BIRMINGHAM CITY University

CMP6200
Individual Undergraduate Project
2024 – 2025

University Artificially Intelligent Assistant

Course: Computer & Data Science
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Abstract

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Acknowledgements

I would like to acknowledge...

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Term	Definition
RAG	Retrieval-Augmented Generation is...

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1.1 Problem definition

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1.2 Scope

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1.3 Rationale

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1.4 Aims and Objectives

This project aims to aid new and existing students alike while they are attending university with helpful information about university itself, such as university societies, locations/campuses, and policies through the medium of a digital chatbot companion to converse with. The project's objectives are:

- Conduct a thorough literature review on the surrounding topics, namely AI, LLMs and NLP.
- Create effective documentation for all stages of development, highlighting challenges faced during the process.
- Leverage Retrieval-Augmented Generation alongside a cloud-based LLM to query a vector database of university-related data.
- Develop a chatbot capable of accurately answering user queries related to university buildings, policies, and societies with a minimum 80% accuracy rate.
- Evaluate the effectiveness of an AI assistant on university student acclimatization.

1.5 Background information

Possibly unnecessary.

Literature Review

2.1 Review of Literature

2.1.1 Artificial Intelligence (AI)

Researchers have always wanted to harness the processing power of computers to act in a manner indistinguishable from that of humans from as long ago as 1950, where the question was posed 'Can machines think?' (Turing, 1950). Ever since, constant innovations were made in computer intelligence and machine learning, from playing games of checkers at a better level than human players (Samuel, 1959) to classifying the contents of millions of images using convolutional neural networks (Krizhevsky, Sutskever and Hinton, 2012).

Recently, AI is used across many disciplines for different purposes to complete tasks faster than, and in some cases better than, human workers, especially with the introduction of large language models (LLMs) (Maedche et al., 2019). Wirtz et al. (2018) write that 'service robots' [1] can complete a variety of tangible or intangible actions, such as two-way conversation with chatbots.

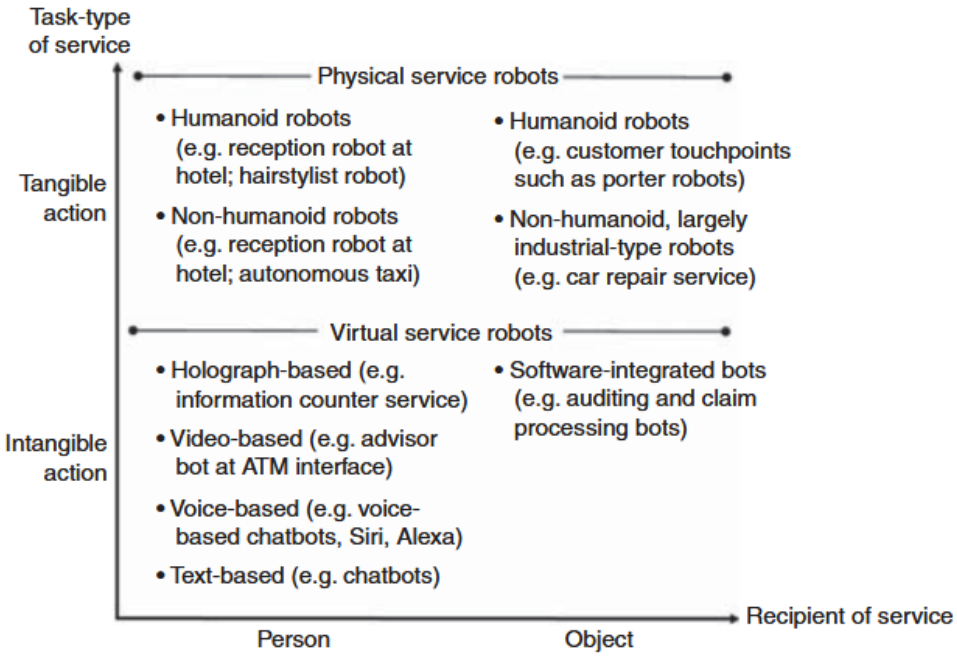

Figure 2.1: Service robots categorization by task-type and recipient of service (Wirtz et al., 2018).

When developing an AI project, it is important that the development process is ethical and human-centred, which is known as Human-Centred AI (HCAI). Another issue is the "black-box problem" - the inability to know an AI's reasoning, meaning that eXplainable AI (XAI) is a growing necessity (Miró-Nicolau, Jaume-i-Capó and Moyà-Alcover, 2025).

[1] Defined as "system-based autonomous and adaptable interfaces that interact, communicate and deliver service to an organization's customers" (Wirtz et al., 2018, p.909)

Focusing on HCAI and XAI means the focus shifts from the machine to the user and their experience using the AI. Shneiderman (2020) strongly advocates for the promotion of HCAI for the benefit of both companies and their users, which is a commonly accepted idea due to the ethical risks of using AI.

Because AI calculates outcomes from its training data rather than understanding social norms and perspectives, using it in sociotechnical systems poses serious risks due to the 'traps' it can fall into, because it cannot account for every possibility such as the personal tendencies and biases of its users (Selbst et al., 2019), and therefore developers require a shift in focus - from the final product to the development process itself and end users, which also echoes Shneiderman's views.

2.1.2 Natural language processing (NLP)

The ability for a computer to interpret and understand human language greatly enhances the scale of their capabilities. This was recognised during the 1950s, where machine translation from Russian to English was demonstrated for the first time, albeit in a basic form (Jones, 1994). Ever since, NLP has been a key topic in computing, especially in recent years, with its applications widening in scope with modern processing power.

One of the key advancements in NLP is vectorisation, a process where data is embedded into a numerical equivalent that a computer can interpret, enabling Natural Language Understanding (NLU) and the identification of semantic similarities between words through the use of an embedding model like Word2Vec (Mikolov et al., 2013) without the need to manually label data. Word2Vec was a key innovation in NLP, and Mikolov and Le went on to improve it further with Doc2Vec (Le and Mikolov, 2014), which could embed entire documents into semantically searchable vectorised forms.

Embedding models have further improved since, most notably with Vaswani et al. (2017)'s Transformer architecture enhancing models such as BERT (Devlin et al., 2019), which establishes context through analysing multiple neighbours of a word rather than reading from left to right, gaining a higher understanding of the text it processes. Many embedding models have since been developed, though one of the most reputable is OpenAI's recent text-embeddings-3 model (OpenAI, 2024c), which can be used in the development of the chatbot at a low cost.

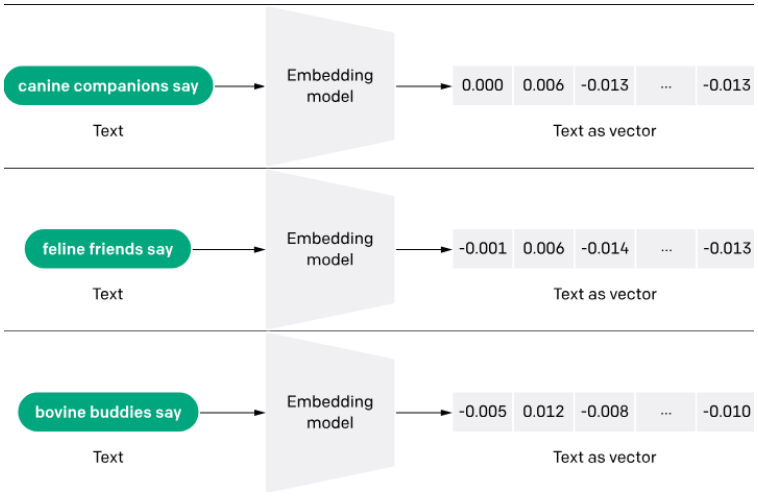

Figure 2.2: A basic overview of vectorisation (OpenAI, 2024a).

2.1.3 Large language models

LLMs are colossal machine learning models that leverage NLP to generate text, and have become widely used across industries in place of technical support and human resources (Vrontis et al., 2022). The training data required for an LLM is immense, reaching 45 terabytes of text data for ChatGPT in 2023 (Dwivedi et al., 2023).

This data is harvested from websites and social media due to them being the largest repositories of opinionated text data (Dubey et al. (2024), Z. Wang et al. (2016)). However, meticulous care is taken into the specific sources used to remove Personally Identifiable Information (PII) to minimise privacy and ethical concerns (Dubey et al., 2024).

The previously mentioned Transformer by Vaswani et al. (2017) became a staple in LLMs due to the major reduction in necessary processing power to produce higher-quality results, and it continues to underpin many LLMs today, including ChatGPT (Brown et al., 2020). Even with these enhancements, LLMs are still extremely performance intensive, requiring more than 8 top-range server-grade GPUs to run some of the most powerful high-parameter models like LLaMA 3.1's 405 billion parameter model (Dubey et al., 2024), and many therefore use cloud API solutions to access LLMs.

The amount of parameters in a model does not entirely account for the quality of its responses, as studied by Ouyang et al. (2022) in Figure 2.3 wherein their surveys revealed their fine-tuned LLM "InstructGPT" with over 100x less parameters than a 175 billion parameter GPT3 model would often give answers preferred by its human assessors, which reveals that the fine-tuning and prompt engineering of an LLM is as vitally important to the quality of its responses as the amount of parameters.

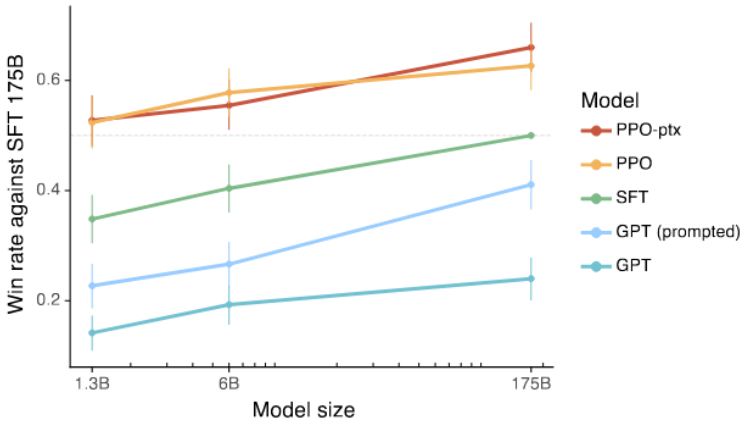

Figure 2.3: Human evaluations of the GPT models produced by Ouyang et al. (2022). PPO and PPO-ptx are their models.

The simplest way to measure the accuracy and quality of an LLM's responses is through human evaluation surveys such as that conducted by Ouyang et al. (2022), though software approaches such as DeepEval can be used. DeepEval offers 14 metrics to test LLM outputs with (DeepEval, 2024), with a notable metric being "G-Eval", originally introduced by Liu et al. (2023), which uses an "LLM-as-a-judge" approach where an LLM will evaluate and grade the quality of the output.

2.1.4 Retrieval-Augmented Generation

While LLMs are highly useful tools across many industries, they are not without limitations. The most notable of these limitations are hallucinations (P. Lewis et al., 2021), where the LLM will fabricate information that conflicts with user input, earlier conversation context or true facts (Zhang et al., 2023). This occurs as a direct result of the LLM's parametric memory[2] being overfitted or biased, which can be counteracted through introducing an external knowledge source, known as non-parametric memory (Komeili, Shuster and Weston (2022), Siriwardhana et al. (2023)).

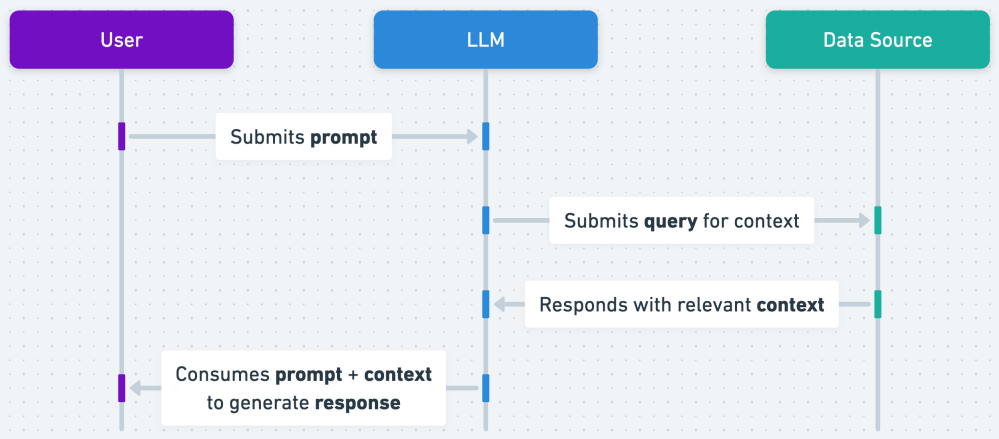

Figure 2.4: A basic overview of a RAG workflow (OpenAI, 2024b).

Siriwardhana et al. (2023) expanded upon the earlier works of Karpukhin et al. (2020) and M. Lewis et al. (2020) by creating "RAG-end2end", which explored the capabilities of RAG on a dynamically updating knowledge store, meaning the LLM itself would not have to be retrained every time the data updates, saving enormous amounts of processing power.

RAG is dependent upon external knowledge stores such as vector databases, which store and process vectorised data for non-parametric memory (Li, 2023), which makes them an essential part of the backend of a RAG-enabled chatbot as studied by Odede and Frommholz (2024).

Many software options exist for vector databases, such as Milvus (J. Wang et al., 2021), Pinecone (Pinecone, 2024), Chroma (Chroma, 2024). Xie et al. (2023) compared these three, citing Pinecone's 'robust distributed computing capabilities and scalability', and its common usage in real-time searching scenarios. Pinecone was also used in chatbots by Odede and Frommholz (2024) and Singer et al. (2024), showcasing its potential as a vector database solution for chatbots.

However, another open-source option with proven capabilities is FAISS, which was designed by engineers at Facebook (now Meta) which can be up to 8.5x faster than alternative options as written by Johnson, Douze and Jégou (2017). The speed and open-source nature of FAISS are very desirable in real-time applications such as chatbots, with FAISS also supporting direct integration with LLM development frameworks such as LangChain.

[2]Knowledge that the LLM has from its training data (Siriwardhana et al., 2023).

LangChain (LangChain, 2024) is a popular open-source framework for LLM development, and RAG pipelines by extension. that can be used to connect backend elements together, as described by Singer et al. (2024) when they used it to chunk their text data and connect to their vector database to store their embedded data.

2.1.5 Agentic RAG

A very recent development in the LLM space is the use of "agents". Agents increase the capabilities of LLMs by giving them access to tools created by developers, effectively allowing the LLM to execute its own code to perform tasks such as web searching and data retrieval. Agents can also evaluate themselves, as demonstrated in Figures 2.5 and 2.6, wherein the LLM will execute an action based on the query and evaluate the results. If the results are unsatisfactory, it can perform a slightly different action until a suitable answer is found. In a RAG context, this would often refer to continuous optimisation of the semantic search query used on the vector database.

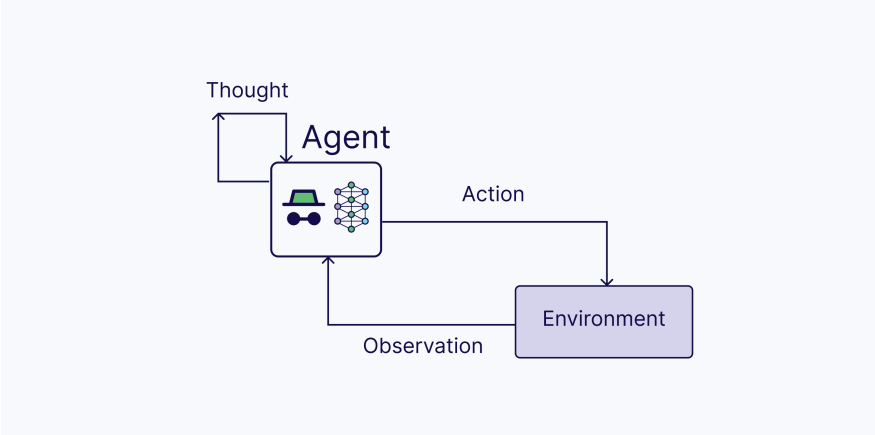

Figure 2.5: A basic ReAct (Reason + Act) agent workflow (Weaviate, 2024).

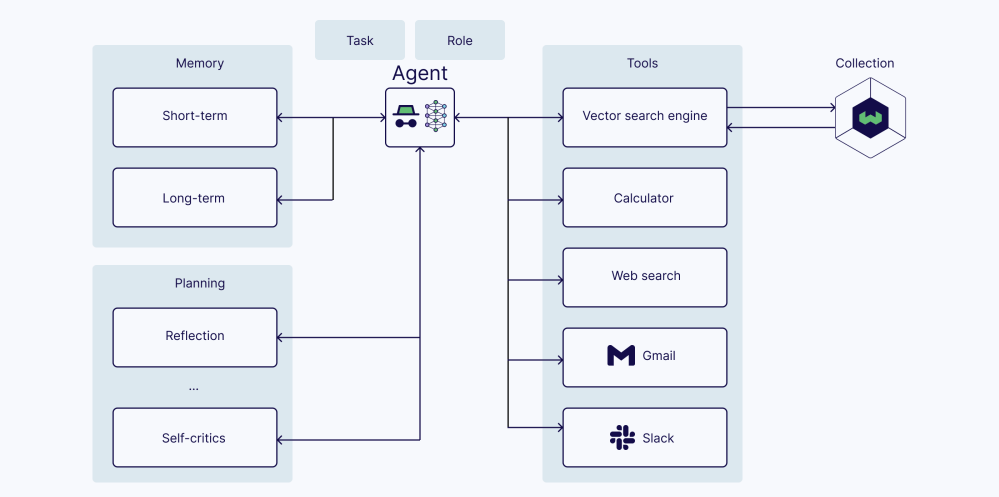

Figure 2.6: An advanced example agent workflow (Weaviate, 2024).

Figure 2.6 demonstrates the ability for agents to leverage multiple tools not only limited to searching a vector store, and also showcases their reflective and self-evaluative capabilities. With an agent that uses an architecture like this, answers would be extensively evaluated and regenerated until the agent deems them a suitable answer to the user's query. While this largely increases the time taken to generate results, it ensures those results will be accurate and useful to the end user.

In academic works, Woo et al. (2025) explored the implementation of augmenting base LLMs with agentic retrieval capabilities in a RAG workflow, which enhanced the accuracy of a GPT4 LLM by 95% on their medical Q&A dataset.

M. Bran et al. (2024)'s works were among the best reviewed in demonstrating the capabilities of Agentic AI, with their model they named ChemCrow having the ability to call a massive variety of tools including web search and even accessing advanced chemistry equipment to formulate chemical catalysts from a singular natural language prompt.

2.1.6 Chatbots / Conversational Agents

Conversational agents, better known as chatbots, leverage NLP in order to simulate a conversational flow between a user and machine, and have become mainstream products in recent years (Liao et al., 2018), though have existed as far back as 1966 with the creation of "ELIZA" for the IBM-7094 (Weizenbaum, 1966). As time has passed, advancements in chatbots have occurred in "waves", where each new wave has brought a major innovation (Schöbel et al., 2024).

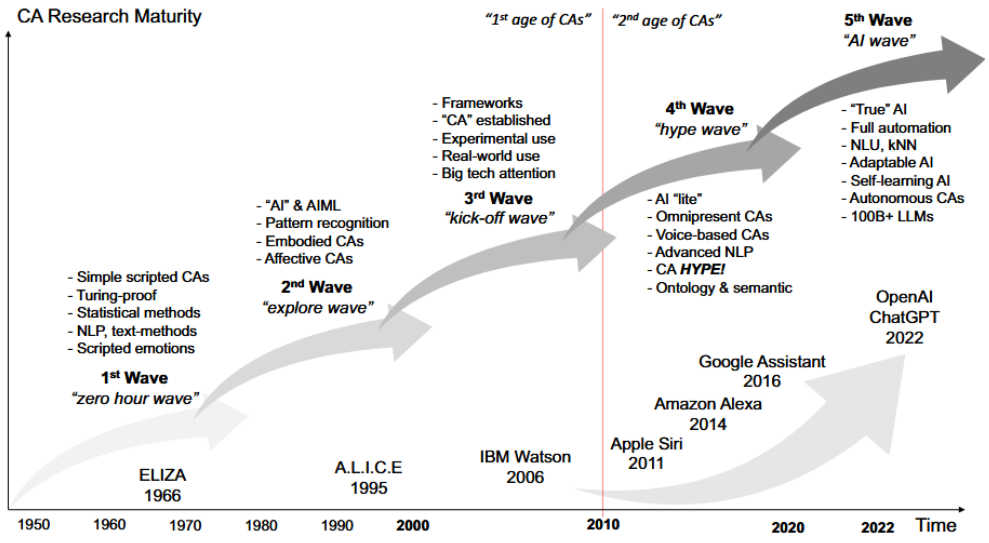

Figure 2.7: The five waves of conversational agent research (Schöbel et al., 2024).

Due to these considerable developments in the field, chatbots are now widely used across industries such as education (Kuhail et al., 2023). However, the use of the latest wave of chatbots based on LLMs poses significant risks, especially in educational settings as studied by Neumann et al. (2024), due to the risk of hallucinations being interpreted as absolute fact, although Shuster et al. (2021) argued that this risk can be greatly reduced through

introducing RAG to the backend LLM, which is further backed by the RAG-based chatbot created by Ge et al. (2023), which they found to also give superior answers to those of a general-purpose chatbot without RAG.

Many platforms exist to aid chatbot development, though they are typically aimed at users from non-IT backgrounds (Srivastava and Prabhakar, 2020). Popular platforms include IBM's watsonx Assistant (IBM, 2024a), Google's Dialogflow (Google, 2024) and Microsoft's Bot Framework (Microsoft, 2024). However, these are primarily targeted at enterprise clients which is reflected in their pricing. Instead of using these, the chatbot can be manually developed using LangChain as its framework.

2.1.7 User experience and Human-Computer Interaction

The way people interact with their devices has drastically evolved over time, from early MS-DOS command-line interfaces (CLIs) to mouse-based graphical user interfaces (GUIs), to touch screens (Kotian et al., 2024), greatly broadening the userbase of computers worldwide. Therefore, inclusive and accessible design is increasingly important to maximise the audience of any software, especially considering the growing disabled population (Putnam et al., 2012).

As well as being inclusive, the design should also be user-centred, meaning it should be an iterative process that is constantly taking user feedback into account (Chammas, Quaresma and Mont'Alvão, 2015). However, there are some barriers in this process when developing chatbots, as studied by Clark et al. (2019) in their survey of university students who stated that they view chatbots as tools, and would not converse with them in the same way as they would a person, which would limit their potential use and hinder the overall design process.

Users also often struggle to get chatbots to respond how they want, as their prompts may be poorly understood due to issues like overgeneralisation (Zamfirescu-Pereira et al., 2023), and studies show that they grow impatient after around 2 to 6 failed attempts, often branding the product as poor if this occurs (Luger and Sellen, 2016).

2.2 Summary

In conclusion, this literature review has revealed multiple key focus areas for the chatbot's development. The overall design of the chatbot must be iterative and human-centred, and user feedback should be obtained at every possible opportunity to ensure the resultant product is high quality.

A deep exploration into AI, specifically in its applications in NLP, LLMs and RAG, has revealed that the best approach will be to leverage a pre-existing cloud-based LLM, such as GPT-4o-mini, via an API, as running an LLM on a local machine would require an infeasible amount of processing power.

The non-parametric memory accessed through RAG would be a vector database created with Pinecone storing embeddings generated by OpenAI's text-embeddings-3-small model, and the overall framework will be LangChain. This will keep the cost of the project low while maintaining a tolerable level of quality in the bot's responses.

Methods and Implementation

This chapter focuses on the experimental design and implementation of the artefact.

3.1 Methodology

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3.2 Design

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3.3 Implementation

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Evaluation

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4.1 Methodology

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4.1.1 Metrics

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4.1.2 Baseline systems

4.1.3 Dataset

Likely not applicable. OpenAI's models are all closed-source.

4.2 Results

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4.3 Discussion

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Conclusions

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Recommendations for future work

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