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The evolving landscape of generative AI: Architectures, Applications, and ethical governance in 2024-2025

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Abstract

Generative Artificial Intelligence (AI) has undergone a profound evolution, transitioning from a niche research area to a pervasive technology with significant societal and economic impact. This paper provides a comprehensive review of the latest advancements in generative AI architectures and methodologies from 2024 to mid-2025, highlighting the shift towards more sophisticated multimodal and agentic AI systems. We analyze the burgeoning applications of generative AI across diverse sectors, including content creation, healthcare, and software development, while critically examining the complex ethical challenges such as bias, misinformation, intellectual property, and data privacy. Furthermore, we discuss the societal implications, particularly concerning labor market shifts and the imperative for robust regulatory frameworks. Drawing on recent trends and legislative developments like the EU AI Act, this paper proposes a framework for responsible development and deployment, aiming to maximize the benefits of generative AI while mitigating its inherent risks.

Keywords: Generative AI, large language models (LLMs), multimodal AI, AI agents, ethical AI, AI regulation, EU AI act, societal impact, deep learning

1. Introduction

The year 2024 and the first half of 2025 have solidified generative AI's position as a pivotal technological force. Unlike traditional AI systems that primarily analyze and predict based on existing data, generative AI excels at creating novel, high-fidelity content across various modalities—text, images, audio, video, and code. This transformative capability, powered by breakthroughs in deep learning, particularly large language models (LLMs) and diffusion models, has spurred unprecedented innovation and adoption across virtually every sector.

This paper aims to provide a timely and comprehensive overview of the generative AI landscape. We begin by dissecting the architectural advancements that underpin this rapid progress. Subsequently, we explore the myriad applications that are currently redefining industries. Crucially, we then delve into the multifaceted ethical concerns and societal impacts, acknowledging the growing apprehension around issues such as misinformation, job displacement, and the need for robust governance. Finally, we discuss emerging regulatory frameworks, with a particular focus on the EU AI Act, and propose strategies for responsible development and deployment of generative AI.

2. Architectural Advancements in Generative AI (2024-2025)

The period between 2024 and mid-2025 has seen a significant evolution in generative AI architectures, moving beyond foundational Transformer models towards more integrated and autonomous systems. A defining trend has been the rise of multimodal AI systems, with models like Google's Gemini and OpenAI's GPT-4o demonstrating advanced capabilities in understanding, processing, and generating content across text, image, audio, and video modalities simultaneously. This integration mimics human perception, leading to more context-aware and intuitive AI applications (eClerx, 2025; [x]cube LABS, 2025) ^[3, 14], with current research focusing on seamless integration, improved decision-making through cross-referencing multiple data types, and advancements in AI creativity.

Another major development is the shift from reactive, prompt-based AI to proactive, autonomous AI agents. Models like OpenAI's 'o1' and Anthropic's Claude series are exhibiting enhanced reasoning capabilities, enabling them to undertake complex, multi-step tasks with minimal human intervention, such as web Browse or application administration

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(eClerx, 2025; [x]cube LABS, 2025) ^[3, 14]. This involves modular agentic architectures and frameworks for multi-agent collaboration, often integrating reinforcement learning and chain-of-thought reasoning to improve decision-making processes.

While multimodal and agentic AI are prominent, core Large Language Model (LLM) and diffusion model research continues. There's a growing focus on efficiency and model size, with efforts to develop smaller, more efficient models that can run on edge devices, addressing concerns around computational cost, energy consumption, and data privacy (Medium, Heka AI, 2025) ^[7]; techniques like model quantization are gaining traction. Furthermore, as the available "good" training data approaches saturation, the emphasis has shifted to data quality over quantity, meaning careful handling is needed for the increasing proportion of AI-generated data on the internet to avoid performance degradation in new models (Medium, Heka AI, 2025) ^[7]. We also observe the exploration of hybrid architectures, combining LLMs with other techniques like State-Space Models (SSMs) to achieve state-of-the-art performance with higher efficiency. Lastly, there's a clear trend towards tailoring general foundation models for specific domains, creating domain-specific foundation models like medical vision-language models (e.g., MedGemma) to achieve higher accuracy and effectiveness in specialized applications (Data Science Dojo, 2025) ^[2].

3. Transformative Applications across Industries (2024-2025):

Generative AI's practical applications have expanded dramatically in the past year, impacting various sectors. In Content Creation and Media, generative AI tools are now integral to content pipelines, rapidly producing articles, marketing copy, social media content, and scripts. For visual media, tools like Midjourney and DALL-E continue to evolve, generating sophisticated artwork, product designs, and realistic images from text prompts, while video generation from text or images is maturing, enabling faster prototyping and specialized effects. Personalized storytelling and music composition are also becoming more accessible (Beyond Key, 2025; [x]cube LABS, 2025) ^[1, 14].

In Software Development, generative AI has become an indispensable "AI pair programmer," with tools like GitHub Copilot and Google Cloud's Gemini Code Assist generating code snippets, assisting with debugging, refactoring code, and automating documentation. The emergence of agentic AI further promises to automate complex workflows in the software development life cycle, shifting engineers' focus to higher-level design and critical thinking (Gartner, 2025) ^[5].

Within Healthcare and Life Sciences, generative AI is accelerating drug discovery by designing novel molecules and predicting their properties. In medical imaging, it aids in enhancing image quality, synthesizing data for training other AI models, and generating comprehensive reports. Personalized medicine is advancing through AI's ability to develop customized treatment plans based on individual patient data, and synthetic data generation is crucial for privacy-preserving research (EU Science Hub, 2025).

For Business and Customer Experience, hyper-personalization is a significant trend, with AI tailoring user experiences based on real-time data and preferences, from e-commerce to customer service (Beyond Key, 2025) ^[1]. Chatbots and virtual assistants are becoming highly sophisticated, handling complex conversations and resolving inquiries autonomously, thereby improving

customer satisfaction and operational efficiency (World Economic Forum, 2025) ^[13].

Finally, in Education, generative AI is being explored to customize learning materials, create personalized educational experiences for students, and assist educators with administrative tasks like summarization and content generation (EU Science Hub, 2025) ^[4].

4. Ethical and Societal Implications

The rapid proliferation of generative AI has brought to the forefront a complex array of ethical and societal concerns that demand urgent attention. One significant issue is misinformation and deepfakes, as generative AI's ability to produce highly realistic fake text, images, audio, and video poses a substantial risk for spreading false information, manipulating public opinion, and causing reputational damage. The ease and scale of creation exacerbate the challenge of distinguishing authentic from synthetic content, thereby eroding public trust in digital information (SAS Voices, 2025; Research AIMultiple, 2025) ^[9, 10].

Another critical concern is bias and discrimination: generative AI models, often trained on vast datasets that may reflect societal biases, risk perpetuating and even amplifying these biases in their outputs. This can lead to discriminatory content in areas like job descriptions or marketing materials, or even biased decision-making if AI is used for sensitive applications such as risk assessment (UPES, 2025) ^[12].

Intellectual property and copyright also present significant legal and ethical questions. The training of generative AI models on vast quantities of copyrighted material raises concerns regarding intellectual property rights and fair use, with disputes over authorship and the ownership of AI-generated content that mimics or combines existing works becoming increasingly common (UPES, 2025) ^[12].

Furthermore, data privacy and confidentiality are paramount, as generative AI models require immense amounts of data, raising concerns about sensitive information disclosure, and the potential misuse of personal data used for training or processed through AI platforms (UPES, 2025) ^[12].

Generative AI also poses a risk of labor market disruption: while it can significantly boost productivity, particularly in high-skill professions, it also risks job displacement for tasks that can be automated or augmented (University of Oxford, 2025) ^[11]. Professions exposed to AI include writing, accounting, programming, and graphic design, though it also creates new demands for AI-related skills and transversal skills like critical thinking and emotional intelligence, necessitating significant upskilling and reskilling initiatives (EU Science Hub, 2025; World Economic Forum, 2025) ^[13].

Accountability and human oversight are challenging due to the autonomous nature and "black box" problem of some generative AI models, which make it difficult to assign responsibility for errors or harmful outputs; thus, establishing clear accountability frameworks and ensuring appropriate human oversight are critical (SAS Voices, 2025) ^[10].

Finally, the increasing human-like interaction capabilities of generative AI could lead to psychological and social impacts, as individuals might form emotional attachments to AI entities, potentially affecting mental health and social cohesion (SAS Voices, 2025) ^[10].

5. Regulatory Frameworks and Responsible AI Governance (2024-2025): Recognizing the profound implications of generative AI, governments and organizations worldwide are scrambling to develop regulatory frameworks and ethical guidelines, with the European Union's AI Act standing out as a pioneering effort. Enacted in 2024, the EU AI Act (Regulation (EU) 2024/1689) is the world's first comprehensive legal framework for AI, adopting a risk-based approach that categorizes AI systems into four levels. The "Unacceptable Risk" category bans practices such as harmful manipulation, social scoring, and untargeted biometric scraping. "High Risk" AI systems, which pose serious risks to health, safety, or fundamental rights (e.g., in critical infrastructure, education, employment, or law enforcement), face strict obligations including risk assessment, data quality, logging, human oversight, and conformity assessments (European Union, 2025; ModelOp, 2025) ^[4, 8]. "Limited Risk" systems require transparency, such as informing users when interacting with an AI system (e.g., chatbots) and clear labeling of AI-generated content like deepfakes. Finally, "Minimal Risk" systems encompass most AI applications and have no specific obligations beyond existing legislation. The EU AI Act serves as a global benchmark, influencing discussions and potential regulations in other jurisdictions. Compliance with its provisions, particularly for high-risk AI and General Purpose AI (GPAI) models, necessitates robust risk management, data governance, and continuous monitoring ([x]cube LABS, 2025) ^[14]. Beyond governmental regulation, various organizations are contributing to global initiatives and industry standards by developing ethical AI principles and best practices. These often emphasize fairness, transparency, accountability, privacy, and human control, with the overarching goal of establishing a common understanding of responsible AI development and deployment to encourage self-regulation within the industry. Looking to the future, the trajectory of generative AI in 2024-2025 indicates a continued push towards more autonomous, multimodal, and domain-specialized systems. Key future directions include enhanced AI agents, with the development of increasingly sophisticated AI agents capable of greater autonomy, complex reasoning, and seamless integration into workflows, potentially leading to "superagency" in the workplace (McKinsey, 2025) ^[6]. There's also a trend towards more accessible and efficient models, reflecting continued efforts to develop smaller, more efficient, and potentially open-source models that can be deployed on a wider range of devices, democratizing access to powerful generative AI capabilities. Advanced human-AI collaboration will see the focus shifting from simple AI tools to intelligent collaborators that augment human creativity and productivity, enabling humans to concentrate on tasks requiring critical thinking, ingenuity, and empathy. Crucially, addressing ethical challenges will involve increased research and development into explainable AI (XAI), bias detection and mitigation techniques, and robust watermarking or provenance tracking for AI-generated content to combat misinformation. Lastly, an evolving regulatory landscape means that as technology advances, regulatory frameworks will need to continuously adapt to address new risks and ensure that innovation proceeds responsibly. In conclusion, generative AI represents a monumental technological leap with the potential to redefine industries and human-computer

interaction. While its capacity for innovation is undeniable, the complexities surrounding its ethical implications and societal impacts necessitate a proactive and collaborative approach. By prioritizing responsible development, fostering transparent practices, and implementing robust governance, we can harness the transformative power of generative AI to drive progress and create a more equitable and prosperous future.

6. Conclusion

In conclusion, the period spanning 2024 to mid-2025 marks a pivotal chapter in the evolution of generative AI. We've witnessed a significant architectural leap beyond foundational Transformer models, leading to the widespread adoption of sophisticated multimodal and autonomous AI agent systems. These advancements have propelled generative AI into transformative applications across virtually every sector, from revolutionizing content creation and software development to accelerating breakthroughs in healthcare and enhancing customer experiences.

However, this rapid progress is accompanied by a complex array of ethical and societal concerns that demand urgent and sustained attention. The potential for misinformation, deepfakes, and algorithmic bias, alongside challenges related to intellectual property and labor market disruption, underscores the critical need for responsible development. The emergence of robust regulatory frameworks, exemplified by the EU AI Act, signals a global commitment to addressing these challenges by establishing clear guidelines and promoting transparency and accountability. Looking ahead, the trajectory of generative AI points towards even more integrated, efficient, and specialized systems. The focus will increasingly shift towards enhancing human-AI collaboration, developing more accessible models, and rigorously addressing ethical pitfalls through advancements in explainable AI and bias mitigation. Ultimately, generative AI represents a monumental technological leap with the potential to redefine industries and human-computer interaction. To fully realize its promise and mitigate its risks, a proactive, collaborative, and ethically grounded approach to development and deployment is not merely advisable but essential for shaping a more equitable and prosperous future.

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