Speaking to Machines: An Information-Theoretic Perspective on Dilemmas, Approaches, and Solutions in Human-Machine Communication (Postprint)

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Abstract

Purpose: The explosive popularity of chatbots represented by ChatGPT has sparked boundless public speculation about the future of human-computer communication, and the resulting dilemmas in human-computer communication warrant attention and investigation.

Methods: Based on the perspective of Shannon' s information theory, this paper explores the practical dilemmas of human-computer information exchange and interprets the causes of information uncertainty in human-computer communication from the information entropy perspective.

Results: The study finds that defects in algorithmic corpora, value occlusion, strong algorithmic robustness, and the lack of multimodal corpora in real-world dimensions can all lead to increased information entropy in human-computer communication.

Conclusion: Countermeasures for information entropy reduction must be considered from the aspects of information completeness, accuracy, timeliness, etc., to achieve efficient and smooth human-computer communication.

Full Text

Preamble

Speaking to Machines: Dilemmas, Pathways, and Countermeasures in Human-Machine Communication from an Information Theory Perspective

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Abstract: The explosive popularity of chatbots like ChatGPT has sparked infinite imagination about the future of human-machine communication, yet the dilemmas arising therein warrant attention and discussion. This article examines the practical dilemmas in human-machine information exchange from the perspective of Shannon' s information theory, interpreting the causes of information uncertainty in human-machine communication through the lens of information entropy. The study finds that algorithmic corpus defects, value occlusion, excessive algorithmic robustness, and the absence of real-world multimodal corpora can all lead to increased information entropy in human-machine communication. Countermeasures for entropy reduction must be considered from the perspectives of information integrity, accuracy, and timeliness to achieve efficient and smooth human-machine communication.

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1. Conceptual Analysis of Information Entropy, Noise, and Human-Machine Communication

Shannon introduced the concept of information entropy in his seminal work "A Mathematical Theory of Communication," defining it as a measure of the uncertainty or disorder of random information [1]. Information entropy theory expanded the meaning and application scope of entropy, extending it from physics to information science and social sciences as a generalized entropy that measures the uncertainty or disorder of any system. Noise, another concept proposed by Shannon, refers in information theory to anything unintentionally transmitted and attached to a signal due to technical failures or imperfections, causing distortion between transmitted and received signals—that is, interference with normal information transmission [2]. Broadly defined, human-machine communication, also known as Human-Computer Interaction (HCI), is the study of interactive relationships between program systems and users [3]. With technological advancements, human-machine interaction has evolved from interface-based interaction to information and even emotional interaction. The concept of "machine" encompasses not only computer equipment but also robots and artificial intelligence. Chatbots are conversational agents that communicate

with humans through natural language [4]. Information entropy forms the foundation of algorithmic technology; by capturing and analyzing information about people and things through algorithms, uncertainty can be eliminated to achieve harmonious development of information systems [5]. This paper focuses specifically on information interaction and exchange between humans and chatbots, using information entropy and noise as theoretical frameworks to examine uncertainty and distortion in human-chatbot communication processes.

2.1 Algorithmic Corpus Defects Leading to Information Entropy Increase

Algorithmic corpora are large document collections gathered and organized for algorithms to calculate word similarity based on information content or co-occurrence frequency [6]. Current AI chatbot corpora primarily derive from pre-programmed knowledge bases or are obtained through user interaction and web searches. Under this technical framework, due to commercial considerations and user privacy security concerns, massive amounts of data cannot be shared, creating limitations for corpus expansion. Even when data fragmentation exists, existing AI algorithmic technology struggles with massive training parameters. Meanwhile, multimodal corpora from real-world dimensions are excluded from AI learning model training sets, posing a future challenge for chatbot generalization.

2.1.1 Information Entropy Increase Caused by "Data Islands"

"Data islands" originate from "information islands" theory, where data is stored separately across different entities or departments, becoming isolated datasets that cannot interconnect, share, or integrate [7]. While data' s replicability makes it naturally shareable, the formation of data islands has practical inevitability. Discrete data ownership directly leads to divergent demands among different stakeholders, and the specific rights 界定 of data in economic activities remain under discussion in legal academia [8]. Whether due to diverse stakeholder demands or current legal limitations on data economic rights, algorithmic models face constraints in their selection scope for original corpora. Theoretically unlimited-capacity algorithms are forced into selective data absorption due to the reality of data islands, and missing algorithmic corpora inevitably result in insufficient information capacity compared to the complete information set. This significantly increases information probability uncertainty and intensifies information system disorder, bringing about information entropy increase.

2.1.2 Information Entropy Increase Caused by "Data Inflation"

AI algorithms obsessively expand the breadth of language model response ranges, and continuous training parameter expansion in corpora causes the amount of information needed to determine an event to inflate, increasingly raising information entropy values. However, algorithmic mechanisms and logic remain imper-

fect and immature. The disconnect between data and technology manifests as prolonged response times, reduced probability of outputting valid information, and increased language output disorder in AI language models. Conversely, to improve accuracy and flexibility, the amount of information needed to determine an event must be reduced—that is, shrinking training parameter quantity and scope to increase system internal order and reduce information entropy, thereby enhancing response depth. Yet this also means narrowing response capability ranges, making it difficult to address timely issues.

2.2 Value Occlusion Leading to Information Entropy Increase and Structural Aphasia

Machine-generated texts cannot match specific questions with targeted answers, only generalizing special issues using universal information panaceas to improve output efficiency and response speed. Consequently, machine texts favor widely disseminated authoritative reports and 百科 entries with high information density during reference selection. Algorithmically anointed information sources are granted authoritative status and massive online exposure, making chatbots new gatekeepers rewriting online information dissemination order. As algorithmic "dissemination" exchange, high-quality information data controlled by tech media giants forms the information cornerstone of AI-Generated Content (AIGC), creating deeply coupled symbiotic relationships between algorithm developers and data owners with aligned interests.

The cost of standardized authoritative answers is the elimination of diverse interpretive spaces for objective facts. Deep, differentiated interpretations are deemed "low-probability events" by algorithms and get occluded, blocking 多元 paths to understanding objective things. Unidirectional "information consensus" appears as "perfect facts" under chatbot compilation. Behind the "unified alignment" of machine text content lies algorithmic technology' s powerful discursive authority in cyberspace, plunging minority groups into structural aphasia under algorithmic filtering, with the value space revealed by the long-tail effect being selectively buried.

2.3 Invalid Information and Noise Generation Caused by Excessive Algorithmic Robustness

Science fiction writer Ted Chiang noted in a New Yorker article that ChatGPT rewrites online source material rather than quoting verbatim, like a student summarizing texts in their own words instead of simply copying, creating an illusion that ChatGPT understands textual material [9]. Based on transformer architecture, ChatGPT is a product of pre-trained language models; it lacks cognitive understanding of human knowledge symbols, merely performing mechanical element traversal and probabilistic symbol arrangement of stored information under machine logic. When algorithms cannot effectively recognize user-input language texts, their probabilistic conclusions often deviate from original inputs,

even fabricating commonsense-defying content. Seemingly reasonable answers 实质上 result from noise generated by algorithms excessively pursuing robustness that deviates from or even violates facts.

Google Senior Vice President and Search Head Prabhakar Raghavan stated in an interview that when facing results from AI-driven chatbots, people must remain vigilant [10]. Seemingly "minor" data changes can cause vast discrepancies between facts and machine answers, and this hidden uncertainty risk makes users doubt information certainty and reliability, especially when questions fall outside their familiar professional domains. During processes of verifying content authenticity and source accuracy, human-machine information exchange quality and efficiency substantially decrease.

2.4 Information Entropy Increase Caused by Real-World Multimodal Corpus Absence

Limited by algorithmic technology and logic, existing AI chatbots can only connect to textual corpora, simulating human language output through single visual modality—that is, generating understandable text—while struggling to translate auditory, tactile, olfactory, and other multimodal perception channel symbols into training parameters and multimodal symbolic system expressions. This restricts chatbots' interpretive space for expression and information transmission, whereas human users in real space constantly experience multimodal discourse influence. When AI chatbots achieve widespread application, differentiated language texts input by users from diverse cultural backgrounds and knowledge structures increase machine "understanding" difficulty of human natural language, reducing AI chatbot probability of outputting valid information when processing complex texts. This deviation between database corpora and real-world corpora increases information uncertainty in human-machine communication—that is, entropy increase.

Achieving multimodal corpus supplementation for AI algorithms requires multidisciplinary support and development. First, chatbots must translate concrete, three-dimensional, dynamic multimodal symbols into code data for algorithmic training while ensuring output multimodal discourse integrity and accuracy. Second, multimodal discourse grammar lacks strict grammatical markers and linear relationships, carrying strong subjectivity; people from different cultural backgrounds and knowledge structures may 分歧 on defining semantic relationships between multimodal components. Finally, due to uncertain interactive and complementary relationships between modal systems, AI algorithms must estimate semantic complementarity between modal system components across different contexts to output effective multimodal discourses expressing specific information [11].

3. Pathways and Countermeasures for Human-Machine Communication Entropy Reduction

3.1 Enhancing Information Integrity

According to the maximum entropy principle, algorithmic model underlying corpora should contain all entity data information as much as possible [12], requiring big data corpora to ensure breadth and depth in information sources. While deeply mining online data information, corpora must also widely absorb various non-publicly available information to ensure sufficient coverage, such as digitizing physical books and newspapers and fusing image, audio, and video data. This process inevitably encounters challenges like commercial interest conflicts and privacy risks, posing new challenges for algorithm developers. Information integrity is the foundation for achieving entropy reduction and improving human-machine communication efficiency; only by establishing multi-dimensionally deep-mined databases can future algorithmic models achieve breakthroughs and discover truly complete answers meeting user requirements under massive data support.

Current chatbots often suffer from logical confusion and coarse, redundant information. To overcome these limitations, people typically believe minimal redundancy represents optimal human-machine communication, yet this minimalist pursuit paradoxically traps them in instrumental rationality thinking patterns. In fact, redundancy is not literally "redundant" useless information but additional information added during transmission or storage to ensure information integrity and accuracy [12]. Scholars like Fiske argue redundancy' s functions mainly lie in facilitating precise encoding and strengthening social connections, playing important roles in offsetting noise and detecting errors in interpersonal communication [13]. Similarly, when optimizing algorithmic models and improving information efficiency in human-machine communication, we must pause to re-examine redundancy' s value in translation processes, recognizing its lubricating role. Building upon original data texts, appropriate redundancy utilization can 反而 reduce excessive information density and obscurity, enhancing user understanding and achieving entropy reduction from another angle.

3.2 Ensuring Information Accuracy

Information accuracy manifests in two dimensions: information comprehension and content output. Comprehension accuracy focuses on precise interpretation of user expressions, learning from interpersonal communication. In human conversation, unclear content can be clarified through further explanation; AI in "communication" might similarly inquire about uncertain information from users to determine meaning rather than relying solely on massive databases for semantic judgment, thereby responding more accurately. Output accuracy emphasizes information source reliability and traceability. Microsoft' s New Bing chatbot combines search engine content positioning capabilities with GPT' s natural language processing, continuously injecting new knowledge through real-time

updated web information. It performs comprehensive searches and answer integration for user questions, providing a realistic feasible model for information traceability.

3.3 Strengthening Information Timeliness

Information content possesses extremely high timeliness; recent events hold high information value that rapidly decays over time, especially real-time updated data like breaking news, market trends, and traffic/weather conditions [11]. Massive data knowledge forms the foundation of chatbot algorithmic models, while real-time updates reduce human-machine communication temporal barriers and enhance interaction efficiency. To meet user demand for such instant information, chatbots require not only massive knowledge bases but also rapid capabilities for collection, integration, processing, and transmission. Minimizing information integration and feedback time ensures good user experiences. Microsoft and Google have attempted embedding chatbot modules into their search engines, enabling dynamic content adjustment based on real-time crawled data —a significant breakthrough compared to ChatGPT' s offline corpus dependency. Strong timeliness online corpora represent substantial progress.

4. Future Prospects for AI Chatbots

4.1 Domain Specialization

ChatGPT represents OpenAI' s beneficial attempt to demonstrate technical prowess, yet its commercial blueprint unfolds toward a general algorithmic model as the ultimate goal—to become the infrastructure owner for algorithmic development, maintaining universality and compatibility for program development across any 细分 field. Its core commercial 诉求 currently lies in providing paid natural language processing API integration interfaces for enterprises and individuals. This necessitates a redefinition of general AI: general AI algorithms cannot fulfill fantasies of robots being "omniscient and omnipotent" but merely provide preliminary natural language processing and human-computer interaction capabilities for finely 分工 AI robots. Specific algorithmic development tendencies and differences remain dominated by their own task attributes; a "grand unification" general AI model cannot truly achieve omniscience in practice, only promoting unified underlying frameworks in algorithmic development. From individual developers'perspective, ready-made remote API ports 确实 avoid repetitive labor in writing language function code, allowing development focus to return to business functional requirements. Chatbots developed under this model need only be fed specific domain training parameters and deeply optimized within private datasets, combining big data pre-trained logical thinking with precise specific data invocation. Through cloud computing-local data linkage, efficient single-domain specialized chatbots can be created, improving professionalism and accuracy in specific domain responses. Future chatbots will no longer merely "chat" but truly leverage powerful logical processing and analyti-

cal induction capabilities, finding broad applications in military reconnaissance, business forecasting, teaching assistance, and other specialized domains.

4.2 Multimodal Simulation

From text-only assistants to voice-text dual-modal voice assistants, to 具象化 multimodal simulation virtual avatar chatbots—throughout human-machine communication technology history, multimodal, simulation, and scenario-based AI language models seem to be perpetual goals and inevitable trends. Fundamentally, AI big data language models aim to achieve value reconstruction of all elements in the human world. The first step reconstructs human semantic world values; the next critical breakthrough should point to value reconstruction of all elements beyond semantics in human practice fields—precisely aligning with metaverse requirements for social element reconstruction, relationship rule reconstruction, and reality scenario reconstruction in the digital civilization era [14]. Three-dimensional, visualized language models based on multimodal data analysis and processing can integrate language with other meaning resources like images, expressions, actions, and sounds for semantic expression. This not only enhances machine language symbols' role in meaning exchange but also enables more comprehensive and accurate user interpretation of machine-expressed discourse meaning. If such language models can be presented through simulation, they will provide more application space for multimodal interactive communication.

4.3 Scenario Customization

Current chatbots' inability to accurately understand user needs largely stems from passive, isolated information input. User-chatbot communication follows a question-answer language symbol exchange pattern where chatbots lack effective perception of users' non-verbal communication symbols, causing machines to mechanically answer real needs from literal meaning only, unable to comprehend specific contexts and deeper implications behind discourse. Scenario-based human-machine communication can break through rigid question-answer patterns. Under the 加持 of "scene five forces" composed of mobile devices, social media, big data, sensors, and positioning systems [15], users' complex real-world situations can be quantified in real-time into multi-dimensional interoperable information flows, providing data support for personalized chatbot scenarios. Consequently, chatbots can escape passive information reception-integration-output mechanization, actively building and dynamically adjusting scenario elements to create personalized, immersive communication experiences. Mechanical, isolated human-machine communication becomes natural and widespread through scenario reconstruction. Meanwhile, ethical issues arising from data sharing and immersive experiences must be considered—charming scenarios must be built upon "human-centered" logic.

ChatGPT' s global popularity has once again 高调 returned AI technology to public vision, with chatbots overnight becoming the version answer to human

efficiency machine roles. Focusing on the small 切口 of chatbots and centering on core concepts of "information entropy" and "noise," this paper discusses stage dilemmas and future possibilities in human-machine information exchange. Chatbots' functional positioning determines they will develop toward high-efficiency automation as the main axis, advancing to meet human 多元化 needs. At the initial stage of technological innovation cycles, algorithmic development dominated by commercial logic 无疑 accelerates development 进程, but at the cost of instrumental rationality dominance driven by commercial interests, further strengthening chatbots' tool attributes. Heidegger argued that purely instrumental interpretations of technology neglect its value dimension—technology is no longer "neutral" but dominates modern world understanding as a "framework"[16]. However, this does not mean chatbots'future is entirely determined by instrumental rationality. Instead, instrumental and value rationality are both 对立 and 统一 in technological development [17]. Value rationality plays a decisive guiding role in chatbots' future development. Whether from perspectives of human social, emotional, or work efficiency needs, humans remain the end goal rather than tools or means. Chatbots' future development must take human dignity and needs as essential requirements, proceeding from a human-centered standpoint to ensure human subjectivity is not 消解 by machines and avoid human enslavement or domestication by machines. As chatbot technology commercialization proceeds vigorously, value rationality suppression intensifies. How to achieve organic unity between value and instrumental rationality, break down communication barriers between humans and machines, and make chatbots truly become bridges for human-machine communication warrants careful consideration.

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Note: Figure translations are in progress. See original paper for figures.