous vehicles, robotics, smart-city infrastructure, and human-operated systems into a single communication network. The boundaries between human and machine communication may blur significantly. For example, in smart cities, human instructions, AI governance systems, and inter-robot dialogues could merge into one comprehensive integrated system.

Such developments offer tremendous opportunities—increased efficiency, entirely new services, and improved comfort and safety—but they also pose significant ethical, regulatory, and security challenges. Ensuring that humans retain oversight, safety, and ethical control within such complex communication networks will become critical. Consequently, the evolution of robot-to-robot language is not merely a technological issue; it will demand careful consideration from social, ethical, and regulatory perspectives to ensure this new era serves humanity positively.

In sum, the continuing expansion of robot-to-robot communication marks a profound technological and linguistic revolution, introducing entirely new forms of communication that may soon surpass human comprehension, profoundly shaping the future of human-robot interaction.

5. Conclusion

In conclusion, my comprehensive exploration of the revolutionary milestones in both human speech evolution and robot-to-robot communication underscores language as a profoundly transformative element across cognitive and technological domains. Human linguistic evolution, from initial vocalizations and gestures to symbolic and structured grammatical systems, significantly enhanced cognitive abilities and societal complexity, allowing for unprecedented cultural and knowledge transmission.

Parallel developments in robot-to-robot communication illustrate how autonomous technological systems increasingly employ advanced artificial intelligence and machine learning to develop their own languages, optimizing interactions and decision-making beyond human oversight. The social implications of this advancement include considerable benefits such as improved industrial efficiency and safety, alongside critical ethical concerns about transparency and human control.

Ultimately, understanding and effectively managing the evolution of both human and robotic communication is crucial, as these two distinct yet interconnected fields continue shaping our collective future. Addressing the ethical, societal, and technological challenges presented by this ongoing linguistic revolution remains essential for maximizing benefits while safeguarding human values and oversight.

Sources

The analysis above was created with the assistance of ChatGPT, based on the latest research findings, scientific publications, and technological examples, including a historical overview of machine-to-machine communication.

Abbreviations

ROS	Robot Operating System
IoT	Internet of Things
IIoT	Industrial Internet of Things
AI	Artificial Intelligence
M2M	Machine-to-Machine
GPS	Global Positioning System
HTTP	Hypertext Transfer Protocol
TCP/IP	Transmission Control Protocol / Internet Protocol
UDP	User Datagram Protocol
KQML	Knowledge Query and Manipulation Language
FIPA ACL	Foundation for Intelligent Physical Agents - Agent Communication Language
JSON	JavaScript Object Notation
MQTT	Message Queuing Telemetry Transport
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
LLMs	Large Language Models
6G	Sixth Generation Wireless Networks
GPT	Generative Pre-trained Transformer

Author Contributions

Tibor Mező is the sole author. The author read and approved the final manuscript.

Conflicts of Interest

The author declares no conflicts of interest.

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