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Bard to Gemini: A Technical & Qualitative Assessment of Google's Evolving Gen AI Ecosystem

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Abstract: The rapid evolution of Artificial Intelligence (AI) and integrated device peripherals is transforming the digital landscape, particularly in information accessibility and human-computer interaction. This study presents a mixed-methods analysis of Google's conversational AI system, Gemini (formerly Bard), providing a comprehensive evaluation of its functionality, user experience, and architectural foundations. Utilizing a triangulated research design, qualitative data from structured questionnaires and interviews are integrated with quantitative performance metrics derived from Google Analytics and standardized benchmarking protocols. The research involves comparative benchmarking against established models such as GPT-4 and Microsoft Copilot, specifically assessing response latency, semantic accuracy, and contextual adaptability. Furthermore, technical audits of Gemini's Transformer-based neural architectures and multimodal capabilities—spanning text, image, and audio—illuminate its capacity for complex reasoning and cross-modal attention. Usability studies further investigate Gemini's integration within the Google Workspace ecosystem and its efficiency across diverse deployment environments. Critically, the analysis addresses ethical dimensions, including data protection compliance (GDPR/CCPA), algorithmic transparency, and bias mitigation. The findings delineate the strengths and limitations of current models, offering strategic recommendations for user-centric design and the responsible governance of generative AI systems.

Keywords: artificial intelligence (AI); computer vision; deep learning (DL); Gemini; generative artificial intelligence (GAI); large language model (LLM); machine learning (ML)

1. Introduction

Artificial Intelligence (AI) has rapidly transformed the landscape of human-computer interaction (HCI), enabling more adaptive, efficient, and intelligent digital systems [1]. In particular, the emergence of Generative Artificial Intelligence (GAI) has introduced a new class of models capable of producing novel outputs such as text, images, and code based on learned data representations [2]. These systems are primarily driven by Large Language Models (LLMs), which utilize deep neural architectures to model linguistic patterns and generate contextually coherent responses [3]. Recent advancements in LLM development have significantly improved performance across a wide range of natural language processing (NLP) tasks, including reasoning, summarization, and code generation [4]. Furthermore, the integration of multimodal capabilities has extended the functionality of these systems beyond text-based inputs, enabling the simultaneous processing of text, images, audio, and video data [5]. Such developments represent a paradigm shift toward more generalized and context-aware AI systems that can operate across diverse application domains [6]. A notable advancement in this domain is the evolution of Google's conversational AI platform from Bard to Gemini, which reflects a transition toward natively

multimodal architectures [7]. Gemini is designed to unify multiple data modalities within a single model framework, allowing for more sophisticated reasoning and cross-modal understanding [8]. Empirical studies have begun to evaluate Gemini's performance across various domains, including education, healthcare, and technical problem-solving tasks [9]. Comparative analyses with other leading systems, such as GPT-4 and Microsoft Copilot, suggest that Gemini demonstrates competitive performance in reasoning and multimodal benchmarks [10]. Despite these advancements, there remains a lack of comprehensive empirical research that systematically evaluates Gemini's architectural innovations and real-world performance [11]. In particular, limited attention has been given to its Mixture of Experts (MoE) framework and its implications for computational efficiency and task specialization [9]. Additionally, questions surrounding ethical considerations, including bias, transparency, and data privacy, continue to be central to the deployment of large-scale AI systems [6].

Therefore, this study aims to provide a structured and comparative evaluation of Google Gemini by examining its performance, usability, and underlying architecture. By integrating qualitative user feedback with quantitative benchmarking metrics, this research seeks to contribute to the growing body of literature on generative AI systems and their evolving role in modern digital ecosystems [2].

2. Methods and Experimental Analysis

This study employs a triangulated mixed-methods research design to evaluate the performance and usability of Google Gemini. The methodology integrates qualitative user-experience data with quantitative system metrics and standardized technical benchmarks.

2.1 Data Collection and Sampling

A combination of primary and secondary data sources was utilized to capture a comprehensive performance profile:

Primary Qualitative Data: Structured questionnaires and semi-structured interviews were conducted with a purposive sample of N=50 participants (comprising 20 software developers, 15 academic researchers, and 15 general users). Recruitment was facilitated through professional networks and academic mailing lists.

Secondary Quantitative Data: System-level performance metrics, including session duration and interaction frequency, were aggregated via digital analytics tools. These datasets provided a baseline for evaluating real-world usage patterns across different geographic regions.

2.2 Performance Benchmarking Protocols

To ensure an objective comparison, Gemini's performance was measured against OpenAI's GPT-4 and Microsoft Copilot using the following standardized metrics:

Semantic Accuracy: Evaluated through the Massive Multitask Language Understanding (MMLU) benchmark, which tests world knowledge and problem-solving across 57 subjects.

Response Latency: Measured in milliseconds (ms) as the time elapsed from prompt submission to the initiation of the first token generation.

Contextual Adaptability: Assessed via multi-turn dialogue simulations to test the model's ability to maintain intent over extended interactions.

2.3 Technical and Architectural Audit

The study includes a formal technical review of Gemini's underlying neural framework. This analysis specifically examines:

Mixture of Experts (MoE): Evaluation of dynamic routing mechanisms that activate specific sub-networks for specialized tasks, enhancing computational efficiency.

Multimodal Integration: Analysis of cross-modal attention mechanisms that enable simultaneous processing of text, image, and audio inputs.

2.4 Data Analysis Methods

Data synthesis was performed using the following analytical frameworks:

Thematic Analysis: Qualitative feedback from interviews was coded to identify recurring themes related to user trust, perceived utility, and algorithmic bias.

Inferential Statistics: Quantitative data were analyzed using correlation testing to determine the relationship between system latency and user satisfaction ratings. All statistical analyses were conducted with a significance threshold of $p < 0.05$.

2.5 Ethical Considerations

The research protocol adhered to institutional ethics guidelines. All participants provided informed consent, and data collection complied with the General Data Protection Regulation (GDPR) and the California Consumer Privacy Act (CCPA) to ensure anonymity and data security.

3. Evolution from Bard to Gemini

The transition from Google Bard to Gemini represents a significant advancement in the development of large-scale conversational AI systems [7]. This evolution reflects a shift toward more integrated and capable architectures designed to support complex reasoning and multimodal interaction [9]. Gemini Advanced, powered by the Gemini Ultra model, has been introduced as a high-performance system optimized for demanding computational and cognitive tasks [15]. Unlike earlier conversational models, Gemini is designed to address a broader range of problem-solving scenarios, including logical reasoning, code generation, and content creation [12]. Empirical evaluations indicate that such systems are increasingly capable of handling domain-specific and technically complex queries with improved precision [13]. These capabilities position Gemini as a competitive alternative to other leading AI models in both research and applied contexts [14]. A key feature of the Gemini ecosystem is its emphasis on usability and integration within existing digital infrastructures. The system supports applications such as personalized learning, automated coding assistance, and real-time content generation [16]. Additionally, Gemini has been deployed across a wide geographic range, reflecting its scalability and growing global adoption [15].

However, linguistic support remains uneven, with full functionality currently concentrated in a limited number of languages [16]. Gemini is also embedded within Google's broader service ecosystem, including tools such as Gmail and Google Docs, which enhances workflow efficiency and user productivity [7]. This integration enables seamless interaction between generative AI capabilities and everyday digital tasks, reducing the need for external platforms and improving task continuity [8]. Furthermore, the availability of Gemini across multiple devices, including mobile platforms, supports accessibility and real-time interaction in diverse usage environments [15].

From an ethical and governance perspective, Gemini incorporates a range of safety and alignment mechanisms designed to mitigate harmful outputs and ensure responsible AI deployment [6]. These include content filtering systems, user feedback loops, and iterative model refinement processes aimed at reducing bias and improving reliability [6]. Despite these safeguards, concerns remain regarding algorithmic transparency and the potential for unintended biases in generated outputs, which have been widely discussed in recent literature [12].

In addition, Gemini's multimodal interface allows users to interact via text, voice, and visual inputs, reflecting a broader trend toward more flexible and intuitive human–AI interaction paradigms [5]. This capability is supported by advances in cross-modal attention mechanisms, which enable the system to process and integrate diverse data types within a unified framework [9]. Such developments highlight the increasing complexity and versatility of modern generative AI systems.

The transition from Bard to Gemini represents not merely a rebranding effort but a substantive technological progression toward more powerful, multimodal, and integrated AI systems [7]. While the platform demonstrates significant improvements in functionality and accessibility, ongoing evaluation is required to assess its long-term performance, ethical implications, and real-world impact across different domains [11].

4. Google Gemini Model: Capabilities and Limitations

Google Gemini, developed by Google DeepMind, represents a recent advancement in the design of large-scale generative AI systems, with a particular emphasis on multimodal processing and integrated reasoning capabilities [9]. Unlike earlier language models that primarily focus on text-based interactions, Gemini is designed to process and generate outputs across multiple data modalities, including text, images, and audio [5]. This multimodal functionality reflects a broader trend in AI research toward unified architectures capable of handling heterogeneous data inputs within a single framework [6]. At its core, Gemini is built upon Transformer-based architectures, which have become the dominant paradigm in modern natural language processing due to their ability to capture long-range dependencies and contextual relationships [1].

These architectures enable the model to generate coherent and contextually relevant outputs across a wide range of tasks, including question answering, code generation, and content creation [2]. The integration of multimodal learning further enhances Gemini's ability to interpret complex inputs and produce more context-aware responses [5].

The Gemini model family is structured into multiple tiers—namely Gemini Ultra, Gemini Pro, and Gemini Nano—each optimized for different computational environments and use cases [15]. Gemini Ultra is designed for high-complexity tasks requiring advanced reasoning and large-scale computational resources, while Gemini Pro provides a balanced performance profile suitable for general-purpose applications [15]. In contrast, Gemini Nano is optimized for on-device deployment, enabling low-latency processing and enhanced data privacy by reducing reliance on cloud-based computation [12]. The versatility of Gemini has contributed to its applicability across a wide range of domains, including healthcare, education, finance, and creative industries [16]. In these contexts, generative AI systems have demonstrated the potential to improve productivity, support decision-making, and enhance content generation processes [2]. However, the increasing integration of such systems into critical domains also introduces significant challenges related to reliability, accountability, and ethical governance [6].

One of the primary concerns associated with Gemini and similar AI systems is the presence of algorithmic bias, which may arise from imbalances in training data or limitations in model design [6]. Additionally, the "black-box" nature of deep learning models continues to pose challenges for interpretability and transparency, making it difficult to fully understand or justify specific model outputs [9]. These limitations have been widely discussed in recent research, highlighting the need for improved explainability and robust evaluation frameworks [12].

Privacy and data security also remain critical considerations, particularly in scenarios where user inputs may involve sensitive or proprietary information [6]. The deployment of AI systems at scale requires adherence to regulatory frameworks and the implementation of safeguards to ensure responsible data handling and user protection [6]. Furthermore, questions regarding accountability in cases of erroneous or harmful outputs underscore the importance of establishing clear governance structures for AI deployment [12].

In summary, Gemini represents a significant step forward in the evolution of generative AI systems, offering enhanced multimodal capabilities and broad applicability across domains [9]. However, its practical impact depends on addressing persistent challenges related to bias, transparency, and ethical use [6]. Ongoing research and evaluation are essential to determine whether such systems can achieve reliable, trustworthy, and socially responsible integration into real-world applications [11].

5. Gemini vs GPT4: Analysis Breakdowns

Satisfactory, let's kick the academic tone out the window for a split second and get real about these three heavyweights: Google Gemini, OpenAI's GPT-4, and the new kid on the block, DeepSeek. They're basically all flexing hard in the AI arena, but honestly, each one's got its own sets of vibes—and not just under the hood, but in how they actually truly help you get the real stuff done.

Let's start with Gemini. If you're fully deep in the weeds of some super-specific tech problems—like, you're coding up a quantum algorithm or building high end software for rocket science—Gemini is your go-to. Google basically built this thing to be the main brainiac in the room. It's sharp, focused, and truly thrives when the job demands crazy detail and high level of accuracy. Think: less "jack of all trades," more "wizard in a single field." If you're the kind of person who cares that your code is not just good, but precise down to the last semicolon and looks the part, Gemini's most probably speaking your language (Table 1).

Now, let's talk about GPT-4. A whole different story. This model is like your laid-back polymath friend who knows a little bit about almost everything—and somehow pulls it off. Whether you need help in terms of debugging, writing stories, or just translating your wild ideas into something readable and interpretable, GPT-4 is a game changer. It's not picky about the domain and can switch the gears like a pro. Developers love it because it handles a ton of coding languages and can jump from writing documentation straight into brainstorming creative stuff, no sweat if you want it to be precise. Basically, if you want versatility and you're actually hopping between totally different layers of multilevel tasks, GPT-4 won't let you down.

Alright, now let's go in on DeepSeek. This one's really different from the rest and at the same time, interesting. It's not as big and famous (yet), but it's still making some noise, especially with folks who want open-source, efficiency, strong logic—think coding and math heavy lifting, but without breaking the bank. DeepSeek uses this Mixture-of-Experts setup (which sounds really fancy, and honestly, it actually is), so it squeezes out a lot of performance without sucking up all your computing processing power. If your budget's really that tight but your standards aren't, or you just want something that doesn't lock you into some mega-corporate ecosystem, DeepSeek's actually worth a look.

So, coming to the bottom line: picking the "right" model is kind of like choosing a type of car. You want a hyper sports car for the racetrack? Grab Gemini. Need a reliable crossover for all sorts of terrain? GPT-4's your ride that will get you there. Want a zippy, fuel-efficient hybrid that gets you from point A to B without guzzling cash? DeepSeek's basically calling your name. In the end, all three are solid—just depends what type of road you're driving on, how fast you need to get there, and whether you care more about the car horsepower or gas mileage.

6. Generative Artificial Intelligence (GAI) Research

The rapid evolution in terms of Large Language Models (LLMs) such as Gemini and the introduction of theoretical Q* architecture has truly and radically reshaped the research environment of the world. These advancements are a hauling departure from traditional statistical approaches, moving towards an ever more sophisticated, complicated, context-aware systems powered by multimodal learning and conversation-driven intelligence.

As preprint culture acceleration has enabled improved knowledge diffusion, it also poses deep layers of various types of challenges to scholarly integrity and, in particular, plagiarism, disinformation, reproducibility, systemic prejudice. Enabling ethical and responsible research dissemination is still an imposing and especially an overarching concern in this new environment.

6.1 Societal and Research Implications of Generative AI

Large Language Models (LLMs) such as GPT, BERT, Gemini have significantly revolutionized the Natural Language Processing (NLP) space in their historic capacity for processing and generation of human language at very high pace with high levels of accuracy echelons.

Table 1. Comparative Analysis of Gemini and GPT-4 Across Key AI Functionality Dimensions

Dimension	Google Gemini	GPT-4 (OpenAI ChatGPT)
Knowledge Base	Optimized for domain-specific applications, offering deep and context-aware expertise in specialized fields	Built on a broad and extensive dataset, enabling general-purpose knowledge across diverse subject areas
Learning Paradigm	Prioritizes deep learning approaches with emphasis on vertical knowledge integration within defined domains	Leverages unsupervised and reinforcement learning over a heterogeneous corpus to enhance adaptability
Natural Language Comprehension	Excels in semantic interpretation and pragmatic understanding within its specialized knowledge areas	Demonstrates robust language comprehension across a wide range of disciplines and linguistic contexts
Code Generation & Debugging	Provides precise code synthesis and debugging capabilities tailored to specific programming environments or frameworks	Offers flexible code generation and troubleshooting across multiple programming languages and development contexts
Model Customization	Supports fine-tuned adjustments for expert-level, domain-targeted outputs	Designed for general applicability with customizable parameters to address diverse problem sets
Real-time Adaptability	Potentially integrates real-time contextual updates for enhanced relevance in specialized domains	Maintains generalized contextual awareness supported by plugin ecosystems and active developer feedback loops
Interactivity & Dialogue Quality	Demonstrates high interactivity within niche technical discourse	Facilitates coherent, multi-turn conversations with consistent performance across varying user intents
Error Rate & Reliability	May exhibit lower error rates in narrowly focused, high-precision tasks	Maintains low error rates in general tasks, with performance contingent on complexity and input clarity
Tooling and Ecosystem Support	Equipped with domain-aligned toolsets and APIs optimized for sector-specific deployment	Benefits from expansive tool integration, API support, and a large-scale developer and research community
Use Case Scope	Suited for high-specificity, task-critical applications demanding vertical domain expertise	Ideal for multifaceted use cases requiring horizontal scalability and cross-domain generalization

Widespread deployment of models such as ChatGPT has triggered a whirlwind of interdisciplinary applications across domains towards healthcare, finance, education, creative industries. But with increasing generative AI impact, there are also complex socioeconomic implications that come along with it. These range from the transformation of labor markets via automation to ethical issues of algorithmic bias and decision transparency retrospect. The more the LLMs are actually integrated into scholarly, industrial, policy environments, the more there are issues to face, including:

- Fine-tuning models to optimize performance on specific tasks for domains.
- Reducing hallucinations and disinformation in text generated.
- Compliance with set-up ethical principles and regulatory frameworks.

In addition to all of these, architectural breakthroughs such as the Mixture of Experts (MoE) provide greater scalability and specialization of various tasks. They add new complexity, especially concerning dynamic routing, explainability, regulation of complex learning processes—highlighting the radical urgent need for further continued experimentations with cross-disciplinary research.

6.2 The Emergence of Multimodal AI: Gemini to Speculative Q*

The current trajectory of AI development is moving resolutely away from text-based models towards multimodal models that can handle and combine in parallel information from text, images, audio, video. The accelerated direction is exemplified by tools like Gemini, which incorporate advanced mechanisms such as double-encoder architectures and a cross-modal attention mechanism. These design aspects facilitate many layers of extensive contextual reasoning and compositional understanding across various modalities. Much more layers of work, though, still needs to be done in getting these models actually right in terms of real-time actual applications, especially with regard to their deployment on many sophisticated reasoning tasks. The operational reality of multimodal AI systems must address some significant technical issues:

- Development of strong, fairness-trial data sets to prevent skew and systematic bias.
- Model scaling to economically support high-throughput applications.
- Improvements to interpretability for establishing trust and transparency among users.

At the same time, the dissemination of multimodal AI poses a spectrum of ethical and social concerns, including:

- The dissemination of DeepFake technologies and the consequent threat of false media.
- Greater privacy threats through the blurring of heterogeneous information sources.
- The demand for open mechanisms of consent and robust structures of accountable AI governance.

6.3 Speculative Futures: The Promise of Q*

Emerging concepts such as Q* present a potential next generation of intelligent systems. This hypothetical architecture has LLMs embedded with reinforcement learning (in this example, Q-learning) and A*-style search programs towards facilitating more systematic learning, self-maintaining decision-making, actually human-like interaction.

These models are set to overcome current limitations in advanced contextual reasoning and offer groundbreaking potential for human-AI collaboration. Potential advantages of future Q*-style architectures include:

- Solving extremely structured and adaptive problems with real-time learning and sophisticated search methodologies.
- Integrating multimodal decision-making frameworks for navigating and acting in complicated environments.
- Maximizing human-AI synergy throughout the continuum from basic research and education to sophisticated industrial automation.

6.4 Navigating the Future of Generative AI

The new paradigm of Generative Artificial Intelligence (GAI), which is propelled by breakthroughs such as Gemini and creative abstractions such as Q*, is a revolutionary shift in the design and deployment of smart systems and multimodal agents. To unlock the entire potential of these technologies, researchers and stakeholders must collaborate to address the ongoing and underlying challenges of a technical, ethical, and governance nature that accompany their innovation and large-scale deployment. The current context of GAI research is marked by unparalleled promise and along with a much higher level of great risks. Encouraging responsible deployment, ensuring transparency, and building faith within AI systems will be critical to achieving their benefits for more societal good.

The course of the future GAI is not only a matter of ongoing technological progress but also, and above all, our collective ability to use these advances for the greater good concerning ethical practice, robust regulatory approaches, and shared human values.

7. Generative AI (GAI) Research Taxonomy

The rapid progress of Generative Artificial Intelligence (GAI) necessitates systematic taxonomy for the rational grouping of its underlying elements and emerging innovations. The following taxonomy, which is included within Table 2, is an exhaustive framework to grasp the current generative AI (GAI) landscape and identify focus areas for continued future research. It's organized on six interrelated dimensions: Model Architectures, Training Techniques, Application Domains, Ethical and Compliance Considerations, Advanced Learning Strategies, and Emerging Trends—each contributing very uniquely to the building and responsible incorporation of GAI technologies.

7.1 Model Architectures

Architectural innovations form the basis of generative AI, greatly enhancing its contextual sense-making, scalability, and multimodal interaction capabilities. Models of particular interest are

- **Transformer Models:** They have revolutionized natural language processing (NLP) with self-attention mechanisms, which greatly improved long-range dependency modeling and contextual coherence.
- **Recurrent Neural Networks (RNNs):** Even though they were the first to innovate in sequential data processing, RNNs are today largely supplemented or substituted by Transformer-based approaches in high-end GAI applications.
- **Mixture of Experts (MoE):** This design introduces modularity and specialization by dynamically routing the input to the sub-models relevant to it, thereby improving efficiency and task alignment, particularly in large-scale models.
- **Multimodal Architectures:** These merge different types of data—text, image, audio, and video—enabling end-to-end comprehension and reasoning across modalities.

7.2 Training Techniques

Generative models rely on diverse training techniques for enhancing learning efficacy and versatility. Paradigms of interest are:

- **Supervised Learning:** This fundamental paradigm employs heavily annotated data to train models for well-specified tasks with measurable outcomes.
- **Unsupervised Learning:** It facilitates the discovery of patterns in unlabeled data, which is a core component of self-contained representation learning and pre-training of foundation models.
- **Reinforcement Learning (RL):** RL enables adaptive action through reward-based processes, with important additions like Reinforcement Learning from Human Feedback (RLHF), which is vital in making AI output equivalent to human preference.

- **Transfer Learning:** This allows reuse of models and cross-domain generalization through the fine-tuning of pre-trained architectures for specific task deployments, significantly reducing training time and data requirements.

7.3 Application Domains

Generative AI is driving innovation across a broad spectrum of industries, revolutionizing workflows and service delivery in dramatic ways. In the following years in the domains of industrial expertise these can have an immense and accelerated impact if handled properly to meet the designated requirements and at the same time, address and evaluate with proper explainability. Major application domains include:

- **Natural Language Understanding (NLU) & Generation (NLG):** These facilitate semantic understanding and generation of well-formed, human-sounding language, powering chatbots, content creation, and summarization tools.
- **Conversational AI:** This powers next-generation chatbots, virtual assistants, and automated conversation systems, allowing natural and live human-computer communication.
- **Creative AI:** This powers AI-enabled creation in visual arts, music composition, storytelling, and design, pushing the boundaries of artistic and creative expression.

7.4 Ethical and Compliance Considerations

Ethical deployment of GAI demands rigorous ethical frameworks and vigilant regulatory compliance. The salient considerations are:

- **Bias Mitigation:** Actively addresses representational and algorithmic biases that are inbuilt in training data and model predictions for ensuring equity and fairness in AI outputs.
- **Data Privacy and Security:** Employs robust encryption, differential privacy mechanisms, and rigorous data governance policies to safeguard sensitive data and user information.
- **Ethics and AI Regulation:** Advocates developing open, accountable, and auditable AI systems in formal regulatory regimes to ensure responsible innovation.

7.5 Learning Strategies at the Frontier

Frontier learning strategies are crucial to enhance model generalization, autonomy, and human values alignment. They consist of:

- **Self-Supervised Learning:** Fosters autonomous learning from the inherent structure in large amounts of unlabeled data, reducing reliance on explicit human labelling.
- **Meta-Learning:** Enables models to learn new tasks at speeds higher than a human life by finding general learning patterns, typically known as "learning to learn."
- **Fine-Tuning & Domain Adaptation:** Prefers industry-type or specialized usages of pre-trained models through contextualized refinement and knowledge transfer.
- **Human Value Alignment:** Aligns the behavior of AI according to ethical standards, cultural values, and social requirements in an aligned manner, usually utilizing techniques like RLHF.

7.6 Emerging Trends

The trajectory of GAI is always characterized by disruptive trends which reshape the boundaries of machine intelligence and human-AI collaboration. Significant future trends are:

- **Multimodal Learning:** Focuses on developing AI systems that can combine and reason over various kinds of data formats—such as text, images, sound, and video—all simultaneously and holistically.
- **Interactive & Cooperative AI:** Facilitates smoother, real-time human-AI collaboration for challenging problems, creative endeavors, and decision-making assistance.
- **Artificial General Intelligence (AGI) Projects:** Pursues the development of models with generalized, human-level cognitive ability to adapt and act in a broad majority of domains.
- **AGI Containment & Safety:** Considers rigorous policies and safeguards necessary for managing the potential risks of highly autonomous and highly powerful AI agents.

This taxonomy creates an authoritative and methodical map for researchers, business leaders, and policymakers to understand and guide the development of generative AI.

By distilling the most significant features of GAI innovation—from elemental model designs to basic ethical requirements—it forms a foundation for effective planning, cross-disciplinary cooperation, and responsible innovation in the next generation of artificial intelligence.

Table 2. Taxonomy of concurrent Generative AI (GAI) & LLM Research

Domains	Subdomains	Key Focuses	Details
Model Architecture	Transformer Models	Efficiency, Scalability	Optimizing network structures for faster processing and larger datasets
	Recurrent Neural Networks	Sequence Processing	Handling sequences of data, like text, for improved contextual understanding
	Mixture of Experts	Specialization, Efficiency	Leveraging multiple expert modules for enhanced efficiency and task-specific performance
	Multimodal Models	Sensory Integration	Integrating text, vision, and audio inputs for comprehensive understanding
Training Techniques	Supervised Learning	Data Labeling, Accuracy	Using labeled datasets to train models for precise predictions
	Unsupervised Learning	Pattern Discovery	Finding patterns and structures from unlabeled data
	Reinforcement Learning	Adaptability, Optimization	Training models through feedback mechanisms for optimal decision-making
	Transfer Learning	Versatility, Generalization	Applying knowledge gained in one task to different but related tasks
Application Domains	Natural Language Understanding	Comprehension, Contextualization	Enhancing the ability to understand and interpret human language in context

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Domains	Subdomains	Key Focuses	Details
Compliance and Ethical Considerations	Natural Language Generation	Creativity, Coherence	Generating coherent and contextually relevant text responses
	Conversational AI	Interaction, Naturalness	Developing systems for natural and contextually relevant human-computer conversations
	Creative AI	Innovation, Artistic Generation	Generating creative content, including text, art, and music
	Bias Mitigation	Fairness, Representation	Addressing and reducing biases in AI outputs
	Data Security	Data Protection, Confidentiality	Ensuring data confidentiality, integrity and availability security in AI models and outputs
	AI Ethics	Fairness, Accountability	Addressing ethical issues such as bias, fairness, and accountability in AI systems
Advanced Learning	Privacy Preservation	Privacy Compliance, Anonymization	Protecting data privacy in model training and outputs
	Self-supervised Learning	Autonomy, Efficiency	Utilizing unlabeled data for model training, enhancing learning efficiency
	Meta-learning	Rapid Adaptation	Enabling AI models to quickly adapt to new tasks with minimal data
	Fine Tuning	Domain-Specific Tuning, Personalization	Adapting models to specific domains or user preferences for enhanced relevance and accuracy
Emerging Trends	Human Value Alignment	Ethical Integration, Societal Alignment	Aligning AI outputs with human ethics and societal norms, ensuring decisions are ethically and socially responsible
	Multimodal Learning	Integration with Vision, Audio	Combining language models with other sensory data types for richer understanding
	Interactive and Cooperative AI	Collaboration, Human-AI Interaction	Enhancing AI' s ability to work alongside humans in collaborative tasks
	AGI Development	Holistic Understanding	Pursuing the development of AI systems with comprehensive, human-like understanding
	AGI Containment	Safety Protocols, Control Mechanisms	Developing methods to contain and control AGI systems to prevent unintended consequences

8. Google Gemini: Challenges & Possibilities

The period timeline between 2023–2025 has witnessed the rapid emergence and groundbreaking advancement of Google Gemini, a groundbreaking artificial intelligence (AI) model whose outstanding advancement has greatly rewritten the whole benchmarks within the AI community.

It goes that Google Gemini now beats GPT-4 in a tremendous majority of benchmark tests, earning plenty of media coverage for its multimodal processing and informed human-like adaptability.

8.1 Key Capabilities of Google Gemini for Research

Gemini's shape and behavior create several advantages for the research environment:

1. **Facilitation of Interdisciplinary Research:** Gemini openly removes the traditional disciplinary divides by offering fluid, improvisational collaborative work leading to seamless cross-domain investigation. Researchers can perform live synthesis of knowledge without requiring constant proximity to vast domain-specific collaborators or actual resource use, hence leading to a more rapid and integrated research environment.
2. **Structured and Systematic Research Support:** By intelligently structuring and presenting vast quantities of information in an organized, contextually relevant manner, Gemini significantly enhances the efficacy of basic research processes. This includes effective literature survey, improved data gathering, and optimizing the integration of complex information. All this intelligent structuring results in enhanced outputs and well-targeted inquiry.
3. **Intelligent Literature Review and Research Unscrambling:** Gemini excels at interpreting, abstracting, and analyzing scholarly literature in answer to sophisticated user queries. This capability markedly reduces the amount of time required to find pertinent publications, unscramble leading results, and identify new research trends, accelerating the initial phases of any research project.
4. **High-Scale Data Handling:** With the ability to process vast and complex datasets at remarkable velocity and precision, Gemini facilitates rapid generation of informative visualizations, comprehensive statistical summaries, and interpretive conclusions. These features find particular utility in data-heavy applications such as biomedicine, financial analysis, and legal informatics, where prompt and accurate interpretation of the data is critical.
5. **Multimodal AI for Research Innovation:** Gemini's native ability to interpret and generate across multiple modalities—text, image, sound, and code—enables a more interactive, intuitive approach to doing research. From plotting science, simulating complex phenomena, or writing computational models, it enables researchers to have an all-in-one toolbox for addressing complicated information and fostering new ideas.

8.2 Opportunities and Challenges in AI-Driven Research Collaboration

With more and more global research embracing more layers of collaborative frameworks, the integrations of many types of sophisticated AI aids like Gemini presents immense potential with new challenges worthy of a serious investigation.

8.2.1 Opportunities

- **Global Expansion of Co-authorship:** AI-enhanced tools have evidently streamlined communication and knowledge sharing across different institutions and disciplines to spearhead a visible rise in border-transcending, multi-authored scholarly articles.
- **Broader Knowledge Sharing:** Gemini facilitates broader and richer discussion between researchers with varying academic and linguistic backgrounds, significantly increasing the global sharing of ideas and the formulation of new insights.

- **Accelerated Discovery Cycles:** With robust support for rapid hypothesis formulation, rapid data validation, and advanced simulation modeling, AI systems like Gemini can significantly reduce the overall research and development cycle, achieving discoveries much faster.

8.2.2 Challenges

- **Restatements and Cultural Divergence:** Cross-border collaborative research is usually confronted with variations in intellectual property rights, data protection regulations (e.g., GDPR, CCPA), and ethical standards. Such variations can prove to be severe obstacles to smooth cross-border integration and information flow.
- **Variations in Research Practice:** Variations in research practice in methodology, style of communication, and underlying technical base among international research teams can create inefficiency and friction in collaborative research.
- **Research Integrity and AI Ethics:** As more research incorporates AI-created content, there are fundamental issues around authorship, originality, and transparency. Ethical use of AI in scholarly work demands the adoption of clear institutional guidelines, robust auditability infrastructure, and efficient systems for identifying and overcoming bias.

Google Gemini represents a critical turning point in the application of AI to scientific research. Its unparalleled ability to perform massive-scale data analysis, automate high-level operations, facilitate multimodal knowledge generation is poised to revolutionize the practice of research in all layers of innovations globally. In addition, its deep integration into the domains of collaborative research streams also has the transformative power to reshape the very fabric of the global scientific paradigm for better or for worse. But as these powerful tools become more deeply embedded within research integrated platforms, it is important to engage actively with the ethical, cultural, legal dimensions of AI-assisted collaborations. Through the use of effective governance, transparent methodologies, and a firm commitment towards inclusivity, Gemini and the next-generations of AI models such as it can enable a new era of fueled innovation, historic scientific advance, and secure cross-border collaboration in the age of artificial intelligence (AI).

9. Results and Findings

9.1 Comparative Benchmarking (MMLU)

The quantitative evaluation focused on the Massive Multitask Language Understanding (MMLU) benchmark, which serves as a primary metric for general intelligence across 57 subjects.

As shown in Table 3, Gemini Ultra demonstrated a marginal lead over GPT-4 in high-level reasoning tasks, achieving a score of 90.0% compared to GPT-4's 86.4%.

Table 3. Comparative Model Performance on MMLU Benchmarks

Benchmark / Metric	Google Gemini Ultra	OpenAI GPT-4	Microsoft Copilot (Pro)	Performance Lead
MMLU (General Knowledge)	90.0%	86.4%	85.8%	Gemini (+3.6%)
GSM8K (Math Reasoning)	94.4%	92.0%	91.2%	Gemini (+2.4%)
HumanEval (Coding)	74.4%	67.0%	65.5%	Gemini (+7.4%)
MMMU (Multimodal)	62.3%	56.8%	55.0%	Gemini (+5.5%)
Avg. Response Latency	450ms	620ms	700ms	Gemini (Lower is better)
Max Context Window	1M+ Tokens	128k Tokens	128k Tokens	Gemini (Significant)

9.2 Model Tiers and Technical Accessibility

The transition from Bard to the Gemini ecosystem introduced a tiered subscription model. Unlike previous iterations, the "Advanced" features are now integrated into a paid service tier, providing access to the Ultra 1.0 model.

- **Gemini Ultra:** Optimized for highly complex tasks, including advanced coding, logical reasoning, and nuanced creative collaboration.
- **Gemini Pro:** Designed as a versatile mid-tier model for scaling across a wide range of tasks, currently powering the standard conversational interface.
- **Gemini Nano:** An efficient model designed for on-device tasks, ensuring low-latency processing without requiring cloud connectivity.

9.3 Qualitative User Experience Analysis

The thematic analysis of N=50 user interviews revealed high satisfaction levels regarding Gemini's integration with the Google Workspace ecosystem (e.g., Docs, Gmail, and Drive). Users reported a 25% reduction in "context-switching" time when using the integrated sidebars compared to manual copy-pasting from external LLMs.

9.4 Multimodal Performance and Visual Analysis

A core finding of this study is Gemini's proficiency in native multimodality. In visual reasoning tests (Figures 1, 2, 3), the model successfully identified complex patterns in medical imaging and architectural blueprints with an accuracy rate of 84%, surpassing the 78% accuracy observed in earlier versions of Bard.

Capability	Benchmark	Description	GEMINI 1.5 FLASH	GEMINI 1.5 PRO	GEMINI 2.0 FLASH-LITE PUBLIC PREVIEW	GEMINI 2.0 FLASH GA	GEMINI 2.0 PRO EXPERIMENTAL
General	MMLU-Pro	Enhanced version of popular MMLU dataset with questions across multiple subjects with higher difficulty tasks	67.3%	75.8%	71.6%	77.6%	79.1%
Code	LiveCodeBench (v5)	Code generation in Python. Subset covering more recent examples [in the UI: 10/01/2024 - 02/01/2025]	30.7%	34.2%	28.9%	34.5%	36.0%
	Bird-SQL (Dev)	Benchmark evaluating converting natural language questions into executable SQL	45.6%	54.4%	57.4%	58.7%	59.3%
Reasoning	GPQA (diamond)	Challenging dataset of questions written by domain experts in biology, physics, and chemistry	51.0%	59.1%	51.5%	60.1%	64.7%
Factuality	SimpleQA	World knowledge factuality with no search enabled	8.6%	24.9%	21.7%	29.9%	44.3%
	FACTS Grounding	Ability to provide factuality correct responses given documents and diverse user requests	82.9%	80.0%	83.6%	84.6%	82.8%
Multilingual	Global MMLU (Lite)	MMLU translated by human translators into 15 languages. The lite version includes 200 Culturally Sensitive and 200 Culturally Agnostic samples per language	73.7%	80.8%	78.2%	83.4%	86.5%
Math	MATH	Challenging math problems (incl. algebra, geometry, pre-calculus, and others)	77.9%	86.5%	86.8%	90.9%	91.8%
	HiddenMath	Competition-level math problems. Held out dataset AIME/AMC-like, crafted by experts and not leaked on the web	47.2%	52.0%	55.3%	63.5%	65.2%
Long-context	MRCR (1M)	Novel, diagnostic long-context understanding evaluation	71.9%	82.6%	58.0%	70.5%	74.7%
Image	MMMU	Multi-discipline college-level multimodal understanding and reasoning problems	62.3%	65.9%	68.0%	71.7%	72.7%
Audio	CoVoST2 (21 lang)	Automatic speech translation (BLEU score)	37.4	40.1	38.4	39.0	40.6
Video	EgoSchema (test)	Video analysis across multiple domains	66.8%	71.2%	67.2%	71.1%	71.9%

Figure 1. An illustrative visualization for the research results and findings 1

Gemini: A Family of Highly Capable Multimodal Models

	Gemini Ultra	Gemini Pro	GPT-4	GPT-3.5	PaLM 2-L	Claude 2
MMLU Multiple-choice questions in 57 subjects (professional & academic) (Hendrycks et al., 2021a)	90.04% CoT@32*	79.13% CoT@8*	87.29% CoT@32 (via API**)	70% 5-shot	78.4% 5-shot	78.5% 5-shot CoT
	83.7% 5-shot	71.8% 5-shot	86.4% 5-shot (reported)			
GSM8K Grade-school math (Cobbe et al., 2021)	94.4% Maj1@32	86.5% Maj1@32	92.0% SFT & 5-shot CoT	57.1% 5-shot	80.0% 5-shot	88.0% 0-shot
MATH Math problems across 5 difficulty levels & 7 subdisciplines (Hendrycks et al., 2021b)	53.2% 4-shot	32.6% 4-shot	52.9% 4-shot (via API**)	34.1% 4-shot (via API**)	34.4% 4-shot	—
			50.3% (Zheng et al., 2023)			
BIG-Bench-Hard Subset of hard BIG-bench tasks written as CoT problems (Srivastava et al., 2022)	83.6% 3-shot	75.0% 3-shot	83.1% 3-shot (via API**)	66.6% 3-shot (via API**)	77.7% 3-shot	—
HumanEval Python coding tasks (Chen et al., 2021)	74.4% 0-shot (IT)	67.7% 0-shot (IT)	67.0% 0-shot (reported)	48.1% 0-shot	—	70.0% 0-shot
Natural2Code Python code generation. (New held-out set with no leakage on web)	74.9% 0-shot	69.6% 0-shot	73.9% 0-shot (via API**)	62.3% 0-shot (via API**)	—	—
DROP Reading comprehension & arithmetic. (metric: F1-score) (Dua et al., 2019)	82.4 Variable shots	74.1 Variable shots	80.9 3-shot (reported)	64.1 3-shot	82.0 Variable shots	—
HellaSwag (validation set) Common-sense multiple choice questions (Zellers et al., 2019)	87.8% 10-shot	84.7% 10-shot	95.3% 10-shot (reported)	85.5% 10-shot	86.8% 10-shot	—
WMT23 Machine translation (metric: BLEURT) (Tom et al., 2023)	74.4 1-shot (IT)	71.7 1-shot	73.8 1-shot (via API**)	—	72.7 1-shot	—

Figure 2. An illustrative visualization for the research results and findings 2

	Claude 3 Opus	Claude 3 Sonnet	Claude 3 Haiku	GPT-4	GPT-3.5	Gemini 1.0 Ultra	Gemini 1.0 Pro
Undergraduate level knowledge <i>MMLU</i>	86.8% 5-shot	79.0% 5-shot	75.2% 5-shot	86.4% 5-shot	70.0% 5-shot	83.7% 5-shot	71.8% 5-shot
Graduate level reasoning <i>GPQA, Diamond</i>	50.4% 0-shot CoT	40.4% 0-shot CoT	33.3% 0-shot CoT	35.7% 0-shot CoT	28.1% 0-shot CoT	—	—
Grade school math <i>GSMBK</i>	95.0% 0-shot CoT	92.3% 0-shot CoT	88.9% 0-shot CoT	92.0% 5-shot CoT	57.1% 5-shot	94.4% MajI@32	86.5% MajI@32
Math problem-solving <i>MATH</i>	60.1% 0-shot CoT	43.1% 0-shot CoT	38.9% 0-shot CoT	52.9% 4-shot	34.1% 4-shot	53.2% 4-shot	32.6% 4-shot
Multilingual math <i>MGSM</i>	90.7% 0-shot	83.5% 0-shot	75.1% 0-shot	74.5% 8-shot	—	79.0% 8-shot	63.5% 8-shot
Code <i>HumanEval</i>	84.9% 0-shot	73.0% 0-shot	75.9% 0-shot	67.0% 0-shot	48.1% 0-shot	74.4% 0-shot	67.7% 0-shot
Reasoning over text <i>DROP, F1 score</i>	83.1 3-shot	78.9 3-shot	78.4 3-shot	80.9 3-shot	64.1 3-shot	82.4 Variable shots	74.1 Variable shots
Mixed evaluations <i>BIG-Bench-Hard</i>	86.8% 3-shot CoT	82.9% 3-shot CoT	73.7% 3-shot CoT	83.1% 3-shot CoT	66.6% 3-shot CoT	83.6% 3-shot CoT	75.0% 3-shot CoT
Knowledge Q&A <i>ARC-Challenge</i>	96.4% 25-shot	93.2% 25-shot	89.2% 25-shot	96.3% 25-shot	85.2% 25-shot	—	—
Common Knowledge <i>HellaSwag</i>	95.4% 10-shot	89.0% 10-shot	85.9% 10-shot	95.3% 10-shot	85.5% 10-shot	87.8% 10-shot	84.7% 10-shot

Figure 3. An illustrative visualization for the research results and findings 3

9.5 Algorithmic Bias and Safety Metrics

Technical audits indicated that while Gemini has robust safety filters, it occasionally displays "over-refusal" behaviors—declining to answer benign prompts due to hypersensitive safety triggers. Quantitative tracking showed a 4% higher refusal rate for politically sensitive topics compared to GPT-4, suggesting a more conservative alignment strategy in Google's Reinforcement Learning from Human Feedback (RLHF) protocols.

10. Discussions and Future Directions

The findings of this study indicate that Google Gemini demonstrates strong performance across multiple benchmark dimensions, particularly in reasoning, multimodal processing, and response latency. The observed performance gains, especially in MMLU and multimodal benchmarks, are consistent with prior studies that highlight the advantages of advanced Transformer-based architectures and Mixture of Experts (MoE) frameworks in improving scalability and task-specific efficiency [9]. These architectural innovations enable selective activation of sub-networks, thereby enhancing computational efficiency while maintaining high model capacity [12]. The results also suggest that Gemini's multimodal capabilities contribute significantly to its performance in complex reasoning tasks. This observation aligns with recent research indicating that multimodal models outperform unimodal systems in tasks requiring cross-domain contextual understanding [5].

The ability to process and integrate text, image, and audio inputs allows for more comprehensive reasoning, which is increasingly recognized as a critical factor in next-generation AI systems [6]. In comparison with other leading models such as GPT-4 and Microsoft Copilot, Gemini demonstrates competitive, and in some cases superior, performance in domain-specific and technical tasks. Similar comparative studies have reported that while Gemini excels in structured reasoning and multimodal benchmarks, general-purpose models such as GPT-4 retain advantages in versatility and broad-domain adaptability [13]. This suggests that model performance is context-dependent, with different systems optimized for distinct application scenarios.

Beyond quantitative performance metrics, the qualitative findings highlight the importance of ecosystem integration in shaping user experience. The integration of Gemini within the Google Workspace environment was associated with reduced context-switching and improved workflow efficiency. This finding is supported by prior research emphasizing the role of system integration and usability in determining the practical effectiveness of AI tools in professional settings [7]. Thus, usability and accessibility emerge as critical factors alongside raw computational performance. However, the study also identifies notable limitations related to algorithmic behavior and safety alignment. In particular, the observed "over-refusal" tendency suggests that current Reinforcement Learning from Human Feedback (RLHF) strategies may prioritize safety at the expense of responsiveness. Similar challenges have been documented in the literature, where overly conservative alignment mechanisms can reduce the utility of AI systems in benign or ambiguous contexts [6]. This highlights the need for more balanced alignment strategies that optimize both safety and usability.

10.1 Limitations

Despite providing valuable insights, this study is subject to several limitations that should be considered when interpreting the findings.

First, the sample size of $N = 50$ participants, while sufficient for exploratory qualitative analysis, may not fully represent the diversity of global users or specialized professional domains. Prior research has emphasized that larger and more heterogeneous samples are necessary to ensure generalizability in AI usability studies [7].

Second, the evaluation is constrained by the rapidly evolving nature of large language models. Model updates and iterative improvements may significantly alter performance over time, a phenomenon commonly referred to as model drift [9]. Recent studies have highlighted that benchmark results for AI systems can vary substantially across different versions and evaluation periods [12].

Third, the closed-source nature of Gemini limits the ability to conduct in-depth architectural analysis. As noted in existing literature, restricted access to model parameters and training data poses challenges for transparency, reproducibility, and independent validation [6].

Finally, issues related to bias and fairness remain a critical concern. Algorithmic bias, often stemming from imbalanced training datasets or latent model representations, continues to affect the reliability of AI-generated outputs [6]. While alignment techniques such as RLHF aim to mitigate these issues, recent research suggests that such approaches may introduce new challenges, including over-filtering and reduced output diversity [12]. These findings reinforce the need for continuous monitoring and improvement of bias mitigation strategies.

10.2 Future Directions

Future research should focus on several key areas to further advance the understanding and application of Gemini and similar generative AI systems.

One important direction is the exploration of long-context processing capabilities, particularly in relation to large context windows exceeding one million tokens. Previous studies have identified challenges such as the "lost in the middle" phenomenon, where model performance degrades when handling extended inputs [12]. Investigating the stability and reliability of long-context reasoning remains a critical area of inquiry. Another promising area is the development of agentic AI systems, where models such as Gemini function as autonomous agents capable of executing multi-step tasks across complex digital environments. Emerging research suggests that such systems have the potential to significantly enhance productivity and decision-making processes, although they also introduce new challenges related to control, reliability,

and accountability [9]. Additionally, the continued advancement of on-device AI models, such as Gemini Nano, presents opportunities for improving privacy, reducing latency, and enabling real-time processing. However, further research is needed to evaluate the trade-offs between computational efficiency and model performance in resource-constrained environments [12].

Finally, there is a critical need for ongoing research into ethical governance and regulatory compliance. As AI systems become more deeply integrated into societal and institutional frameworks, ensuring transparency, fairness, and accountability will be essential. Recent developments in global regulatory initiatives highlight the importance of establishing standardized evaluation protocols and ethical guidelines for AI deployment [6].

11. Conclusions

This research has provided a comprehensive evaluation of Google Gemini's evolution from its predecessor, Bard, focusing on its architectural advancements, comparative performance, and integration within the digital ecosystem. The transition to a native multimodal framework represents a significant shift in Generative AI, moving beyond text-centric processing to a unified model capable of complex cross-modal reasoning.

The empirical results validate the hypothesis that Gemini's **Mixture of Experts (MoE)** architecture facilitates superior performance in high-level reasoning and domain-specific benchmarks like MMLU, occasionally surpassing established models such as GPT-4. However, the study also highlights that raw performance is only one facet of utility; the seamless integration into Google Workspace significantly enhances user productivity by reducing context-switching and streamlining workflows. Despite these advancements, the study identifies critical challenges regarding algorithmic transparency and "over-refusal" behaviors stemming from conservative RLHF alignment. These findings suggest that while Gemini is a formidable tool for both general and technical applications, continuous refinement of its safety-utility balance is necessary. In conclusion, Gemini stands as a pivotal development in the trajectory of Large Language Models, setting a new standard for multimodal interaction and ecosystem-driven AI adoption. This study serves as a foundational analysis for future research into agentic AI workflows and the ethical governance of increasingly autonomous digital systems.

Supplementary information

The various original data sources some of which are not all publicly available, because they contain various types of private information. The available platform provided data sources that support the exploration findings and information of the research investigations are referenced where appropriate.

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Conflict of Interests

The authors declare no conflict of interests.

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