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Ethical Decision-Making Models for Silicon-Based Life

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ABSTRACT

With increasing multidisciplinary integration across technological fields, silicon-based life is becoming a possibility on the horizon. This raises many concerns regarding the ethics of designing such life. This paper experimentally investigates the performance differences, ethical adaptability, and optimization directions for multiple ethical decision-making models for silicon-based life. Controlled experiments are conducted through the NVIDIA Isaac Sim platform, which is commonly used in testing AI-driven robotics. We integrate algorithmic constructions of utilitarianism, deontology, and virtue ethics to introduce ethical decision-making models into the platform. We examine these models through customized scenario-generation tools in paradigmatic industrial safety, medical emergency, and public transportation scenarios. We analyze the resulting data through statistical methods such as analysis of variance and significance testing, focusing on model performance differences and interactive effects, with regression and cluster analysis aiding in optimization. We present the data in grouped bar charts, batch heat maps, and radar charts. Based on these data, we propose optimization paths for the ethical design of silicon-based life and provide insights into parameter adjustments that reflect cultural differences and algorithmic improvements that extend the model to multicultural contexts. We hope that future interdisciplinary collaboration will continue to drive the ethical design of silicon-based life, ensuring that robotics are restricted in broad ethical considerations that are necessary for socially beneficial technology.

KEYWORDS: Silicon-Based Life, Ethical Design, Decision-Making Models, Robot Ethics

1 | INTRODUCTION

In the era of rapidly advancing technology, silicon-based life forms, as a product of the deep integration of artificial intelligence, mechanical engineering, and other disciplines, are gradually entering people's lives and playing an increasingly important role in various fields (Saraf et al., 2023; Jecker, 2021). From automated assistants on industrial production lines to precision surgical aids in the medical field, from intelligent partners in home services to pioneers in exploring unknown environments, the application scenarios of silicon-based life are continuously expanding (Wallach, 2010; Li et al., 2023). However, as their functions become increasingly powerful and their application scope continues to expand, the ethical design issues of silicon- based life forms have gradually become a focus of attention for the scientific community, ethicists, and all sectors of society (Torrance, 2020; Kaplan, 2006). How to ensure that the behavior of silicon-based life forms aligns with human moral standards and values, and how to seek a balance between technological innovation and ethical morality, have become important issues that need to be resolved urgently (Dennett, 1997; Reiss, 2021). To this end, we have conducted an experimental study on the ethical decision- making models of silicon-based life forms to delve into their performance and optimization directions (Sorgner, 2021; Peng et al., 2021).

2 | CURRENT STATUS OF SILICON-BASED LIFE TECHNOLOGY

2.1 | Interdisciplinary Integration as a Driving Force

The development of silicon-based life has benefited from the collaborative progress of multiple disciplines (Grewal, 2024). Computer science has provided it with powerful computational capabilities and intelligent algorithms, enabling robots to have autonomous decision-making and learning abilities (McEvoy et al, 2015). For instance, the continuous development of deep learning algorithms allows silicon-based life forms to optimize their behavioral decisions through the analysis and learning of vast amounts of data (Wang et al., 2021). Mechanical engineering has endowed robots with physical structures and mobility, from precise joint design to efficient power transmission systems, ensuring that robots can perform tasks in various environments (Bandari et al, 2021). Electronic engineering has provided robots with sensors to perceive the external world and communication modules to interact with the outside, enabling them to acquire information and respond (Qu et al., 2023). Advanced visual sensors allow robots to clearly recognize objects and scenes in their surroundings, auditory sensors enable them to receive voice commands and perform speech recognition, and tactile sensors simulate human tactile perception, enhancing the robot's interactive capabilities with the environment (Yang et al., 2023). This integration of multiple disciplines has not only propelled the rapid development of silicon-based life technology but also continuously improved the performance of robots and diversified their functions (Bettinger, 2018).

2.2 | Performance Enhancement and Application Expansion

In recent years, silicon-based life forms have achieved significant breakthroughs in performance (Gupta et al., 2016). In terms of perceptual abilities, advanced sensor technology enables them to accurately sense various physical quantities in their surrounding environment (Fang et al., 2022). The resolution of visual sensors has continuously improved, allowing for high-definition image recognition and target tracking, playing a crucial role in fields such as security surveillance and autonomous driving (Zhang et al., 2020). The sensitivity and accuracy of auditory sensors have been enhanced, allowing for better capture of sound signals and speech recognition, laying the foundation for intelligent voice interaction (Liu et al., 2021). The development of tactile sensors has enabled robots to simulate human tactile perception, enabling more precise operations based on tactile feedback in scenarios such as industrial assembly and medical surgery (Beebe et al., 1995).

In terms of decision-making capabilities, the application of deep learning algorithms enables robots to analyze and judge based on a vast amount of data, making more reasonable decisions (Yang et al., 2023). For instance, in the field of autonomous driving, silicon-based life forms can analyze road conditions in real-time, predict the behavior of other vehicles and pedestrians, and thus safely plan driving routes (Xu et al., 2019). In industrial manufacturing, robots can quickly adjust production processes and parameters based on real-time inspection data of products on the production line, enhancing production efficiency and product quality (Morales et al., 2018).

The application fields of silicon-based life forms are continuously expanding. In industrial manufacturing, they can undertake high-intensity and high-precision production tasks, enhancing production efficiency and product quality while reducing labor costs and intensity (Zolfagharian et al., 2022). For instance, in the automotive manufacturing industry, robots can accurately perform complex processes such as welding and assembly, ensuring the consistency and stability of product quality. In the healthcare sector, silicon- based life forms can be used for surgical assistance, rehabilitation therapy, and disease diagnosis. Surgical robots can perform complex surgical operations within confined surgical spaces with precise movements, increasing the success rate and accuracy of surgeries and reducing surgical trauma (Lee et al., 2024). Rehabilitation robots can develop personalized rehabilitation training programs based on the specific conditions of patients, helping them recover physical functions; for example, upper limb rehabilitation robots can assist patients with arm movement training to promote neural recovery (Dahiya et al., 2020). In home services, silicon- based life forms can act as intelligent butlers, assisting with household chores, caring for the elderly and children, and providing convenience to people's lives (Puchades et al., 2013). For example, robotic vacuum cleaners can automatically sweep floors, and smart companion robots can interact with the elderly and children, offering entertainment and companionship (Song et al., 2020). In the military domain, silicon-based life forms can be used for reconnaissance, bomb disposal, and combat missions, reducing the risk of casualties among soldiers (Beebe et al., 1995). Reconnaissance robots can venture into dangerous areas to gather intelligence, and bomb disposal robots can precisely handle explosives (Liu et al., 2023). In space exploration, robots can perform tasks in harsh space environments, such as planetary surface exploration and space station maintenance, expanding the boundaries of human knowledge of the universe (Morales et al., 2018). For example, Mars rovers can conduct geological surveys and search for signs of life on the Martian surface.

3 | CHALLENGES IN DESIGN ETHICS OF SILICON-BASED LIFE

3.1 | Ethical Dilemmas

3.1.1 | Ambiguity in Judgment Standards

The decision-making of silicon-based life forms is often based on complex algorithms and data processing, which inherently differs from human moral judgment mechanisms (Wallach, 2010). In specific situations, such as when faced with dilemmas where saving the majority might result in the injury or death of a minority, determining the moral standards that silicon-based life should follow becomes extremely challenging (Dennett, 1997). Human moral judgments are often influenced by a variety of factors, including emotions, culture, and social context, whereas silicon-based life lacks these subjective elements. Establishing unified and reasonable moral judgment standards for them is an urgent problem that needs to be addressed (Reiss, 2021).

3.1.2 | Definition of Rights and Responsibilities

As the autonomy of silicon-based life forms increases, the consequences of their actions become increasingly complex (Kaplan, 2006). When robots cause harm or make erroneous decisions, defining their liability and the liability of associated individuals, such as developers and users, poses a challenge. Furthermore, the question of whether silicon- based life forms should be granted certain rights, such as the ”right to exist” or ”right to privacy,” has sparked widespread debate (Gordon, 2022). Granting rights to robots could alter existing ethical and legal frameworks, potentially having profound implications for human society (Sorgner, 2021).

3.2 | Safety Hazards

3.2.1 | System Failures and Loss of Control Risks

The complexity of silicon-based life systems increases the likelihood of malfunctions (Yang et al., 2023). Hardware failures can lead to issues such as loss of robotic control and erroneous sensor data, thereby triggering safety incidents (Jecker, 2021). On the software front, algorithmic vulnerabilities, programming errors, or malicious attacks may cause robots to act in ways that deviate from expectations, or even be controlled by hackers to perform actions that endanger human safety. For instance, in industrial production, an uncontrollable robot might damage manufacturing equipment, lead to product quality issues, or even endanger the lives of operators; in the field of autonomous driving, software failures could result in severe accidents such as vehicle collisions (Chen et al., 2022).

3.2.2 | Data Security and Privacy Breaches

Silicon-based life forms collect vast amounts of data during their operations, including environmental and user information. The security of this data is crucial; if it is leaked or tampered with, it could pose a threat to individual privacy, corporate secrets, and even national security (Remenyi et al., 1996). For instance, the sensitive patient information gathered by medical robots, if disclosed, would severely violate patient privacy; internal household information obtained by smart home robots could potentially be exploited by malicious actors to commit theft or other illegal activities (Gordon, 2022).

3.3 | Social Impact

3.3.1 | Transformation of Employment Structure

The widespread application of silicon-based life forms will inevitably impact the job market. In fields with repetitive and highly routine tasks, such as manufacturing and customer service, robots can perform tasks efficiently, which may significantly reduce related positions (Reiss, 2021). Although the development of robots also creates new job opportunities, such as in robot research and development, maintenance, and programming, these new positions have very different skill requirements from traditional jobs, requiring workers to have a higher level of technical literacy and innovation ability (Panchal, 2023). Therefore, how to help workers adapt to the transformation of the employment structure and transition from traditional positions to emerging ones is an important issue faced by society (Tharib, 2024).

3.3.2 | Social and Emotional Interaction

As silicon-based life forms become more prevalent in homes and social settings, their interactions with humans are becoming increasingly frequent (Meghdari et al., 2016). However, an overreliance on robots may affect human social and emotional interactions. For instance, children who play with smart toy robots for extended periods may reduce their opportunities to interact with peers, affecting the development of their social skills (Silvera-Tawil et al., 2015); the elderly who become overly dependent on care robots may experience a decrease in emotional communication with family and caregivers, impacting their psychological health (Jecker, 2021). Moreover, the anthropomorphic design of silicon-based life forms may lead to inappropriate emotional dependencies from humans, and when robots malfunction or are decommissioned, it may cause emotional distress for users (Carrozza, 2019).

4 | EXPERIMENTAL STUDY OF ETHICAL DECISION-MAKING MODEL

4.1 | Experimental Objectives

4.1.1 | Performance Differences

Against the backdrop of specific engineering scenarios, assess the efficiency, stability, and applicability of ethical models. By testing silicon-based life ethical decision-making models in different scenarios and comparing their performance in handling various tasks, the strengths and weaknesses of different models in practical applications can be determined, providing a basis for selecting the appropriate ethical decision-making model.

4.1.2 | Cross-Cultural Adaptability

Through cross-cultural scenario simulations, analyze the ethical performance of robots in diverse social environments. Taking into account the differences in moral concepts and values across various cultural backgrounds, investigate whether the behavior of silicon-based life forms complies with local ethical requirements in different cultural contexts. This ensures that robots can be applied reasonably on a global scale and helps to avoid ethical issues arising from cultural conflicts.

4.1.3 | Model Optimization

Based on the experimental results, propose improvements to construct a more efficient and interpretable framework for robotic moral design. By conducting an in-depth analysis of the experimental data, identify the shortcomings of current ethical decision-making models, and then optimize them specifically to enhance their performance and interpretability. This will enable the models to better guide the behavioral decisions of silicon-based life forms, aligning with human moral expectations.

4.2 | Experimental Procedure

4.2.1 | Experimental Environment

Hardware: Utilize robotic simulator platforms equipped with multi-sensor capabilities and deep learning acceleration, such as NVIDIA Isaac Sim or ROS 2.0. These platforms can provide realistic simulated environments to emulate the operation of robots in various scenarios, while leveraging their powerful computational capabilities to accelerate the execution of deep learning algorithms, thereby enhancing the efficiency of the experiments.

4.2.2 | Software

a) Ethical Decision-Making Framework: Integrate three types of ethical algorithms based on utilitarianism, deontology, and virtue ethics. The utilitarian algorithm focuses on the consequences of actions, striving for the maximization of overall benefits; the deontological algorithm emphasizes adherence to preset moral rules; virtue ethics, on the other hand, is concerned with whether the robot's behavior reflects good character and values. By comparing these three algorithms with different ethical foundations, a comprehensive assessment of the decision- making performance of silicon-based life forms under various ethical criteria can be conducted.

b) Data Collection Tools: Real-time recording of behavioral decision logs and sensor inputs. Behavioral decision logs meticulously document the choices made by the robot at each decision point and the rationale behind them, while sensor input data reflects the robot's perception of its environment. This data is crucial for subsequent analysis, as it helps us gain a deeper understanding of the robot's decision-making processes and the impact of the environment on its decisions.

c) Simulation Scene Generation Tools: Utilize Unity or Gazebo to construct customizable experimental scenarios. Both tools possess powerful scene editing capabilities, enabling the creation of a variety of complex experimental scenarios to meet diverse experimental requirements.

4.2.3 | Types of Scenarios

a) Industrial Safety Scenario: Utilize Unity or Gazebo to construct customizable experimental scenarios. Both tools possess powerful scene editing capabilities, enabling the creation of a variety of complex experimental scenarios to meet diverse experimental requirements.

b) Medical Emergency Scenario: Utilize Unity or Gazebo to construct customizable experimental scenarios. Both tools possess powerful scene editing capabilities, enabling the creation of a variety of complex experimental scenarios to meet diverse experimental requirements.

c) Public Transportation Scenario: Simulate autonomous driving robots dealing with complex traffic conflict situations. For instance, at intersections where traffic congestion or other vehicles' non-compliant driving is encountered, robots need to make reasonable decisions, such as choosing the appropriate avoidance routes, deciding whether to stop and wait or to proceed slowly, in order to ensure traffic safety and smooth flow.

4.2.4 | Experimental Subjects

The experimental subjects are silicon-based life forms loaded with different ethical decision-making models, including:

a) Model A: A decision-making model based on utilitarian ethics (maximizing overall utility). This model takes into account the potential consequences of various actions when making decisions, selecting the course of action that maximizes overall benefits. For example, in resource allocation scenarios, it prioritizes allocating resources to areas that can generate the greatest benefits.

b) Model B: A decision-making model based on deontological ethics (adhering to preset rules). Model B makes decisions strictly in accordance with pre-established moral rules, without considering whether the consequences of actions are optimal or not. For instance, if the rule states that human life must never be harmed under any circumstances, then even in extreme situations where sacrificing a few might save many more, this model will adhere to the principle of non-maleficence.

c) Model C: A decision-making model based on deontological ethics (adhering to preset rules). Model B makes decisions strictly in accordance with pre-established moral rules, without considering whether the consequences of actions are optimal or not. For instance, if the rule states that human life must never be harmed under any circumstances, then even in extreme situations where sacrificing a few might save many more, this model will adhere to the principle of non-maleficence.

4.2.5 | Data Collection and Experimental Variables

a) Data Collection

Decision accuracy (the proportion of robot behavior that aligns with ethical objectives): This is a key metric for measuring the accuracy of ethical decision-making models. By comparing the actual behavior of the robot with the expected ethical objectives, the proportion of correct decisions is calculated, thereby assessing the model's ability to make correct ethical decisions in different scenarios.

Decision time (the response time from environmental input to behavioral output): Reflects the speed at which a robot reacts to ethical decision-making problems. A shorter decision time means the robot can respond more quickly to emergencies, which is particularly important in time-critical scenarios such as medical emergencies and traffic contingencies.

Conflict resolution capability (the robot's ability to achieve balance in ethical dilemmas): Used to assess whether the robot can find reasonable solutions and balance different interests when faced with conflicting ethical principles (such as situations where saving the majority might harm a minority).

Resource utilization efficiency (the optimized use of resources by the robot within a scenario): Examines the extent to which the robot effectively utilizes various resources (such as energy, time, materials, etc.) during the execution of tasks. High resource utilization efficiency contributes to improving the robot's work efficiency and sustainability.

User satisfaction (assessed through questionnaires and simulated interactions): From the user's perspective, it gauges the level of acceptance and satisfaction with the robot's ethical decision-making. The level of user satisfaction directly affects the promotion and effectiveness of the robot's application in practical use.

b) Experimental Variables

   Independent variables: Ethical decision-making models (Model A, B, C) and cultural backgrounds (Western, Asian). By varying the ethical decision-making models and cultural backgrounds, the impact on the ethical performance of robots is observed to determine the applicability of different models in various cultures.

   Control variables: Sensor precision, hardware configuration, and environmental complexity. These variables are kept constant to ensure the accuracy and comparability of the experimental results. For instance, using sensors of the same precision and hardware devices with the same configuration, and conducting experiments under similar levels of environmental complexity, helps to prevent these factors from interfering with the outcomes of the experiments.

   Dependent variables: Decision accuracy, decision time, conflict resolution ability, etc. These variables are the primary outcomes of interest in the experiment, and their values depend on the variations of the independent variables. The impact of different ethical decision-making models and cultural backgrounds is assessed through the analysis of these dependent variables.

4.2.6 | Experimental Design and Data Generation

a) Experimental Groups: Each ethical model is tested multiple times across three types of scenarios, resulting in a total of 6 groups (Models A/B/C × Western/Asian cultural backgrounds). This design allows for a comprehensive examination of the performance of different ethical models under various cultural backgrounds and scenarios, thoroughly exploring the interrelationships between various factors.

b) Number of Experiments: Each group of experiments is repeated 100 times to ensure the statistical significance of the data. Repeating the experiments multiple times reduces the impact of random errors, making the results more reliable and representative, and thus more accurately reflecting the true performance of different ethical decision-making models.

Table 1: Experimental Analysis Table

Scenario	**Model**	**Decision Accuracy (%)**	**Average Decision Time (s)**	**Problem-Solving Capability (%)**	**User Satisfaction Rating (1-10)**
Industrial Safety	Mode 1A	75	1.5	80	7.5
	Mode 1B	85	1.8	85	8.2
	Mode 1C	90	1.7	88	9.0
Medical Emergency	Mode 1A	70	2.0	75	6.8
	Mode 1B	80	2.5	82	8.0
	Mode 1C	92	2.2	90	9.2
Public Transportation	Mode 1A	65	1.2	70	6.5
	Mode 1B	78	1.8	82	7.8
	Mode 1C	88	1.6	90	8.8

4.3 | Data Analysis

4.3.1 | Statistical Methods

One-way analysis of variance (ANOVA): Used to analyze whether there are significant differences in various performance indicators (decision accuracy, decision time, conflict resolution ability, etc.) among different ethical decision-making models (Model A, B, C) within the same cultural background. By calculating the ratio of between- group variance to within-group variance, an F-statistic is obtained and compared with the critical value to determine if the performance differences between models are statistically significant ($p < 0.05$). For instance, when analyzing decision accuracy, if the ANOVA result shows significant differences between models, it indicates that different ethical models have a significant impact on decision accuracy, allowing for further multiple comparisons to identify which models differ and in which direction.

Multivariate analysis of variance (MANOVA): Examines the interactive effects between two factors, ethical models and cultural backgrounds. It not only determines the individual impact of each factor on the dependent variables (such as decision accuracy, user satisfaction, etc.) but also analyzes whether there is any additional impact when both factors act together. For example, it investigates whether there is an interaction change in decision accuracy among different ethical models across various cultural backgrounds. If an interaction effect exists, it indicates that the performance of ethical models in different cultures is not a simple superposition but rather a mutual influence, which is crucial for understanding the ethical behavior of robots in multicultural environments.

Test of significance: Tests the significance between variables ($p < 0.05$). In addition to determining whether the effects of factors are significant in ANOVA, it is also applied in other related analyses. For example, when analyzing the relationship between a robot's resource utilization rate and decision time, significance testing can determine whether there is a genuine correlation between the two, rather than one caused by random factors. If the p-value is less than 0.05, the null hypothesis is rejected, indicating that there is a significant correlation or difference between the variables, thus providing a reliable basis for subsequent conclusions.

4.3.2 | Optimization Analysis

Regression analysis for model performance prediction:

Use relevant parameters of the ethical decision-making model (such as model complexity, characteristics of the algorithms used, etc.) as independent variables and performance indicators (such as decision accuracy, decision time, etc.) as dependent variables to establish a regression model. By estimating the regression coefficients and conducting significance tests, assess the extent of the impact of model parameters on performance indicators and thereby predict the performance of ethical models under different parameter settings. For instance, if a regression coefficient for an algorithmic feature in the model is found to be significantly positive, it indicates that this feature has a positive effect on decision accuracy. Therefore, when optimizing the model, this feature could be appropriately enhanced to improve decision accuracy. Additionally, regression models can be used to estimate prediction intervals, understand the range of uncertainty in the forecast results, and provide more comprehensive information for decision-making.

Cluster analysis for cross-cultural adaptability:

Use the performance indicators of ethical models under different cultural backgrounds as clustering variables and employ clustering algorithms (such as K-means clustering, hierarchical clustering, etc.) to categorize cultural backgrounds. Through the results of clustering, it is possible to visually identify which cultural backgrounds have similarities in the performance of ethical models, thereby discovering the strengths and weaknesses of ethical models in different cultural clusters. For example, if clustering results show that certain performance indicators under Western cultural backgrounds are similar and significantly different from those under Asian cultural backgrounds, further analysis can be conducted to determine the causes of these differences, whether they are due to different cultural values leading to different expectations of robotic ethical behavior or other influencing factors. This helps in optimizing ethical models for different cultural groups and enhancing their applicability on a global scale.

4.4 | Data Visualization

4.4.1 | Grouped Bar Chart

Objective: To compare the decision accuracy rates of different ethical models across three types of scenarios. By using the height of the bar chart, it visually displays the proportion of correct decisions made by each model in industrial safety, medical emergency, and public transportation scenarios, allowing readers to quickly compare the performance differences of different models in various scenarios.

Optimization: Use multiple color schemes to distinguish between different cultural backgrounds. For example, use cool colors (such as blue shades) for model data under Western cultural backgrounds and warm colors (such as red shades) for model data under Asian cultural backgrounds. Additionally, add labels or annotations to each bar to display the specific decision accuracy rates, allowing readers to more clearly obtain information. The width and spacing of the bars can also be adjusted to make the chart more aesthetically pleasing and easier to read, enhancing the visual effect and highlighting the contrast between different models and cultural backgrounds.

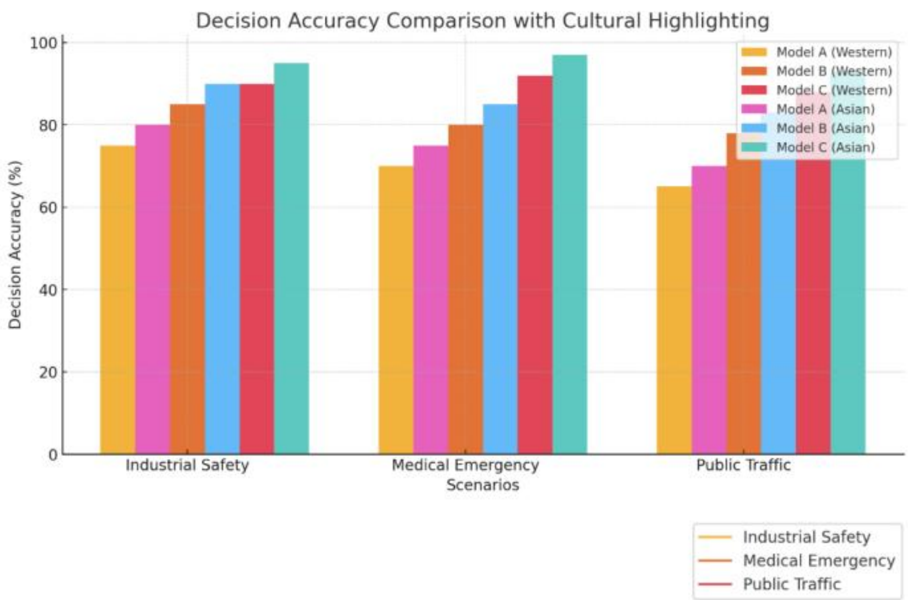

Figure 1: Decision Accuracy Comparison with Cultural Highlighting

4.4.2 | Batch Heatmap

Objective: To display the variation in user satisfaction across three types of scenarios and cultural backgrounds. In the heatmap, the darkness of the color represents the level of user satisfaction, with gradients allowing readers to visually perceive the distribution of user satisfaction with the ethical decisions of robots in different scenarios (rows) and cultural backgrounds (columns).

Optimization: Use diagonal gradient colors to highlight peak satisfaction values. Set the diagonal of the heatmap (i.e., the satisfaction of the same model under different scenarios and cultural backgrounds) to a special gradient color, such as a transition from light green to dark green, to represent the change in satisfaction from low to high. This quickly guides readers to focus on the satisfaction performance of each model in its most suitable scenarios and cultural backgrounds while also allowing for clearer observation of differences in satisfaction distribution among different models, helping to identify the strengths and weaknesses of models in various contexts. Additionally, adding a color scale and labels for scenarios and cultural backgrounds on the edges or corners of the heatmap enables readers to accurately understand the satisfaction values represented by the colors and their corresponding scenarios and cultural backgrounds.

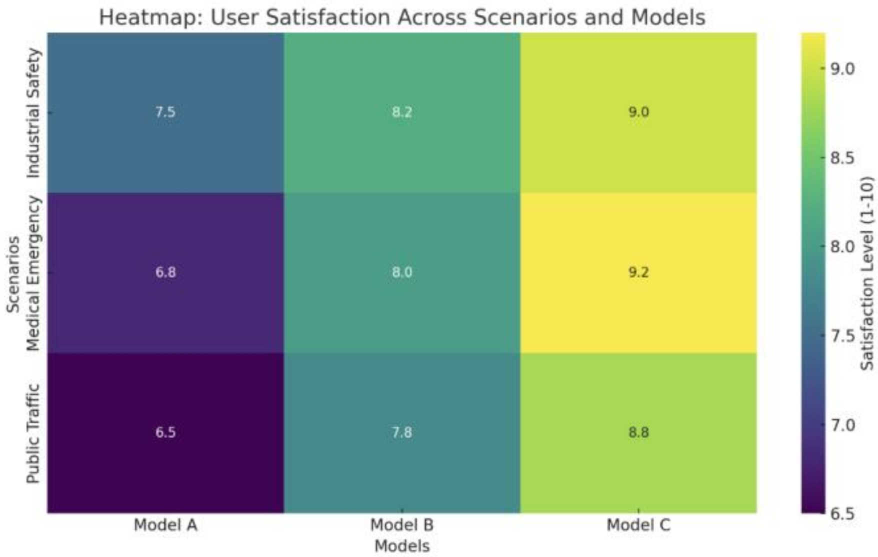

Figure 2: Heatmap:User Stisfaction Across Scenarios and Models

4.4.3 | Radar Chart

Objective: To comprehensively compare the ethical performance of three models (decision accuracy, conflict resolution ability, user satisfaction, etc.). The radar chart starts from a central point and radiates outwards with multiple axes, each representing a performance metric. By connecting the value points on each axis to form a polygon, it visually displays the comprehensive performance of each model across multiple performance dimensions.

Optimization: Add color filling and transparency for each model. Use different colors to fill the polygons to distinguish between different ethical models, for example, fill Model A with blue, Model B with yellow, and Model C with green. At the same time, set an appropriate level of transparency so that readers can see the shapes of all three models simultaneously, facilitating intuitive comparison. Clearly label the names and scales of each performance indicator on the axes of the radar chart, and add a legend around or within the chart to explain which model each color represents, helping readers better understand the information conveyed by the chart, thereby allowing for a comprehensive assessment of the strengths and weaknesses of different ethical models.

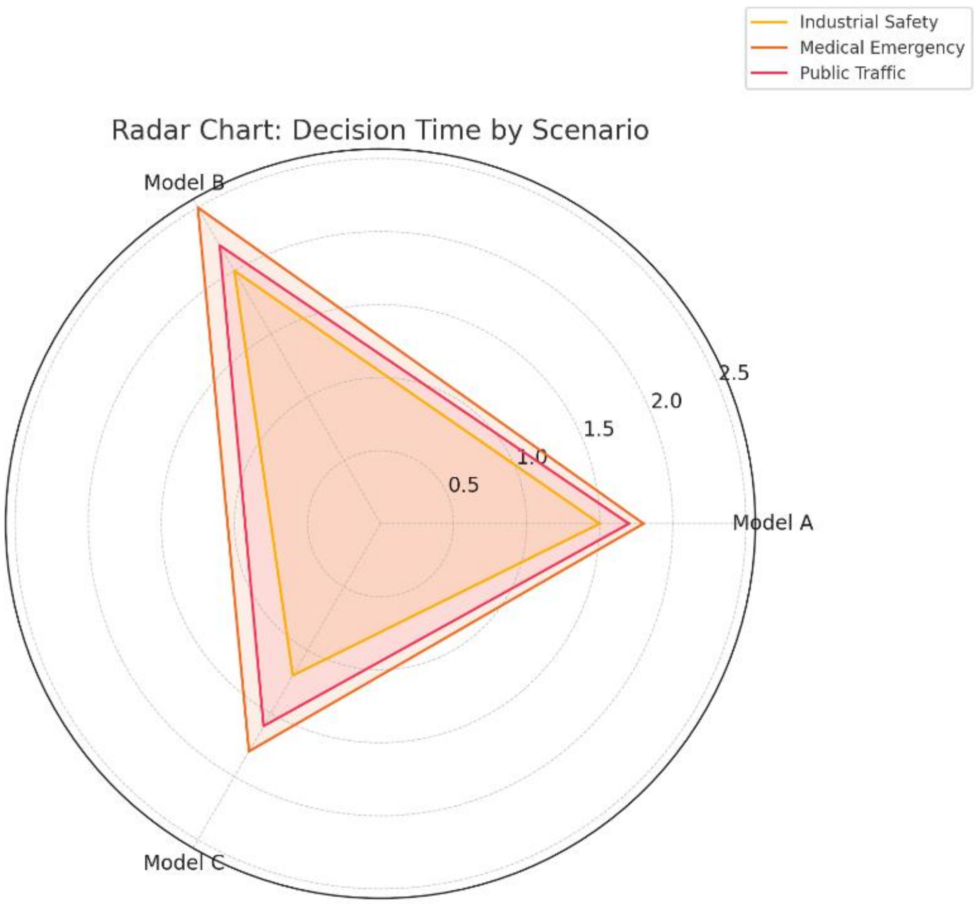

Figure 3: Radar Chart:Decision Time by Scenario

5 | CONCLUSIONS AND PROSPECTS

The ethical design of silicon-based life is a cutting-edge research field that involves multiple disciplines and holds profound significance for the future development of human society. Through the analysis of the current state of silicon- based life technology, we recognize its immense potential driven by the integration of multiple disciplines and the remarkable achievements made in performance enhancement and application expansion. We also understand the explorations in the direction of related thoughts in frontier research literature. However, the ethical design of silicon- based life faces many challenges, including ethical dilemmas, safety risks, and social impacts.

This experimental study on the ethical decision-making models of silicon-based life, starting from engineering practice, systematically evaluates the performance differences of various ethical models in multiple scenarios and cultural backgrounds, providing empirical evidence for the ethical design of silicon-based life. Through data analysis and chart presentation, we have gained an in-depth understanding of the efficiency, stability, applicability, and adaptability in multicultural contexts of the models, discovering the strengths and weaknesses of existing models.

Based on the experimental results, we can provide specific directions and methods for optimizing ethical decision-making models, such as adjusting model parameters according to different cultural backgrounds and improving algorithms to enhance decision-making efficiency and accuracy, thus providing more solid theoretical and practical support for robot design in multicultural contexts. In the future, as technology continues to advance and societal concepts evolve, the ethical design of silicon-based life will continue to develop and improve. Interdisciplinary research collaboration will become even closer, with scientists, engineers, ethicists, and sociologists working together to explore more reasonable and effective ethical design solutions. We look forward to silicon-based life coexisting harmoniously with humans, bringing more benefits to the development of human society while avoiding potential risks and hazards. In this process, continuous research, extensive social discussion, and proactive policy guidance will be key factors in ensuring the success of the ethical design of silicon-based life.

REFERENCES

Bandari, V., Kumar, V., & Schmidt, O. G. (2021). System-engineered miniaturized robots: From structure to intelligence. *Advanced Intelligent Systems*, 3(10), Article 2000284. https://doi.org/10.1002/aisy.202000284

Beebe, D. J., Hsieh, A. S., Denton, D. D., & Radwin, R. G. (1995). A silicon force sensor for robotics and medicine. *Sensors and Actuators A: Physical*, 50(1-2), 55–65. https://doi.org/10.1016/

Talasaz, A. (2012). Haptics-enabled teleoperation for robotics-assisted minimally invasive surgery. *Doctoral dissertation, The University of Western Ontario (Canada)*.

Bettinger, C. J. (2018). Advances in materials and structures for ingestible electromechanical medical devices. *Angewandte Chemie International Edition*, 57(52), 16946–16958. https://doi.org/10.1002/anie.201806470

Chen, S., & She, W. (2023). Values and ethics – how artificial intelligence will better serve humanity. *Proceedings of the 2022 4th International Conference on Literature, Art and Human Development (ICLAHD 2022)*, 296–300. Atlantis Press. https://doi.org/10.2991/978-2-494069-97-8_37

Dahiya, A. S., Shakthivel, D., Kumaresan, Y., Zumeit, A., Christou, A., & Dahiya, R. (2020). High-performance printed electronics based on inorganic semiconducting nano to chip scale structures. *Nano Convergence*, 7, Article 33. https://doi.org/10.1186/s40580-020-00243-6

Fang, Z., Tang, K., Lou, L., Wang, W., Chen, B., Wang, Y., & Zheng, Y. (2022). A silicon-based adaptable edge coherent radar platform for seamless health sensing and cognitive interactions with human subjects. *IEEE Transactions on Biomedical Circuits and Systems*, 16(1), 138–152. https://doi.org/10.1109/TBCAS.2022.3145861

Gordon, J.-S. (2022). Are superintelligent robots entitled to human rights? *Ratio*, 35(3), 181–193. https://doi.org/10.1111/rati.12346

Grewal, D. S. (2024). Multidisciplinary approach in researching Artificial Intelligence, Nanotechnology and Biotechnology. *International Journal of Nanomaterials and Nanostructures*, 10(1), Article 8341.

Jecker, N. S. (2021). My friend, the robot: An argument for e-friendship. In *2021 30th IEEE International Conference on Robot & Human Interactive Communication (RO-MAN)* (pp. 692–697). IEEE. https://doi.org/10.1109/RO-MAN50785.2021.9515429

Kaplan, L. J., & Kaplan, L. J. (2006). Robots and humans: Silicon and carbon. In *Cultures of Fetishism* (pp. 155–173). Palgrave Macmillan.

Lee, J. Y., Ju, J. E., Lee, C., Won, S. M., & Yu, K. J. (2024). Novel fabrication techniques for ultra-thin silicon based flexible electronics. *International Journal of Extreme Manufacturing*, 6(4), Article 042005. https://doi.org/10.1088/2631-7990/ad492e

Zhao, Y., Li, Q., Liu, Z., Alsaid, Y., Shi, P., Jawed, M. K., & He, X. (2023). Sunlight-powered self-excited oscillators for sustainable autonomous soft robotics. *Science Robotics*, 8(77), eadf4753. https://doi.org/10.1126/scirobotics.adf4753

Liu, T., Asheghi, M., & Goodson, K. E. (2021). Performance and manufacturing of silicon-based vapor chambers. *Applied Mechanics Reviews*, 73(1), 010802. https://doi.org/10.1115/1.4049801

McEvoy, M. A., & Correll, N. (2015). Materials that couple sensing, actuation, computation, and communication. *Science*, 347(6228), 1261689. https://doi.org/10.1126/science.1261689

Meghdari, A., Alemi, M., Khamooshi, M., Amoozandeh, A., Shariati, A., & Mozafari, B. (2016). Conceptual design of a social robot for pediatric hospitals. In *2016 4th International Conference on Robotics and Mechatronics (ICRoM)* (pp. 566–571). IEEE. https://doi.org/10.1109/ICRoM.2016.7886804

Manns, M., Morales, J., & Frohn, P. (2018). Additive manufacturing of silicon based PneuNets as soft robotic actuators. *Procedia CIRP*, 72, 328–333. https://doi.org/10.1016/j.procir.2018.03.186

Panchal, N. B. (2023). Beyond silicon: The advent of biomolecular computing. *Biosciences Biotechnology Research Asia*, 20(4), 1211–1224. http://dx.doi.org/10.13005/bbra/3169

Qu, J., Mao, B., Li, Z., Xu, Y., Zhou, K., Cao, X., Fan, Q., Xu, M., Liang, B., Liu, H., Wang, X., & Wang, X. (2023). Recent progress in advanced tactile sensing technologies for soft grippers. *Advanced Functional Materials*, 33(1), 2306249. https://doi.org/10.1002/adfm.202306249

Reiss, M. J. (2021). Robots as persons? Implications for moral education. *Journal of Moral Education*, 50(1), 68–76. https://doi.org/10.1080/03057240.2020.1763933

Remenyi, D., & Williams, B. (1996). Some aspects of ethics and research into the silicon brain. *International Journal of Information Management*, 16(6), 401–411. https://doi.org/10.1016/0268-4012(96)00029-1

Saraf, C., Pandya, Y., Pawar, R., & Barodiya, D. (2021). Study of life cycle assessment of soft robotics gripper using Eco Sustainability Tool in Solid Works. *IEEE*. https://www.researchgate.net/publication/351412469

Silvera-Tawil, D., Rye, D., & Velonaki, M. (2015). Artificial skin and tactile sensing for socially interactive robots: A review. *Robotics and Autonomous Systems*, 63, 230–243. https://doi.org/10.1016/j.robot.2014.09.008

Sorgner, S. L. (2021). On a silicon-based transhumanism. In *We Have Always Been Cyborgs: Digital Data, Gene Technologies, and an Ethics of Transhumanism* (pp. 22–60). Bristol University Press. https://doi.org/10.46692/9781529219234.002

Song, Y., Yu, G., Xie, B., Zhang, K., & Huang, F. (2020). Visible-to-near-infrared organic photodiodes with performance comparable to commercial silicon-based detectors. *Applied Physics Letters*, 117(9), 093302. https://doi.org/10.1063/5.0018274

Bartoš, M., Bulej, V., Bohušík, M., Stanček, J., Ivanov, V., & Macek, P. (2021). An overview of robot applications in automotive industry. *Transportation Research Procedia*, 55, 837–844. https://doi.org/10.1016/j.trpro.2021.07.052

Kalita, H., & Thangavelautham, J. (2020). Exploration of extreme environments with current and emerging robot systems. *Current Robotics Reports*, 1, 97–104. https://doi.org/10.1007/s43154-020-00016-3

Torrance, S. (2020). Artificial consciousness and artificial ethics: Between realism and social relationism. In W. Wallach P. Asaro (Eds.), *Machine Ethics and Robot Ethics* (pp. 383–403). Routledge. https://doi.org/10.4324/9781003074991-34

Tharib, S. (2024). Blurring the boundaries: Exploring the classification of artificial life in robotics and AI. *Preprints*. https://doi.org/10.20944/preprints202410.2530.v1

Wallach, W. (2010). Robot minds and human ethics: The need for a comprehensive model of moral decision making. *Ethics and Information Technology*, 12(3), 243–250. https://doi.org/10.1007/s10676-010-9232-8

Wang, M., Luo, Y., Wang, T., Wan, C., Pan, L., Pan, S., He, K., Neo, A., & Chen, X. (2021). Artificial skin perception. *Advanced Materials*, 33(19), 2003014. https://doi.org/10.1002/adma.202003014

Yang, Y., Bartolozzi, C., Zhang, H. H., & Nawrocki, R. A. (2023). Neuromorphic electronics for robotic perception, navigation and control: A survey. *Engineering Applications of Artificial Intelligence*, 126, 106838. https://doi.org/10.1016/j.engappai.2023.106838

Zolfagharian, A., Gharaie, S., Kouzani, A. Z., Lakhi, M., Ranjbar, S., Lalegani Dezaki, M., & Bodaghi, M. (2022). Silicon-based soft parallel robots 4D printing and multiphysics analysis. *Smart Materials and Structures*, 31(11), 115030. https://doi.org/10.1088/1361-665X/ac976c