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Beyond Pixels: The Journey to Realistic NPCs in Gaming

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Abstract. With the rapid development of the gaming industry, players increasingly demand realism and immersion. The anthropomorphization of NPCs (Non-Player Characters) is crucial for enhancing the gaming experience. This article reviews the development of NPC anthropomorphization technologies, analyzes representative methods and cases, and discusses current limitations and future trends. The article traces the evolution of NPC technologies from early rule-based systems to modern deep reinforcement learning and interdisciplinary approaches, highlighting key milestones. It assesses the advantages and limitations of these technologies at various stages, evaluating their impact on the gaming experience and related fields. Additionally, the article explores current trends in NPC anthropomorphization, particularly the integration of biology, neuroscience, psychology, and computer science, and analyzes the potential and challenges of these emerging methods. Looking forward, the article suggests possible breakthroughs and research focuses for NPC anthropomorphization technologies, offering insights for researchers and practitioners. This study aims to promote innovation in this field, providing players with a more realistic and immersive gaming experience. Furthermore, advancements in NPC technologies will also enhance AI research, driving it towards higher intelligence and broader applications.

Keywords: NPC Anthropomorphization, Game AI, Immersion, Interdisciplinary, Deep Reinforcement Learning.

1. Introduction

The gaming industry has rapidly grown, reaching $159.7 billion in 2020 and projected to hit $201.7 billion by 2023, driven by technological innovations and player demands for realism and immersion[1]. Initially limited by coarse graphics and simple NPC behaviors, advancements in 3D and VR technologies have revolutionized game graphics. NPC design, powered by AI, now focuses on human-like behavior patterns and emotional expressions to enhance player immersion[2]. Researchers highlight that realistic NPCs create stronger player engagement, though balancing human-like behavior with game objectives remains complex[3][4].

NPC anthropomorphism significantly impacts gaming by reducing development costs and enhancing game quality. It advances AI research by simulating human behaviors, but also poses ethical challenges and social impacts, influencing fields like education and tourism[5][6].

This paper reviews the development of anthropomorphic NPC technology, analyzing historical methods, current interdisciplinary trends, and future research directions, aiming to enhance gaming experiences through comprehensive evaluation and innovation. This synthesis not only bridges past and future research but also guides and supports ongoing advancements in the field.

2. Game Development

The gaming industry, deeply intertwined with computer technology, has seen profound advancements over the decades. Enhancing immersion and realism has been a primary focus, achieved through advancements in game graphics and AI-driven NPCs[7]. Early games like "*Pong*" and "*Space Invaders*" featured rudimentary pixel graphics due to limited hardware. However, the 1990s introduced 3D technology, offering greater visual depth in titles like "*Doom*" and "*Quake*". The 21st century saw high-definition and ray tracing technologies, exemplified by "*Red Dead Redemption 2*" and "*Cyberpunk 2077*", further enhancing visual realism[8].

Beyond graphics, NPC anthropomorphism is crucial for immersion. Initially, NPCs served functional roles with scripted behaviors, as seen in "*Super Mario Bros*" and "*Contra*". Machine learning later enabled more dynamic and intelligent NPCs. In "*F.E.A.R.*", enemy NPCs used goal-oriented behavior trees and artificial potential fields for sophisticated tactics[9]. The Nemesis System in Middle-earth: "*Shadow of Mordor*" adjusted NPC abilities and memories in real-time based on player actions[10]. AI milestones like "*OpenAI Five*" and "*AlphaStar*" demonstrated advanced NPC capabilities, influencing NPC behavior modeling[11][12].

Narrative NPCs have evolved from basic story roles in "*Final Fantasy VI*" to complex characters in games like Detroit: "*Become Human*", where player choices significantly impact NPC behavior and story outcomes. This development is aimed at creating more immersive and emotionally engaging experiences. Future NPC design will likely leverage AI, virtual reality, and digital twins to enhance NPC autonomy, sociability, and emotional expression, providing players with richer, more interactive gaming experiences.

3. NPC anthropomorphization technology

3.1. Traditional Methods: Rule-Based Systems and Simple AI Algorithms

Traditional NPC behavior design primarily relied on simple if-else logic and predefined scripts. These methods, though basic, were crucial in early game AI development and still hold value in specific scenarios.

3.2. Finite State Machine (FSM)

A Finite State Machine (FSM) is a computational model used to design systems with a limited number of distinct states, transitions, and rules. FSMs were fundamental in early game AI, enabling behaviors like patrolling and attacking in games like "*Half-Life*" and simulating daily activities in "*The Sims*". FSMs are straightforward and easy to implement but lack flexibility in complex and variable situations.

3.3. Machine Learning Methods: Behavior Pattern Recognition and Prediction Using Machine Learning

Machine learning methods train NPCs to recognize player behavior and respond accordingly, offering greater flexibility and adaptability.

3.4. Decision Tree Learning

Decision tree learning is used for classification and regression tasks, creating a tree structure of decisions. This method was employed in "*Black & White 2*" to enhance NPC behavior and in the *"Forza Motorsport"*series to create adaptive racing AI. Decision trees are intuitive and easy to modify but can become complex and challenging to manage in large projects.

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3.5. Support Vector Machine (SVM)

Support Vector Machine (SVM) is a supervised learning algorithm for classification and regression. SVMs have been used in "*StarCraft*" to predict opponent strategies and in fighting games to create adaptive AI. SVMs perform well in high-dimensional spaces and handle nonlinear classification problems but can be computationally intensive and sensitive to parameter tuning.

3.6. Reinforcement Learning: Methods for NPC Autonomous Learning and Interaction with the Environment

Reinforcement learning (RL) involves an agent learning strategies by interacting with the environment. It is used in various scenarios, such as action games where NPCs learn player attack methods and open-world games where NPCs adapt to player actions and environmental changes.

3.7. Q-Learning

Q-Learning is a model-free RL algorithm that helps an agent find the optimal action-selection policy. It has been used in projects like "*Nero*" (Neuro-Evolving Robotic Operatives) for training robotic soldiers and in the "Unreal Tournament" Pogamut platform for adaptive AI.

3.8. SARSA

SARSA is an on-policy RL algorithm updating Q-values based on the actual next action taken. It has been applied in training AI to play "*Super Mario Bros*." and in "*Minecraft*" to learn complex survival strategies.

3.9. Deep Q-Network (DQN)

DQN combines Q-learning with deep learning, using techniques like experience replay and target networks to address instability. This method has achieved human-level performance in Atari 2600 games and trained AI in "*StarCraft II*" to defeat top human players.

3.10. Policy Gradient Methods

Policy gradient methods directly optimize the policy function. OpenAI Five used these methods to train "*DOTA 2*" AI, capable of defeating professional players, and AI in "*Quake III Arena*" for cooperative and competitive gameplay.

3.11. Bio-Constrained Deep Reinforcement Learning: Advanced Methods to Simulate Real Biological Behavior

Bio-constrained deep reinforcement learning incorporates biological factors into models to create more natural NPC behaviors. This approach aims to simulate human-like limitations, such as signal fluctuations, reaction delays, fatigue, and decision-making difficulties in complex situations. An example is the use of a bio-constrained DQN network in "INFINITE MARIO BROS.," resulting in behaviors closer to human gameplay.

Table 1. Advantages and Disadvantages of Technological Approaches to NPC Anthropomorphization

Method	Advantages	Disadvantages
FSM	Simple concept, easy to debug, low resource demand.	Complex with many states, lacks flexibility.
Decision Tree	Intuitive, easy to modify and extend.	Becomes complex with depth, hard to manage and optimize.
SVM	Handles high-dimensional data, robust to noise, good generalization.	Sensitive to kernel selection, difficult to visualize results.

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Table 1. (continued).

Q-Learning	Learns through interaction, adapts to dynamic environments.	Time-consuming, high computational resources needed.
SARSA	Stable in noisy data, adapts to dynamic environments.	Slow convergence, depends on reward function design.
DQN	Effective in high-dimensional spaces, improves training stability.	Requires significant resources, sensitive to hyperparameters
Policy Gradient Methods	Optimizes directly, good for complex strategies.	Computationally expensive, requires careful tuning.
Bio-Constrained DQN	Realistic behaviors, enhances immersion.	Complex implementation, interdisciplinary knowledge needed

4. NPC Multidisciplinary Integration

4.1. Cross-Disciplinary Applications of Artificial Intelligence

AI enhances NPCs in gaming through natural language processing (NLP), computer vision, machine learning, and deep learning. NLP enables dynamic, context-aware dialogues, creating natural conversations and emotional expressions. Computer vision allows NPCs to recognize visual cues and simulate human visual experiences, enhancing anthropomorphic behaviors. Machine learning lets NPCs learn from player behavior, personalizing the gaming experience. Deep learning's neural networks improve NPC decision-making, leading to sophisticated and realistic behavior patterns[13][14][15].

4.2. Biologically-Inspired NPC Behavior Design

Biological intelligence inspires NPC design. Ant foraging behavior, where simple rules lead to group-level intelligence, informs distributed self-organization in NPCs for tasks like swarm pathfinding and coordinated attacks. Biological research on emergent behaviors and cognitive functions offers models for NPC perception, learning, and memory, achieving more natural group interactions and intelligent behaviors[16][17][18].

4.3. Cognitive and Decision-Making Mechanisms Revealed by Neuroscience

Neuroscience reveals human cognitive and decision-making mechanisms, guiding NPC design. The brain's hierarchical visual system inspires algorithms that process visual inputs from simple to complex, enhancing NPC perception. Neuroscience findings on cognition, language, memory, and emotion inform NPC intelligence, enabling brain-like perception, learning, and reasoning.

4.4. Psychology-Guided Emotion and Personality Modeling

Neuroscience reveals human cognitive and decision-making mechanisms, guiding NPC design. The brain's hierarchical visual system inspires algorithms that process visual inputs from simple to complex, enhancing NPC perception. Neuroscience findings on cognition, language, memory, and emotion inform NPC intelligence, enabling brain-like perception, learning, and reasoning[18][19].

4.5. A Representative Case of Interdisciplinary Integration

Case Study 1: Integrating Neuroscience and Reinforcement Learning for NPC Control

Combining neuroscience with AI has led to more intelligent NPCs. One study, "Brain Topology Improved Spiking Neural Network for Efficient Reinforcement Learning of Continuous Control," introduced the BT-SNN model, inspired by the mouse brain and trained with reward-modulated STDP (RM-STDP)[20]. This model achieved superior learning speed and performance in various

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environments compared to traditional SNN and ANN-based RL algorithms[21]. The BT-SNN's modular and sparse activity patterns, mimicking biological neural systems, significantly enhance NPC realism and adaptability[22].

Case Study 2: Integrating Psychology and Natural Language Processing for NPC Dialogue Generation

Integrating psychology with NLP has improved NPC dialogues. The Speaker-Addressee model introduced by Li et al. [23] uses dual role embeddings to reflect interaction patterns between roles. This model, implemented using an LSTM-based encoder-decoder framework, significantly enhances dialogue coherence and role consistency. By incorporating psychological mechanisms, NPC dialogues become more natural and contextually appropriate, enriching the gaming experience[24].

5. Future perspectives and technological challenges

5.1. Technical Challenges

NPC anthropomorphism faces several technical challenges. Constructing realistic NPCs involves complex factors such as cognition, emotion, and movement, requiring advanced AI models and algorithms. Simplifying system complexity while maintaining high-quality behavior is critical. Additionally, the computational demands for real-time responses and continuous evolution of NPCs are immense, necessitating efficient algorithms and significant computational resources. NPCs must adapt dynamically to changing game environments, requiring them to adjust strategies based on real-time feedback.

5.2. Research Directions

Future research in NPC anthropomorphism relies on interdisciplinary integration. Advances in AI, biology, psychology, and neuroscience will support NPC development. Key areas include improving deep reinforcement learning, utilizing Knowledge Graphs and Few-Shot Learning, and enhancing NPC emotional expression with advanced language models. Insights from brain-like computing and Brain-Computer Interfaces, as well as personality theory and emotion management from psychology, will guide more natural and realistic NPC behavior modeling. Collaborative innovation across disciplines will drive revolutionary impacts in gaming and entertainment.

5.3. Review's limitations

The review is limited by space, preventing detailed ethical discussions in specific contexts, and lacks the impetus for new ethical frameworks. Additionally, there is no consensus or planning for comprehensive knowledge transfer and training in the field.

6. Conclusion

NPC anthropomorphization embodies the game industry's commitment to progress and excellence. It integrates artificial intelligence and cognitive sciences, enhancing the gaming experience and contributing to AI advancements. By combining AI technologies with insights from biology and psychology, developers can create complex, realistic NPC behaviors, improving game quality and player satisfaction. This multidisciplinary approach is particularly valuable for small and medium-sized game studios, reducing development costs and time. Moving forward, continued integration of advanced computational methods and theoretical research will drive further innovation in NPC design, creating more immersive gaming experiences and contributing to intelligent science and digital society.

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