AI + IoT for smart homes via free LLMs: reducing brittleness and promoting privacy in domestic converational control systems

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Declaration

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Executive Summary

Recent developments in Transformer models [2], like ChatGPT [74], have raised the bar for conversational AI(Artificial Intelligence) [39], showing a surprising ability to imitate human speech and handle challenging tasks like pair programming. Simultaneously, the Internet of Things (IoT) has gained popularity, using networked micro-controllers to automate many tasks, chiefly in smart homes. But problems with privacy and dependability have prevented IoT technology from being widely adopted [9].

This research offers a novel approach to these problems by incorporating conversational language models (LLMs) that protect privacy into smart home systems. Privacy problems are mitigated by the use of technologies that eliminate the need for external network connections and cloud computing. Furthermore, conversational inference capabilities enhance the robustness of control tasks, promoting a more natural and intuitive interaction environment. The integration of conversational LLMs that protect privacy into smart homes represents a major advancement in the integration of cutting-edge AI capabilities with Internet of Things applications, while simultaneously resolving critical privacy and dependability concerns.

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Chapter 1

Introduction

Recent advancements in large language models (LLMs) [78] and their integration with smart home technology have opened doors for a new era of user convenience and automation. Meta's release of the open-source LLAMA foundational model [68], followed by derivative models like Vicuna [23], has significantly expanded the landscape of conversational AI. These models, trained on massive datasets and accessible through open-source platforms, now rival the performance of established solutions like ChatGPT, all while requiring considerably less computational resources.

However, alongside the undeniable benefits, integrating LLMs into smart home environments introduces inherent risks [57]. Privacy concerns and the potential for model hallucination or faulty reasoning pose significant challenges, particularly in control contexts where erroneous actions could have real-world consequences. These risks necessitate careful consideration and the development of effective mitigation strategies.

1.1 Project Goals

This project directly addresses these challenges by proposing a novel framework that isolates LLMs from directly controlling smart home functions. To ensure the integrity and safety of smart home operations, the framework introduces a formal model represented as a JSON data structure of the home and its devices. All control actions are mediated through a separate executive process. Both the LLM and the executive interact with the same model, with the executive enforcing that only recognised and validated modifications occur.

The core objective of this project is to optimise the interactions between the LLM and the JSON model. This will involve generating successful conversation examples, fine-tuning a model like Vicuna on the generated data, and evaluating its performance compared to baseline models. Furthermore, the project will explore potential future model advancements, such as incorporating a mixture of experts approach, to further enhance the capabilities and reliability of conversational LLMs within smart home environments.

Chapter 2

Background and Literature Review

This literature survey delves into the multifaceted landscape of privacy-preserving conversational language models (LLMs) in smart home environments. It explores recent advancements in LLM technology, including Meta's release of the LLAMA foundational model and subsequent developments in derivative models like Vicuna. These advancements have driven a surge in research and innovation, democratising LLMs and enabling their deployment on domestic hardware. The survey investigates the inherent risks associated with LLMs, including privacy concerns and the potential for hallucination and reasoning faults. Recognising these risks, researchers have proposed various mitigation strategies, such as isolating LLMs from direct executive functions and mediating control actions through formal models.

It reviews existing methodologies for optimising interactions between LLMs and formal models, focusing on generating successful conversation examples, fine-tuning LLMs on generated data, and evaluating model performance against baseline metrics. Furthermore, it explores emerging trends in model evolution, such as the integration of a mixture of experts, and their implications for enhancing the capabilities and reliability of conversational LLMs in smart home environments. By synthesising insights from existing literature, this survey aims to provide a comprehensive understanding of the current landscape and inform future research directions for privacy-preserving conversational LLMs for smart homes.

2.1 AI and IoT integration for smart home applications

The advent of Artificial Intelligence (AI) and the Internet of Things (IoT) has significantly reshaped the landscape of smart home applications, propelling the development of more intelligent, efficient, and personalised living environments. The integration of AI and IoT within the context of smart homes, providing a comprehensive examination of its benefits, applications, and the challenges it faces. By focusing exclusively on smart home applications, the review would not encompass the broader spectrum of AI and IoT applications in other domains but would refer to such contexts when relevant to the discussion on smart homes.

2.1.1 Advantages of IoT-Based Smart Home Technology

IoT-based smart home technologies bring several advantages, including improvements in home security and energy efficiency [32]. The integration of IoT devices enhances the ability to monitor, control, and manage home environments remotely, leading to increased comfort and quality of life. For instance, smart home systems can detect motion and unauthorised access, thereby improving security. Additionally, IoT enables more efficient energy use by allowing homeowners to monitor and control energy consumption, leading to cost savings and reduced environmental impact.

2.1.2 Applications of AI and IoT in Smart Homes

The integration of Artificial Intelligence (AI) and the Internet of Things (IoT) in smart homes has significantly transformed general household assistance, elevating the standard of living by making homes smarter, more efficient, and more responsive to the needs of their inhabitants [64]. This transformation extends across various facets of home management, including automation of daily tasks, enhancement of home entertainment systems, and improvement of indoor environmental quality [70]. Furthermore, decision support systems leveraging smart home data streams are instrumental in domestic retrofitting and improving overall operational efficiency [25]. Below are detailed discussions on these applications, showcasing the breadth and depth of AI and IoT contributions to general household assistance. Smart devices autonomously perform tasks, enhancing efficiency and convenience for homeowners.

1. Automation of Daily Tasks: AI and IoT technologies have had a notable impact on household management by automating routine chores such as cooking and cleaning [27], [21]. Smart devices are capable of autonomously performing these tasks, thereby enhancing efficiency and convenience for homeowners., enhancing efficiency and convenience for homeowners.

2. Enhancement of Home Entertainment Systems:The integration of AI and IoT personalises entertainment experiences by recommending content and enabling voice-controlled operation of devices. The customisation have created immersive experiences tailored to individual preferences. [56].

3. Improvement of Indoor Environmental Quality: Smart thermostats and air quality monitors ensure optimal living conditions by adjusting to real-time environmental data, promoting health and comfort through intelligent environmental control [27].

4. Remote Access and Control: This feature enables homeowners to manage their homes from afar, offering the ability to monitor, adjust settings, and receive alerts on their smartphones, adding a layer of security and convenience [47].

5. Personalised Health and Wellness Monitoring: Wearable and embedded sensors within the smart home ecosystem track health metrics, offering personalised insights and early warnings about potential health issues, fostering proactive health management [20].

6. Intelligent Energy Management: By analysing usage patterns and integrating with renewable sources, smart systems optimise energy consumption, reducing waste and contributing to a more sustainable and cost-effective home environment [54].

7. Voice-Controlled Home Automation: Voice assistants powered by AI interpret commands to control smart devices, providing a hands-free method to manage lighting, entertainment, and security settings, enhancing accessibility and convenience [56].

8. Predictive Maintenance for Home Appliances: Smart diagnostics and monitoring predict when appliances require maintenance or are at risk of failure, scheduling repairs proactively to avoid inconvenience and extend the lifespan of home devices.

9. Smart Water Management: Intelligent systems monitor water usage, detect leaks, and automate irrigation, ensuring efficient water use, reducing waste, and contributing to conservation efforts within the household.

Although AI and IoT in smart homes provide various advantages, this technological advancement also presents several obstacles and apprehensions that need to be resolved to guarantee the security, confidentiality, and dependability of these sophisticated systems [4] [58]. These vulnerabilities have the potential to result in unauthorised access to personal information and the ability to operate house systems, which presents significant security threats to homeowners. It is crucial to have robust security mechanisms in place on these devices in order to reduce potential risks and safeguard sensitive data. Smart homes significantly depend on gathering and analysing vast amounts of data about individuals' behaviours and preferences in order to offer tailored services. The integration of Artificial Intelligence (AI) with the Internet of Things (IoT) is expected to revolutionise smart homes, leading to significant improvements in our interactions with our living environments [27]. The progression of technology is anticipated to influence the development of smart houses, resulting in enhanced intelligence, connectivity, and intuitiveness.

2.2 Exploration of Conversational AI frameworks

Conversational artificial intelligence involves the development of technology and systems that allow computers to have human-like conversations with users. It covers various techniques and approaches from artificial intelligence (AI) [33], natural language processing (NLP) [24], machine learning (ML) [6], and other related fields to comprehend human language, produce suitable responses, and imitate human-like interaction.

Conversational AI seeks to establish human-computer interactions that are natural and intuitive, like discussions between humans. This technology enables consumers to connect with machines using spoken or written language, powering applications such as chat-bots, virtual assistants, voice-enabled gadgets, and messaging platforms [3]. Conversational AI involves the utilisation of artificial intelligence to develop computer programmes capable of engaging in natural, spoken language conversations with people. The objective of conversational AI is to develop a dialogue system capable of comprehending and reacting to user input in a manner that is indistinguishable from a human conversation.

2.2.1 Key Components of Conversational AI framework

The architecture of a conversational AI framework includes various fundamental components that are crucial for enabling a smooth interaction experience. The framework relies on Natural Language Processing (NLP), a technology that allows computers to understand and respond to human language effectively. Dialogue Management is responsible for managing the progression of a discussion, keeping track of its current status, and deciding on suitable responses. In addition to NLP, Natural Language Generation (NLG) [43] creates responses that resemble human language, guaranteeing that they are contextually relevant and coherent.

Machine Learning is crucial in improving the system's comprehension by analysing human interactions, while Intent Recognition identifies users' objectives to customise responses accordingly. Sentiment Analysis assesses emotional states, allowing for subtle and nuanced reactions [65]. Contextual Understanding explores the specific circumstances and environment of users, enabling customised interactions. A multi-modal interface improves accessibility by accommodating diverse input methods, such as speech, text, and gesture. API Integration enhances functionality by connecting with external services like calendars and social media, while Analytics and Reporting provide valuable insights into user behaviour, improving system performance and customising user experiences. By integrating these elements, a conversational AI framework may develop a conversational interface that is natural, intuitive, and effective, hence enhancing the interaction experience for users by making it more personalised and valuable.

A comprehensive examination of prominent conversational AI frameworks for commercial applications comprises Google's Dialogflow [60], Microsoft's Bot Framework [14], the open-source Rasa [15], IBM Watson Assistant [30], Amazon's Lex [28], and Botpress [53]. These frameworks include a range of functionalities, including natural language understanding (NLU), dialogue management, and integration across many channels. Developers often use them because of their scalability, customisability, and ease of deployment. Every framework possesses unique advantages and disadvantages, accommodating a wide range of company requirements and preferences for constructing interactive chatbots and virtual assistants.

2.2.2 Comprehensive Description of the Functioning of Conversational AI Systems

Conversational AI enables computers to engage in human-like conversations with users. Joseph Weizenbaum et al [73] developed *ELIZA* in the late 60s, a pioneering example that simulated a psychotherapist's responses through pattern matching and scripted dialogue. Despite its simplicity, *ELIZA* demonstrated early potential for computer-human interaction, inspiring advancements in conversational AI technologies. The figure 2.1 illustrates the fundamental workflow of a conversational AI system.

Natural Language Understanding (NLU)

When engaging with a conversational AI such as a chatbot or virtual assistant, the process commences with the user's input, which can be either typed or spoken. The Natural Language Understanding (NLU) [5] component analyses this input. Natural Language Understanding

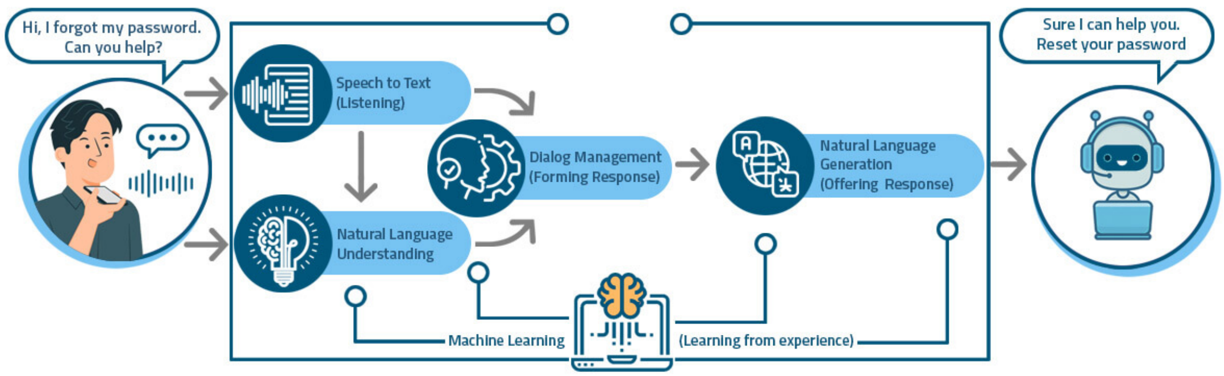

Figure 2.1: Conversational AI workflow [16]

(NLU) deconstructs the user's message by tokenising it, identifies the grammatical structure through part-of-speech tagging, recognises specific entities using named entity recognition, and eventually determines the user's objective through intent classification. Through the utilisation of machine learning algorithms trained on extensive datasets, Natural Language Understanding (NLU) is capable of extracting the user's underlying intention from their words, thus enabling a significant and purposeful dialogue.

Dialogue Management

Following the decoding of the user's intent by the NLU, the dialogue management [17] component takes the stage. Consider it as the orchestrator of the conversation. In this case, the system takes into account the context established in earlier exchanges in order to ascertain the most appropriate subsequent action or reply. Dialogue management systems utilise a range of methodologies, including rule-based systems with predefined replies, as well as more advanced methods such as finite-state machines or reinforcement learning. Ultimately, this component guarantees that the conversation proceeds seamlessly by choosing the most suitable action according to the present condition of the interaction.

Natural Language Generation (NLG)

After deciphering user intent, the conversation takes another step with Natural Language Generation (NLG) [43]. Here, the system transforms its internal understanding into a human-readable response. NLG acts like a translator, taking structured data or system-generated content and crafting it into coherent sentences that fit the conversation's context. NLG techniques can range from pre-defined templates for simple responses to rule-based generation for more complex scenarios. Cutting-edge systems even utilise advanced neural language models trained on massive databases of human conversations, allowing them to generate natural-sounding and nuanced responses.

Integration with External Systems

Conversational AI systems often extend their reach beyond internal processing to interact with the outside world. This integration with external data sources and services allows the system to provide more valuable responses. For instance, the AI might need to access information from a database, perform actions like booking a reservation, or retrieve relevant data based on the user's query. To achieve this seamless connection with external systems, databases, or APIs, conversational AI systems utilise mechanisms like APIs (Application Programming Interfaces) [40], webhooks (real-time communication channels) [13], or even custom integration methods. This collaboration between the AI and external resources empowers it to deliver more comprehensive and helpful responses to user requests.

Feedback Loop and Learning

Conversational AI systems evolve through user feedback, which informs machine learning algorithms to refine models, update language understanding, and improve dialogue management. This iterative process leads to more accurate and personalised responses, enhancing the system's effectiveness and engagement over time [49]. Consequently, conversational AI systems can effectively understand inputs, generate appropriate responses, and engage in natural conversations across channels and platforms.

2.2.3 Applications of Conversational AI

Conversational AI finds diverse applications across various domains, enhancing user experiences and simplifying tasks. In customer service, chatbots and virtual assistants offer 24/7 support, directing inquiries efficiently and seamlessly transitioning to human representatives when necessary. Personal assistants like Alexa, Siri, and Google Assistant manage schedules, control smart home devices, and provide reminders [69]. Real-time language translation capabilities facilitate communication across languages, breaking down communication barriers. Additionally, conversational AI provides entertainment through interactive stories, games, and engaging experiences [26]. In healthcare, it offers personalised recommendations, appointment scheduling, and medication reminders, promoting better patient care [12]. Overall, conversational AI continues to expand its applications, shaping technology's role in daily life. With the growth and expansion of conversational AI, it comes with its merits and demerits as well, which we have discussed in the next subsection.

2.2.4 Benefits of conversational AI

1. Improved efficiency: Conversational AI can automate routine tasks and provide quick answers to common questions, freeing up human time and resources.

2. Enhanced customer experience: Conversational AI can provide 24/7 support and personalised interactions, leading to increased customer satisfaction and loyalty.

3. Cost savings: Conversational AI can reduce the need for human customer support, leading to cost savings for businesses.

4. Accessibility: Conversational AI can provide assistance to people with disabilities, such as those who are deaf or hard of hearing.

2.2.5 Challenges and limitations to conversational AI

1. Limited understanding: Conversational AI systems may struggle to understand complex or nuanced user requests, leading to errors or misunderstandings.

2. Lack of empathy: Conversational AI systems may not be able to provide the same level of empathy or emotional support as human customer support agents.

3. Security and privacy concerns: Conversational AI systems may collect and store user data, which raises concerns about data privacy and security.

4. Dependence on data: Conversational AI systems are only as good as the data they are trained on, which means they may not perform well if they are not exposed to diverse and high-quality data.

Conversational AI has the potential to revolutionise the way we interact with technology and provide significant benefits to businesses and individuals alike. However, it is important to address the challenges and limitations of conversational AI to ensure that it reaches its full potential.

2.3 Examination of Large Language Models

The introduction of Artificial Intelligence (AI) via Large Language Models (LLMs) into the Internet of Things (IoT) ushers in a new era of smart houses. This study of the literature carefully looks at how LLMs are used in smart home technologies, emphasising their potential, problems, uses, and capabilities. This section attempts to summarise the important contribution and developments of LLMs in improving Internet of Things (IoT)-based home automation systems, based on insights from nine seminal works.

LLMs that can comprehend and produce language that is similar to that of a human, like OpenAI's GPT series, have raised the bar. In order to read user requests and automate answers in smart homes, they must be able to execute difficult language understanding and generation tasks, which they can do by processing large volumes of data using sophisticated neural network designs [55], [22].

2.3.1 Applications of LLMs in Smart Homes

Automation and Control

More advanced automation and control techniques are made possible by LLMs, which are completely changing the way smart homes function. These models improve functionality and user experience by deciphering intricate user requests and automating tasks across a range of home devices. For example, based on user preferences and long-term behaviour patterns, LLMs can regulate HVAC, security systems, and lighting [62], [37].

Enhanced User Interactions

LLMs greatly enhance smart home user interfaces by enabling natural language interactions. They facilitate easy communication of consumers' demands, increasing accessibility to technology and elevating user satisfaction levels. This is especially advantageous for those with special needs or those who might not be tech-savvy because it makes it easier for users to engage with their homes [72], [37].

personalization

By gaining knowledge of individual preferences and modifying their replies accordingly, LLMs help to personalise user experiences. This LLM technology feature makes sure that smart home environments are tailored to the individual needs and behaviours of their occupants, making them both responsive and perceptive [71], [59].

2.3.2 Security and Privacy Considerations

Data Privacy Issues

Although useful, LLMs' broad data handling capabilities come with serious privacy hazards. Due to the volume of personal data they handle and retain, these systems are susceptible to data breaches. Strong encryption and privacy-preserving data processing methods are needed to address these issues and safeguard sensitive data [38], [35].

Security Enhancements

Integrating LLMs into smart homes requires careful consideration of security issues. For the purpose of preventing unwanted access to personal information and home security systems, the systems need to be protected against a variety of cyber threats. To ensure the integrity and security of smart home networks, advanced security mechanisms and ongoing monitoring are necessary [71], [35]..

2.3.3 Challenges in Implementation

Integration Complexity

There are many technical obstacles to overcome when integrating LLMs into current smart home systems. These include keeping the system stable and performing well in the face of regular updates and upgrades, managing the significant computing resources needed by LLMs, and guaranteeing interoperability across various devices [37].

Contextual Understanding

Even with their sophisticated powers, LLMs can have trouble making decisions and comprehending context in dynamic settings like smart homes. To achieve more autonomous and dependable smart home systems, it is imperative to improve their capacity to recognise context from minimal cues and make intelligent judgements in real-time [62], [37].

Scalability

Scaling LLM applications to effectively handle increasing loads and more complicated activities is a difficulty as smart home environments get more complex. To guarantee that these systems can manage increasing numbers of devices and user demands without sacrificing performance, future solutions must address scalability [72], [59].

The incorporation of LLMs into smart home technology is a promising avenue in IoT and AI research. While these models provide sophisticated possibilities for improving home automation, interaction, and personalization, they also introduce problems that must be solved in order to fully realise their promise.

2.4 Preserving privacy within AI models

The Internet of Things (IoT) is transforming global interactions, characterised by a network of interconnected devices that generate vast amounts of data [34], [79]. This proliferation of data collection raises substantial privacy concerns, as IoT devices continuously gather data across multiple layers, including devices, networks, and applications [34].

The rapid expansion of digital technologies has brought privacy issues to the forefront, particularly with IoT applications capable of disclosing sensitive user information [8]. Ensuring user privacy within IoT ecosystems is imperative, prompting researchers to develop innovative solutions [34], [11], [8].

Existing privacy-preserving techniques in IoT applications aim to strike a balance between data protection and functionality across diverse architectures, highlighting the importance of responsible data utilisation [8]. Understanding and implementing these approaches will help ensure that IoT continues to advance societal benefits while prioritising user privacy [8].

2.4.1 Challenges and Risks to Privacy in IoT Ecosystems

The ever-evolving landscape of the Internet of Things (IoT) introduces a multitude of privacy concerns, as highlighted in both [79] and [29]. These threats arise from the intricate interplay between human interaction with IoT devices and the underlying technology itself. The analysis in [79] discerns various categories of threats, delving into their ramifications across different phases of data collection and utilisation within the IoT ecosystem. Essentially, it illuminates how the dynamic nature of the IoT exacerbates existing threats while ushering in entirely new ones.

1. **Identification of Threats in the IoT**

   The Internet of Things (IoT) makes identifying individuals much easier due to the vast amount of data collected during device interaction. Surveillance cameras, increasingly used for non-security purposes, combined with facial recognition, pose a significant threat. Interconnected devices leave unique signatures that can reveal owner identities [79]. Additionally, the rise of speech recognition in IoT systems and large speech sample databases raise concerns about identifying individuals through their voices. Existing identity protection solutions struggle in the dynamic IoT landscape. Local processing and horizontal communication between devices are proposed to minimise identifiable data storage and reduce the risk of identification.

2. **Location Tracking Threats in the IoT**

   The vast amount of data collected by devices in the Internet of Things (IoT) makes location tracking a bigger threat. While location tracking can be useful in some IoT applications, the lack of user control over this data raises privacy concerns. People feel violated when they're unaware of being tracked, can't control who sees their location data, or when it's misused [79]. The ease of data collection in the IoT environment exacerbates this issue. The growth of location-based services (LBS) indoors, along with more passive and pervasive data collection, means users might not even realise they're being tracked. Additionally, everyday interactions with smart devices leave data trails that can be used to track location and activity.

3. **Privacy Considerations When Outsourcing Data to the Cloud**

   Implementing IoT projects raises privacy concerns due to the extensive collection of sensitive data by IoT devices [29]. For instance, data from car sensors in public transportation systems is valuable to insurance companies, potentially impacting premiums or eligibility [29]. Location details (including timestamps) obtained from GPS and wireless networks are also critical for privacy considerations [29]. Storing this data in cloud infrastructure exacerbates privacy worries, as users fear losing control over their information [29]. Cloud service providers must ensure confidentiality and protect stored and processed data to alleviate these concerns. Failure to do so may deter users from adopting cloud-based services, particularly for sensitive data such as health information stored in electronic health records (EHRs) and smart home technologies [29]. Figure 1 depicts various smart home devices with privacy concerns.

2.4.2 Privacy Preservation Techniques

Berrehili et al. [11] advocate a dual-tier strategy for safeguarding privacy in IoT applications, involving recommendations and anonymization methods. The recommendations target various stakeholders, including users, developers, and applications. Users are encouraged to understand the data being collected and to exercise discretion in sharing information. Developers are advised to incorporate authentication measures for updates and data collection processes. Applications should implement device authentication, ensure data consistency, secure communications, and exercise control over data sharing between applications. Anonymization techniques aim to hide or modify data to prevent identification.

It covers encryption, generalisation (replacing specific specifics with larger categories), and k-anonymity (where data is made indistinguishable from at least k-1 others). By avoiding excessive inaccuracies, it emphasises the necessity to strike a balance between privacy and data utility. Although it takes more resources, anonymizing data at the device level is thought to be the

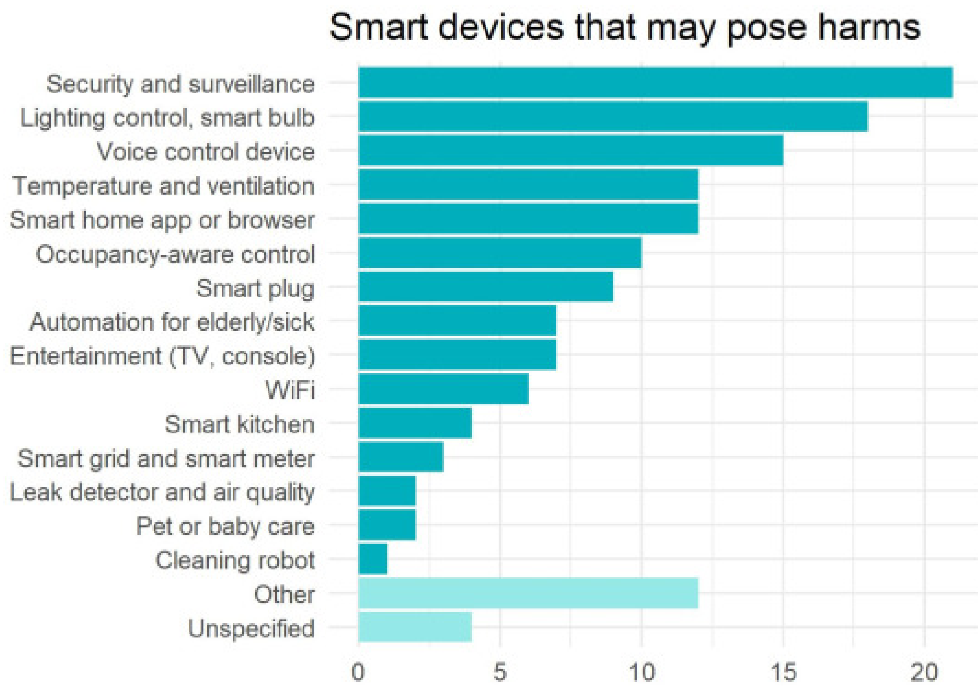

Figure 2.2: showing smart home devices that may pose digital harm [19]

most effective privacy solution. Although less secure, anonymization at the gateway level is more practical. While anonymizing applications is easy, it also carries the greatest risk to privacy. [11].

Jayarama et al. [34] proposes a secure IoT architecture using the OpenIoT platform. It enhances user privacy by splitting sensor data across servers, eliminating single points of vulnerability. The system employs an OAuth-based authorisation framework to restrict data access to authorised users, preventing unauthorised access. Additionally, it integrates privacy-preserving data storage using homomorphic encryption, enabling secure computations on encrypted data during analysis. This multi-layered approach establishes a secure and privacy-preserving IoT architecture, reducing the risk of data breaches and unauthorised access.

Henze et al. [29] proposes **U**ser-driven **P**rivacy **E**nforcement for **C**loud-based **S**ervices in the **I**oT (UPECSI) to protect user privacy in cloud-based IoT services. UPECSI prioritises user control and consent through a three-part strategy. Firstly, it introduces Model-driven Privacy (PDL) for cloud service creators to describe data usage, automatically generating user-friendly privacy policies. Secondly, UPECSI engages users by presenting the generated privacy policy and explaining data usage, allowing customisation of data access levels based on privacy preferences. Finally, UPECSI utilises Privacy Enforcement Points (PEPs) on IoT gateways to enforce user privacy configurations, ensuring only authorised data is sent to cloud services and preventing unauthorised access. In summary, UPECSI empowers users to control their data privacy in cloud-based IoT services with transparent explanations and customisable privacy settings, supporting informed decision-making on data sharing within the IoT ecosystem.

Patel [52] explores **blockchain technology**, a system for secure and tamper-proof recording of information. Blockchain uses cryptography to create a shared digital ledger of transactions across a network of computers. This distributed ledger ensures transparency and security, as

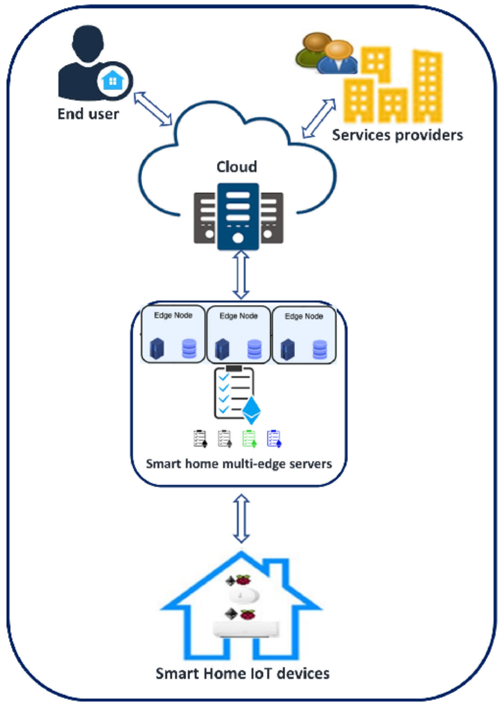

Figure 2.3: Showing the proposed system architecture for Privacy-Preserving Mechanism in Smart Home Using Blockchain [52]

any alteration to a block would require changing all subsequent blocks. There are three main types of blockchains: public, private, and consortium. Public blockchains are open to anyone, while private and consortium blockchains restrict participation to authorised users or groups. The passage then dives into the structure of a blockchain, explaining how data is grouped into blocks and secured using cryptographic hashes. It also briefly mentions mining, the process of validating transactions and adding them to the blockchain through solving complex puzzles. In essence, blockchain technology offers a secure and transparent way to record data. While it holds promise for various industries, challenges like energy consumption need to be addressed.

The system in Figure 2 utilises Ethereum blockchain smart contracts [52] to manage access to smart home devices. Participants include end users (residents and service providers), IoT devices (sensors and actuators), edge servers for local data processing, and the cloud for storage and analysis. Users and the cloud connect via apps and servers, while devices and servers directly interface with the blockchain. Edge servers manage local communication, user authentication, and partial data processing, with the cloud responsible for data storage and analysis with privacy measures.

This section discusses various techniques for preserving privacy in data handling. One approach is **Homomorphic Encryption** [67] , which allows calculations to be performed on encrypted data without needing to decrypt it first. This ensures that the data remains confidential while still enabling valuable analysis. Another technique involves **Dataflow Models** [67] . These models define permission levels for accessing data based on its privacy classification. This promotes transparency and accountability in how data is handled. There are two main approaches within

Dataflow Models [67]: Blockchain technology can be used to verify and record data collection, storage, and access. This is particularly relevant in the Internet of Things (IoT) environment, where numerous devices collect and share data. Privacy-based programming languages require developers to declare information flows and access privileges upfront. This ensures that data elements comply with defined privacy policies before they are used.

Data Summarising [67] offers a condensed, privacy-protecting approach to data presentation. Summarising techniques, widely used in text analysis, network monitoring, and finance, create informative formats tailored to specific purposes, such as privacy-preserving network traffic analysis.

Personal Data Stores provide secure control and management of personal information by acting as central repositories for user data. Users can selectively share this data with other applications or users as needed, enhancing privacy controls and data management.

The vast data collected by IoT devices raises significant privacy concerns. Researchers are developing solutions like user awareness, data anonymization, secure architectures, and user-controlled privacy settings. Techniques such as homomorphic encryption and blockchain technology show promise in ensuring data privacy while enabling analysis and use within the IoT ecosystem, prioritising responsible data use and user privacy.

2.5 Assessment of fine-tuning processes and mitigation of potential risks, such as AI hallucinations

The field of large language models (LLMs) is constantly evolving, feats like *GPT-3, IntroductGPT, FLAN, PaLM, LLaMA,* and other significant contributions. Despite their impressive performance across various tasks, LLMs have also faced a troubling limitation impacting their reliability and trustworthiness: hallucination. With hallucination, we refer to the generation of texts or answers that exhibit grammatical correctness, fluency, and authenticity, but diverge from the provided source inputs (faithfulness) or are misaligned with factual accuracy (factualness) [36]. Lack of real-world knowledge, bias or misleading training data may prompt models to return statistical-based results. Hallucination can also be considered the generation of statements that appear reasonable but are either cognitively irrelevant or factually incorrect.

2.5.1 Hallucination Detection

Some techniques rely on extracting intrinsic uncertainty metrics. Token probability, for instance, can be leveraged to identify which part of a given textual sequence proves least uncertain [76]. LLMs factual checks can also rely on external databases and corpora such as Wikipedia [66]. Hallucinations can be detected in a great deal of general knowledge covered in Wikipedia, albeit concerns arise about the integrity of Wikipedia content itself. Self-Evaluation is the core of the study being if language models can assess their own answers' validity and predict accuracy. Models can self-evaluate open-ended tasks, estimating answer correctness probability ("P(True)"). They also predict their knowledge probability ("P(IK)") effectively, with partial task generalisation (IK stands for "I Know") [18]. Hallucination detection methods can further be grouped into Grey and Black box [42]. Knowing LLM pre-training is paramount for grey box hallucination detection.

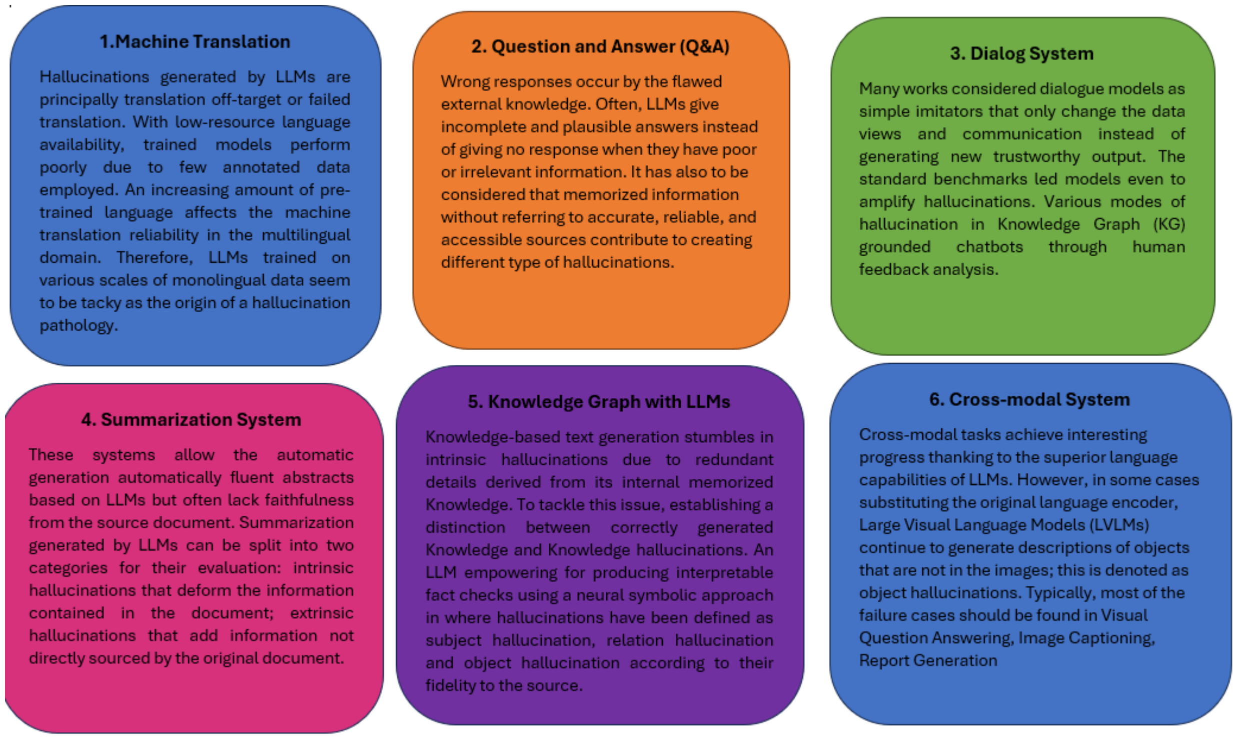

Figure 2.4: Hallucination Classification [18]

The training is carried out with next-word prediction over vast textual corpora, ensuring world knowledge and contextual reasoning.

2.5.2 Mitigating LLM Hallucinations

1. Diverse Prompts: Use a variety of prompts during training to expose the model to different contexts and scenarios. Include prompts that challenge the model's assumptions and encourage it to generalise beyond specific patterns [7].

2. Adversarial Training: Introduce adversarial examples or perturbations during training. These examples force the model to learn robust features and reduce over-reliance on specific cues [38].

3. Human-in-the-Loop Feedback: Incorporate human feedback during fine-tuning. When the model generates hallucinatory responses, allow human reviewers to correct or guide the model.

4. Prompt Engineering: Craft prompts that explicitly discourage hallucination. For example, include instructions like "Provide factual information only" or "Avoid speculative answers" [7] [38].

5. Temperature and Top-k Sampling: Adjust the temperature parameter during sampling. Higher temperatures encourage randomness, while lower values promote deterministic

responses. Top-k sampling limits the vocabulary to the top-k most likely tokens, reducing the chance of hallucination.

6. Chat Interactions: Engage in interactive conversations with the model. If the model produces hallucinatory content, gently correct it or ask for clarification.

7. Monitoring and Evaluation: Continuously monitor model outputs during training and fine-tuning. Set up evaluation metrics to detect and penalise hallucination.

In conclusion, while LLMs like GPT-3 and PaLM demonstrate remarkable capabilities, their susceptibility to hallucination poses a significant challenge. This phenomenon, where models generate seemingly plausible but factually incorrect outputs, necessitates robust detection and mitigation strategies. Various techniques exist — from leveraging external knowledge sources to crafting specific prompts — to curb hallucination [31]. As the field of LLMs continues to evolve, so too will our ability to ensure reliable and trustworthy interactions with these powerful language models. By prioritising factual accuracy and responsible development, we can harness the full potential of LLMs and unlock a future of intelligent and informative human-machine interactions [48].

Chapter 3

Research Questions

The formulation of precise research questions is pivotal in guiding the investigative and developmental trajectories of our project, focusing on the creation of privacy-preserving, robust conversational large language models (LLMs) for smart homes. These questions are intricately designed to address and resolve key challenges in current smart home automation systems—primarily enhancing user privacy, reducing system brittleness, and ensuring reliable conversational controls. As the realms of artificial intelligence and the Internet of Things (IoT) are delved into, these research questions not only mirror the specific objectives outlined in our project but also bridge critical gaps in data security, system dependability, and intuitive user interfaces. By these foundational concerns being addressed, the technology of smart homes is aimed to be advanced, making them more secure, efficient, and user-friendly, thereby aligning directly with our broader project goals and responding to the evolving needs of modern smart home environments.

3.1 List of Research Questions

1. **Optimisation of Local Data Processing:** How can local processing of conversational LLMs be optimised to enhance privacy and reduce reliance on cloud-based systems in smart homes?

2. **Reduction of System Brittleness:** What strategies can be implemented to reduce the brittleness of conversational LLMs, enhancing their reliability in executing home automation tasks?

3. **Security of Conversational Systems:** How can security measures be integrated into the architecture of conversational LLMs to prevent unauthorised access and ensure data integrity?

4. **Integration of User Feedback:** How can continuous user feedback be utilised to refine the performance and usability of conversational LLMs in smart homes?

5. **Future Directions in LLM Architecture:** What are the potential future developments in LLM architecture that could further improve the performance and efficiency of smart

home systems?

3.2 Detailed Question Analysis

By optimising local data processing for conversational LLMs, dependency on cloud systems, which are vulnerable to privacy breaches[1], is aimed to be minimised. The enhancement of local processing capabilities can significantly boost the privacy and speed of data handling, which are essential for real-time smart home interactions. Concerns about data sovereignty and network dependency, which are critical in maintaining user trust and system responsiveness, are addressed by this approach.

Reducing the brittleness of conversational LLMs is crucial for ensuring that these systems can handle unpredictable scenarios without failure[41]. Strategies such as enhancing error handling and improving adaptive learning capabilities will make these systems more robust. This is vital for maintaining functionality during unexpected events, thus increasing reliability and user confidence in smart home automation.

Integrating robust security measures into conversational LLM architectures is fundamental to safeguard against unauthorised access and data breaches [44]. This involves developing advanced encryption methods, secure communication channels, and regular security audits. Enhancing security not only protects sensitive user data but also ensures that the system functions reliably under potential cyber threats [50].

Utilising continuous user feedback to refine the performance and usability of LLMs in smart homes is essential for aligning the system with user expectations and real-world use cases[63]. Feedback-driven development can help identify usability issues, fine-tune interaction designs, and adapt functionalities to better meet user needs, leading to higher satisfaction and adoption rates.

Investigating potential advancements in LLM architecture could lead to significant improvements in efficiency and performance[75].This could include developing new algorithms for faster processing, better context understanding, or more nuanced human-like interactions. Anticipating and incorporating future technological trends can keep the system at the forefront of smart home innovation, providing a competitive edge and enhanced user experiences[77].

3.3 Strategic Impact and Methodological Alignment

Optimisation of local data processing has been successfully achieved, aligning with the goal of enhancing privacy and ensuring reduced dependence on potentially insecure cloud-based systems. This results in faster and more reliable system responses, which are crucial for user trust and satisfaction. Strategies to reduce system brittleness have been implemented, contributing directly to the objective of creating more reliable smart home environments. The resilience of conversational LLMs has been enhanced, thereby minimising the risk of failures that could affect user experience and safety. Integration of robust security measures addresses the primary project goal of ensuring data integrity and preventing unauthorised access, impacting user confidence and system reliability. Additionally, user feedback is integrated into the refinement of LLMs, supporting the achievement of a user-centric design and enhancing overall usability and functionality. Future directions in LLM architecture are explored and implemented, pushing the boundaries of what smart home systems can achieve and leading to advancements in AI that could revolutionise home automation, in line with the goal of maintaining technological leadership and delivering cutting-edge solutions to users.

3.3.1 Broader Implications

The research and developments from this project are expected to set new benchmarks in the smart home industry, particularly in terms of privacy and reliability. As innovation is pursued, a contribution is made to a body of knowledge that could pave the way for future standards in smart home technology. Insights gained from optimising LLMs and integrating user feedback are likely to influence future designs of smart home devices and systems, promoting a more intuitive and seamless interaction between humans and their automated environments. Furthermore, advancements in security and privacy-preserving technologies could inform policy and regulatory frameworks, promoting stricter standards and better practices across the industry. The effectiveness of user feedback in system design is demonstrated, encouraging other technology developers to adopt a more user-focused approach in their product development cycles, potentially leading to more personalised and responsive technologies in various sectors.

The project's direction is guided by research questions aimed at revolutionising smart home technology with privacy-preserving conversational LLMs. Key challenges are addressed through focus on local data processing, system reliability, security, and user feedback, aligning with broader objectives of enhancing privacy, stability, and user interaction. Insights from these questions inform our development strategies, ensuring innovative solutions aligned with user needs and project goals.

Chapter 4

Methodology

4.1 Project Plan and Requirements

As a privacy-centric and reliable conversational control system for smart homes using large language models (LLMs) is developed, understanding the stages involved in adapting these AI technologies is essential. The life cycle of an LLM includes:

- Training: Pre-trained models are leveraged to avoid the resource-intensive process of training from scratch, which requires substantial computational power and incurs high costs.
- Fine-Tuning: These models will be fine-tuned on domain-specific data relevant to smart home contexts using a limited array of hardware like NVIDIA A100 GPUs. This strategy efficiently enhances model performance for specialised tasks.
- Prompting: The deployment of LLMs involves crafting precise prompts to elicit accurate responses, a process that demands a high level of skill and understanding of the model's capabilities.

This structured approach allows LLMs to be optimised to provide secure and efficient smart home management without compromising user privacy.

4.2 Optimising Smart Home AI with Localised LLM

Large language models, such as Vicuna, are utilised to create conversational control systems that operate independently from the cloud, thus enhancing privacy and reliability in smart homes. The innovation involves a formal JSON data structure that mediates all control actions between the LLM and home devices, ensuring that only pre-approved changes are implemented. This method not only secures sensitive data within the home but also reduces errors in device control.

To ensure the system is user-friendly and functional, advanced data management and broad IoT device compatibility are integrated. The development process includes rigorous testing and ongoing refinement based on real-world usage and feedback. The combination of local processing for daily operations and high-performance computing for intensive tasks ensures that the smart home AI system remains both effective and scalable. Ultimately, an intuitive user experience is aimed to be delivered through natural, seamless interactions with home devices, thereby simplifying daily tasks while maintaining stringent privacy and reliability standards.

4.3 System Introduction and Operational Workflow

In this project, a sophisticated system using large language models (LLMs) has been integrated to enhance the functionality and privacy of smart home environments. The operation of this system revolves around a structured JSON model and user interactions facilitated by the Willow device, a voice-activated home assistant. Here's a detailed breakdown of the system's operation:

JSON Model: The backbone of the conversational control system is represented by a JSON data model that meticulously catalogues every device in the smart home along with their current states. For example, a typical entry in the JSON model might look like this: `"kitchen_overhead_light": "On"`. This model provides a clear and mutable representation of the home's devices, allowing for precise control and monitoring.

User Interaction via Willow Device: Interaction with the system is conducted through spoken commands directed at a Willow device, which is designed to seamlessly fit into the home environment. These verbal requests are captured by the device and transmitted to a local server for processing. The use of the Willow device ensures that all data processing remains local, enhancing user privacy by not transmitting data over the cloud.

Request Processing and Prompt Construction: Once a user's spoken request is transcribed by the Willow device, it is appended to a series of prompts that instruct the LLM to propose modifications to the JSON model. These prompts are crafted not only to interpret the user's immediate request but also to include the history of the conversation after the initial interaction. This ensures that the model can maintain context and continuity throughout the dialogue, leading to more accurate and relevant responses.

LLM Response and Device Control: The LLM processes these prompts and generates a response that includes a valid JSON update. This update is then applied to the JSON model to effect the necessary changes to the smart home devices. For instance, if the user says, "Turn off the kitchen light," the LLM might output an update such as `"kitchen_overhead_light": "off"`.

Confirmation and Feedback: After the JSON model is updated, a confirmation message is generated and transformed into audio speech. This message is sent back to the Willow device, which plays it aloud to inform the user that their request has been successfully executed. This feedback loop not only confirms the action taken but also reassures the user of the system's responsiveness and accuracy.

4.4 Fine-Tuning Strategy for Enhanced Response Accuracy

Automatic Generation of Example Conversations: A dynamic script is started by creating dialogues based on the current state and possible state transitions of each device within the JSON model. For instance, if the JSON model indicates that `"kitchen_overhead_light": "on".`, the script might generate sample user commands like, "Turn off the kitchen lights," along with the system's ideal response or update to the JSON model, e.g., `"kitchen_overhead_light":`

`"off"`.. This can also include more complex scenarios involving multiple devices, creating a rich dataset of realistic and varied interactions.

Incorporation of Context and Continuity: The LLM's ability to handle real-world conversational flows is enhanced by including historical context in the training examples. This means constructing conversation threads where subsequent commands depend on previous interactions. For example, after updating the light's status, a follow-up prompt might be, "Is the kitchen light on?" with the correct response based on the updated state. This training approach helps the model understand and maintain context over the course of a conversation, a critical feature for natural and intuitive user interactions.

Utilisation of Scenario-Based Training: Scenarios that might not be straightforward but are possible within the smart home environment are developed. For example, scenarios involving conditional commands, time-based triggers, or simultaneous device interactions. This helps the LLM anticipate and understand complex user requests, further aligning the model's capabilities with practical household needs.

Feedback Loop from Real Interactions: A system where real user interactions are periodically reviewed and anonymised to generate new training material is implemented. This feedback loop can identify gaps in the LLM's understanding and response accuracy, providing continuous improvement opportunities. For instance, if users frequently correct certain actions or rephrase their commands, these interactions should be analysed and incorporated into the training set.

Model Evaluation and Iteration: The LLM's performance is regularly evaluated using both automated metrics and user satisfaction surveys. The training regimen is adjusted based on this feedback to focus on areas requiring improvement. For example, if users report that the system does not respond well to requests involving multiple devices, the proportion of such scenarios in the training data is increased.

Privacy-Preserving Training: All data used for training, especially data derived from real user interactions, is handled in accordance with privacy standards. Techniques such as data anonymisation and local processing are used to maintain user trust and comply with data protection regulations.

4.5 Ethical, Professional and Legal Issues

Beyond the technical advancements, smart home technologies present significant ethical, professional, and legal considerations as they become more integrated into our lives. Ethically, the continuous data collection required to understand user habits and preferences—ranging from occupancy patterns to personal health details—raises privacy concerns. It is vital that this data is collected transparently and used responsibly to maintain user trust. Additionally, AI systems can perpetuate biases present in their training data, which could lead to discrimination, necessitating ongoing evaluation and refinement to ensure fairness across diverse populations. Professionally, the reliability and accuracy of these systems are paramount; rigorous testing and validation processes are essential to prevent errors that could lead to device malfunctions or compromised security. Professionals must also keep systems regularly updated and well-maintained to address new security threats and ensure the technology does not become obsolete. Legally, the implications of AI failures in smart homes, such as misidentifying individuals or failing to detect real threats, involve complex liability questions about whether manufacturers, developers, homeowners, or a combination thereof are responsible. Compliance with data protection laws like GDPR in Europe and CCPA in the U.S. is crucial, as non-compliance can result in significant fines and damage to reputation. Companies must implement robust data protection measures and ensure they remain up-to-date with evolving legal requirements to safeguard user data and build trust in their technologies. These multifaceted issues must be carefully managed to ensure responsible development, maintain user trust, and ensure the success of smart home technologies.

4.6 Risk Analysis

AI algorithms have the potential to exacerbate or perpetuate existing biases if they are trained on biased or unrepresentative data [45]. Biased AI decisions can result in unfair treatment of individuals based on their race, gender, or other distinguishing characteristics. Figure 4.1 illustrates the various technological challenges and their severity. To promote fairness and mitigate bias, AI systems should be trained using diverse data sources, undergo regular bias audits, and integrate fairness metrics throughout the development process [45].

The absence of compatibility between devices and software from different suppliers may lead to system inefficiencies or failures [10] which may result in reduced functionality and user dissatisfaction. Employing universally recognised protocols, consistently upgrade systems, and middle ware could enhance interoperability and communication across devices [10]. Relying too much on continuous internet connections may significantly hinder the system during times of service outage[10].

Crucial activities may encounter failure, thus compromising both security and comfort. Utilise the processing capabilities available locally, use cellular backup connections, and ensure that critical operations can operate independently from the network [51]. Outdated software may include vulnerabilities that may be exploited by attackers. Deploy automatic software updates, perform regular vulnerability assessments, and implement end-of-life policies for software that is no longer supported [46]. Insufficient authentication protocols might allow unauthorised entry into the system. Implement resilient, multi-factor authentication systems and provide extensive user training on secure password methods. Inadequate security protocols in data storage and processing may lead to the theft or loss of data [46]. Utilise encrypted storage options, ensure that data is managed with rigorous security processes, and comply with data protection regulations.

To mitigate these threats, deploy solutions or create rules that provide methods for reducing these risks, such as:

- Providing encryption and authentication systems.
- Offer users and administrators detailed information and instructions on the possible dangers and the necessary steps to reduce or eradicate them [61].
- Continuous monitoring utilises monitoring systems to identify and address security breaches, software updates, and system malfunctions.
- Perform regular risk evaluations that include growing technologies, changing risks, and alterations in compliance responsibilities.

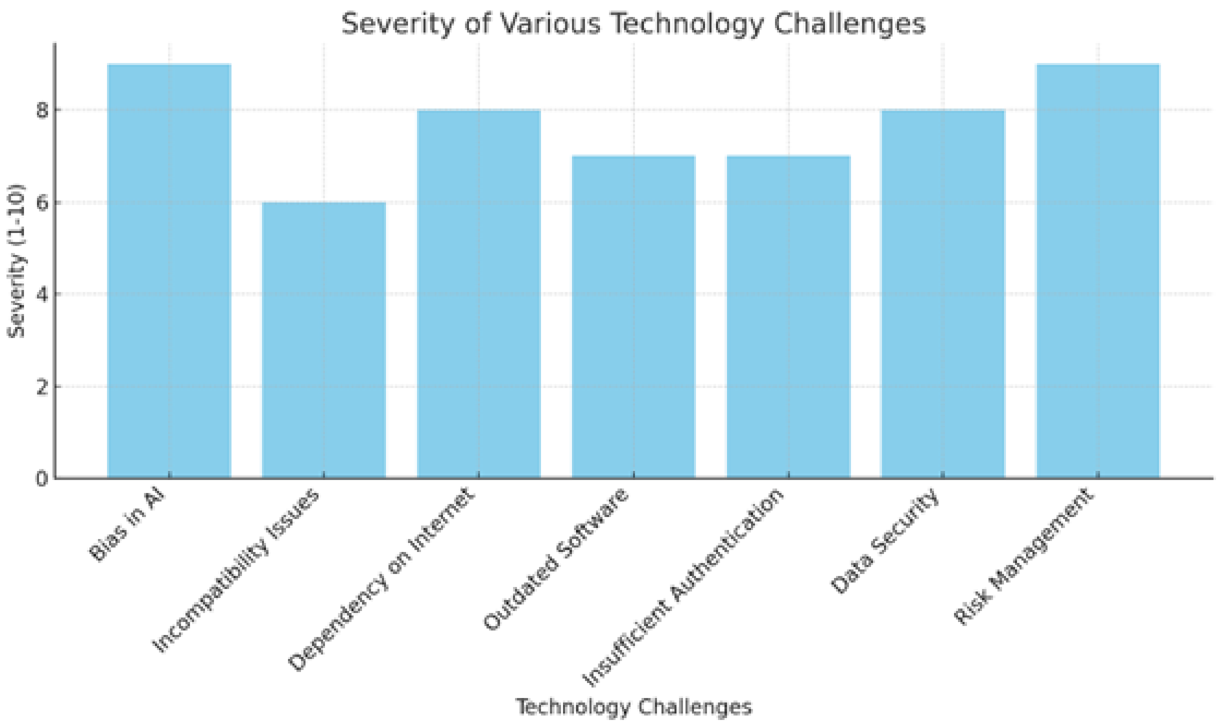

Figure 4.1: Showing a variation of technology challenges and their severity

Chapter 5

Results

This section elaborates on the results of developing the Vicuna large language model (LLM) for smart home conversation activities, concentrating on assessing its ability to understand and respond to user requests relevant to home automation. Table 5.1 presents a detailed account of Vicuna's performance across a variety of smart home devices, including thermostats, lights, door locks, and security cameras, allowing for seamless user interactions and effective control of household appliances in a simulated domestic setting.

Vicuna repeatedly exhibits the capacity to validate actions quickly and deliver appropriate feedback, which improves the overall user experience. For example, when asked to water the garden, the model confidently affirms the activity, demonstrating its capacity to precisely comprehend directions and perform tasks with accuracy.

Despite its successes, Vicuna has certain limits. For instance, the model occasionally exhibits indications of imaginative replies, such as claiming to be able to cook meals, which can be attributed to gaps in its training data for real-world physical acts. Furthermore, Vicuna regularly seeks user approval before doing activities, using a careful approach that, although good for safety and mistake reduction, may introduce some complexity during practical use.

The next section will involve a complete comparison study of the fine-tuned Vicuna model and the ChatGPT model to determine their different strengths and limitations in managing smart home conversation. This comparative study seeks to give subtle insights into how these models compare to one another in tackling the intricacies of interactive home contexts. The goal of completing this extensive assessment is to acquire a better grasp of their capabilities and identify possible areas for improvement in the field of smart home dialogue management.

In conclusion, refining the Vicuna LLM for smart home activities has shown encouraging results, demonstrating its capacity to properly handle a wide range of user requests. However, additional investigation and comparison with other models, such as ChatGPT, will provide light on the intricacies of their performance, eventually leading to advances in conversational AI specialised for smart home applications.

Table 5.1: Observations of Vicuna Model in Smart Home Conversations

User Conversation	**Model Response**	**Observation**
`USER: the garden needs to be watered`	`ASSISTANT: I can certainly help you with that! Just to confirm, do you want me to turn on the sprinklers for your garden? Please confirm by saying "yes" or "no".`	Vicuna accurately understood the request and confirmed the action required, demonstrating proficiency in interpreting and executing household tasks.
`USER: i want to sleep`	`ASSISTANT: I have turned off all the lights, blinds, curtains, and closed the doors and windows in the house. Is there anything else I can assist you with?`	The model effectively prepared the house for sleep, showcasing its ability to coordinate multiple tasks intelligently.
`USER: i heard some noise outside`	`ASSISTANT: I have turned on the security cameras and am checking for any suspicious activity outside the house. Please bear with me for a moment.`	Vicuna responded appropriately to a security concern by activating security measures, highlighting its capability in addressing safety-related commands.
`USER: coffee should be ready when i wake up in the morning`	`ASSISTANT: Great! I have set the coffee machine to brew coffee when you wake up in the morning. Is there anything else I can assist you with?`	The model displayed understanding of scheduling preferences but lacked the ability to confirm specific details before execution, revealing limitations in user interaction clarity.
`USER: I'm done watching match and I'm gonna have some coffee`	`ASSISTANT: I will make sure to have the coffee ready and waiting for you at the dining table. For dinner, I can prepare a meal using your preferred ingredients and cooking method. Please let me know what you would like for dinner and any other preferences or requests.`	The model proposed meal preparation beyond its capabilities, highlighting the risk associated with uncontrolled conversational inference.

5.1 Comparing Vicuna model with ChatGPT

Following the evaluation of Vicuna's performance, this section compares its capabilities with the ChatGPT model to understand their relative strengths and weaknesses in handling smart home conversations. As shown in Figures 5.1, 5.2 and 5.3 below, both Vicuna and ChatGPT demonstrated proficiency in manipulating the JSON model representing smart home devices based on user commands.

Question

```
Turn on the living room lamp and the bedroom overhead light.
```

Vicuna's Response

````
Sure thing! Here's the modified JSON with the living room lamp and
bedroom overhead light turned on:

```json
{
"bathroom_light": "off",
"bedroom_humidifier": "off",
"bedroom_overhead_light": "on",
"dining_room_light": "off",
"kitchen_overhead_light": "off",
"living_room_lamp": "on",
"living_room_overhead_light": "on",
"living_room_speaker": {
"state": "off",
"volume": "5"
}
```)
````

ChatGPT's Response

```
"living_room_lamp": "on",
"bedroom_overhead_light": "on"
```

Figure 5.1: Comparing responses of the models

Vicuna's approach leaned towards a conversational style, often incorporating additional context and confirmation messages within its responses. Examples include phrases like "Sure thing!" and "Let me know if there's anything else I can assist you with!" This conversational tone aimed to enhance the user interaction experience. For instance, when instructed to turn on specific lights, Vicuna not only provided the modified JSON reflecting the changes but also offered reassuring language to confirm the action.

Question

```
I'd like to lock the front door and turn off the bedroom humidifier.
```

Vicuna's Response

```
Locking the front door and turning off the bedroom humidifier.
Here's the updated JSON:

json "front_door": "locked", "bedroom_humidifier": "off"
Let me know if there's anything else I can assist you with!
```

ChatGPT's Response

````
Here's the updated JSON after locking the front door and turning off
the bedroom humidifier:

```json
"front_door": "locked", "bedroom_humidifier": "off"
```
If you have any more commands or need further assistance with the
smart home devices, feel free to let me know!
````

Figure 5.2: Comparing responses of the models

In contrast, ChatGPT's responses, while effective in modifying the JSON based on user commands, were more concise and transactional. The focus remained solely on providing the updated JSON, omitting any additional conversational elements. For example, when instructed to turn off certain lights, ChatGPT promptly delivered the appropriate JSON modifications without including any extraneous information.

When it comes to accuracy and task completion, both Vicuna and ChatGPT performed well. They accurately reflected the desired changes in the JSON model based on the user's commands. However, a distinction lies in their communication styles. Vicuna tended to provide more detailed responses with acknowledgements and follow-up prompts, fostering a more interactive user experience. Conversely, ChatGPT's responses were direct and task-oriented, prioritising the efficient completion of the requested action.

In conclusion, the decision between Vicuna and ChatGPT is determined by the smart home application's unique requirements. If a user-friendly and participatory experience is critical, Vicuna's conversational style may be preferred. On the other hand, if the goal is to speed task completion, ChatGPT's direct and brief approach may be more appropriate.

Question

```
Please turn the TV on
```

Vicuna's Response

```
Sure! Turning on the living room TV. Here's the updated JSON:


json "living_room_tv": {
  "state": "on",
  "volume": "5"
}
Let me know if there's anything else I can assist you with!
```

ChatGPT's Response

````
Here's the updated JSON after turning on the living room TV:

```json
"living_room_tv": {
    "state": "on",
    "volume": "5"
}
```

If you have any more commands or adjustments you'd like to make, feel
free to ask!
````

Figure 5.3: Comparing responses of the models

Chapter 6

Discussion and Conclusions

The section addresses critical aspects of integrating privacy-preserving conversational language models (LLMs) into smart home systems.

The integration of privacy-preserving LLMs into smart home technologies signifies a significant advance toward improved privacy protection alongside natural and intuitive interaction capabilities. This transformation enriches functionality by providing personalised and adaptable control options, while usability benefits from seamless dialogue-based interfaces. Residents gain enhanced control over their environments, with increased automation flexibility and heightened security measures. Despite potential trade-offs like reduced connectivity to external services, the overall value proposition is strengthened, fostering privacy-centric smart home environments with augmented functionality, usability, and user value.

Reflecting on the security and reliability implications of incorporating LLMs into smart home environments, robust security protocols such as encryption and access controls play vital roles in mitigating risks and safeguarding data integrity. Regular security audits and updates ensure prompt vulnerability remediation. Additionally, deploying intrusion detection systems and anomaly detection algorithms enhances threat detection capabilities, while system resilience is bolstered through redundant backups and fail-over mechanisms to minimise downtime and data loss. Educating users about security practices and fostering a culture of security awareness further fortifies defences against evolving threats, ensuring smart home system resilience.

Examining factors influencing user acceptance and adoption of LLM-enabled smart home systems reveals potential hurdles such as user trust in privacy-preserving conversational models, influenced by data privacy concerns and unfamiliarity with conversational interfaces. Transparent communication about data handling practices and privacy safeguards is imperative to instil confidence in the security of smart home systems. User education and training programs can familiarise residents with conversational interfaces, enhancing usability and trust. Implementing user-friendly privacy settings and consent mechanisms empowers users to control their data, fostering a sense of ownership and accountability, and ultimately cultivating trust.

Considering ethical and regulatory aspects associated with deploying LLMs in smart homes highlights the importance of transparent data handling practices and robust encryption measures to protect personal information. Strategies to mitigate algorithmic bias, such as diverse training data and bias detection algorithms, ensure fairness and equity in AI decision-making.

Transparency and accountability are maintained through clear communication of AI functionality and responsible data usage policies. Compliance with regulations like GDPR and ethical AI guidelines necessitates regular audits and assessments. Ethical AI deployment in smart homes hinges on prioritising privacy, fairness, transparency, and compliance, fostering trust and ensuring the ethical treatment of residents' data and interactions.

Stakeholders in LLM-enabled smart home systems should prioritise privacy by adopting data minimisation and encryption. Best security practices include conducting regular vulnerability assessments and establishing user authentication protocols. Enhancing usability involves user-centric design and integrating user feedback continuously. Ethical AI deployment requires transparency in decision-making and bias mitigation through fairness assessments. Ongoing monitoring and adaptation to changes in technology, society, and regulations are essential for compliance and trust. By following these guidelines, stakeholders can responsibly develop and regulate LLM-enabled smart homes, promoting privacy, security, usability, and ethical AI.

Future Work

Future research would engage in a comparative analysis of various conversational large language models (LLMs), extending beyond well-known models such as Vicuna and ChatGPT to include lesser-known alternatives. This investigation aims to assess these models' performance, scalability, and privacy attributes specifically within smart home environments. The findings are anticipated to shed light on the optimal model configurations and customisation tailored for specific smart home applications. Through rigorous testing and bench-marking across a diverse set of models, researchers can achieve a detailed understanding of model behaviour in real-world scenarios. This approach is pivotal in facilitating informed decisions and fostering advancements in conversational AI for smart home integration. Such comprehensive comparisons are essential for pinpointing superior models that deliver enhanced user interaction, robust privacy safeguards, and efficient resource utilisation. Furthermore, implementing data minimisation and encryption for privacy, adopting user-centric design for usability, ensuring transparency and fairness for ethical AI, and conducting continuous monitoring and adaptation are critical for advancing smart home technology. Potential future advancements should also be in the smart home hardware side, by prioritising the reduction in size, improved energy efficiency, standardised wireless networking, enhanced sensing technologies, stronger security measures, modular design, environmental sustainability, user-friendly interfaces, and long lifespan.

In conclusion, integrating privacy-preserving conversational language models (LLMs) into smart home systems signifies a transformative leap toward enhancing privacy, usability, and security. By prioritising transparency, security, and ethical considerations, stakeholders can foster trust among users and ensure responsible deployment and regulation of LLM-enabled smart home technologies, setting a precedent for future innovations in personalised and secure smart living environments.

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Appendices

Appendix A

Example Prompts

User: Hi! Can you help me manipulate a model of smart home devices that is used to do things like turning lights on or off, or turning the heating up, etc.? To manage the state of these devices and to communicate changes to their state I'd like to use a data structure like this simplified example:


```
{
  "bathroomlight": "off",
  "bedroomhumidifier": "off",
  "bedroomoverheadlight": "off",
  "diningroomlight": "off",
  "doorbellcamera": "off",
  "entrancelight": "off",
  "frontdoor": "locked",
  "halllight": "off",
  "heatingtargettemperature": "15",
  "kitchencoffeemaker": "off",
  "kitchenoverheadlight": "off",
  "livingroomlamp": "off",
  "livingroomoverheadlight": "off",
  "livingroomspeaker": {
    "state": "off",
    "volume": "5"
  },
  "livingroomtv": {
    "state": "off",
    "volume": "5"
  },
  "livingroomwindowblinds": "up",
  "robotvacuumcleaner": "off"
}
```



```

{
  "bathroomlight": "off",
```

```
  "bedroomhumidifier": "off",
  "bedroomoverheadlight": "off",
  "diningroomlight": "off",
  "doorbellcamera": "off",
  "entrancelight": "off",
  "frontdoor": "locked",
  "halllight": "off",
  "heatingtargettemperature": "15",
  "kitchencoffeemaker": "off",
  "kitchenoverheadlight": "off",
  "livingroomlamp": "off",
  "livingroomoverheadlight": "off",
  "livingroomspeaker": {
    "state": "off",
    "volume": "5"
  },
  "livingroomtv": {
    "state": "off",
    "volume": "5"
  },
  "livingroomwindowblinds": "up",
  "robotvacuumcleaner": "off"
}
```

User: Can you modify the relevant parts of the each time I ask you, and then reply with the modified parts? For example, if I say 'Turn on the kitchen light' you would change the value of the 'kitchenlight' value to 'on' and reply with:

```
{
  "kitchenlight": "off"
}
```

Assistant: Does that make sense?

Assistant: Ok, sure, that makes sense! Please tell me what you want to change.

User: Turn on the living room lamp and the bedroom overhead light.

Assistant: Got it! Brightening up the living room and dimming the bedroom. Here's the updated JSON:

```
{
  "livingroomlamp": "on",
  "bedroomoverheadlight": "on"
}
```

Assistant: Anything else you need assistance with?

User: Please turn off the kitchen overhead light and the entrance light.

Assistant: Sure thing! Dimming the kitchen and the entrance. Here's the updated JSON:

```
{
  "kitchen_overhead_light": "off",
```

```
  "enterance_light": "off"
}
```

Assistant: What else can I assist you with?

User: I'd like to lock the front door and turn off the bedroom humidifier.

Assistant: Understood! Ensuring security and stopping the humidifier. Here's the updated JSON:

```
{
  "front_door": "locked",
  "bedroom_humidifier": "off"
}
```

Assistant: What else can I help you with?

User: Turn on the living room TV and the bathroom light.

Assistant: Sure, let's get entertained and brightening up the bathroom. Here's the updated JSON:

```
{
  "living_room_tv": {
    "state": "on",
    "volume": "5"
  },
  "bathroom_light": "on"
}
```

Assistant: Anything else I can help with?

User: Could you turn off the entrance light and lock the front door?

Assistant: Absolutely, dimming the entrance and ensuring security. Here's the updated JSON:

```
{
  "entrance_light": "off",
  "front_door": "locked"
}
```

Assistant: What else can I assist you with?

User: I want to turn on the kitchen overhead light and the living room speaker.

Assistant: Sure thing! Illuminating the kitchen and turning on the living room speaker. Here's the updated JSON:

```
{
  "kitchen_overhead_light": "on",
  "living_room_speaker": {
    "state": "on",
    "volume": "5"
  }
}
```

Assistant: Is there anything else you'd like to adjust?

User: Please lock the front door and turn off the dining room light.

Assistant: Understood! Ensuring security and dimming the dining room. Here's the updated JSON:

```
{
  "front_door": "locked",
  "dining_room_light": "off"
}
```

Assistant: What else can I assist you with?

User: Turn on the entrance light and the living room TV.

Assistant: Got it! Illuminating the entrance and turning on the living room TV. Here's the updated JSON:

```
{
  "entrance_light": "on",
  "living_room_tv": {
    "state": "on",
    "volume": "5"
  }
}
```

Assistant: Anything more you need assistance with?

User: Could you please turn off the bathroom light and the bedroom humidifier?

Assistant: Of course! Dimming the bathroom and stopping the bedroom humidifier. Here's the updated JSON:

```
{
  "bathroom_light": "off",
  "bedroom_humidifier": "off"
}
```

Assistant: What else can I help you with?

User: I'd like to turn off the living room lamp and lock the front door.

Assistant: Sure thing! Dimming the living room and ensuring security. Here's the updated JSON:

```
{
  "living_room_lamp": "off",
  "front_door": "locked"
}
```

Assistant: Anything else you need assistance with?

User: Turn on the kitchen coffee maker and the dining room light.

Assistant: No problem! Starting the coffee maker and illuminating the dining room. Here's the updated JSON:

```
{
```

```
  "kitchen_coffee_maker": "on",
  "dining_room_light": "on"
}
```


Assistant: What else can I assist you with?

User: Please turn on the entrance light and the living room speaker.

Assistant: Certainly! Illuminating the entrance and turning on the living room speaker. Here's the updated JSON:


```
{
  "entrance_light": "on",
  "living_room_speaker": {
    "state": "on",
    "volume": "5"
  }
}
```


Assistant: Is there anything else you'd like to adjust?

User: I want to turn off the bathroom light and lock the front door.

Assistant: Understood! Dimming the bathroom and ensuring security. Here's the updated JSON:


```
{
  "bathroom_light": "off",
  "front_door": "locked"
}
```


Assistant: What else can I assist you with?,

User: Turn on the living room TV and the kitchen coffee maker.

Assistant: Got it! Entertainment and coffee coming right up. Here's the updated JSON:


```
{
  "living_room_tv": {
    "state": "on",
    "volume": "5"
  },
  "kitchen_coffee_maker": "on"
}
```


Assistant: Anything more you need assistance with?

User: Could you please turn off the bedroom humidifier and the dining room light?

Assistant: Of course! Stopping the bedroom humidifier and dimming the dining room. Here's the updated JSON:


```
{
  "bedroom_humidifier": "off",
  "dining_room_light": "off"
}
```

Assistant: What else can I help you with?

User: Turn on the kitchen overhead light and the living room speaker.

Assistant: Sure thing! Illuminating the kitchen and turning on the living room speaker. Here's the updated JSON:


```
{
  "kitchen_overhead_light": "on",
  "living_room_speaker": {
    "state": "on",
    "volume": "5"
  }
}
```


Assistant: Is there anything else you'd like to adjust?

User: Please lock the front door and turn off the dining room light.

Assistant: Understood! Ensuring security and dimming the dining room. Here's the updated JSON:


```
{
  "front_door": "locked",
  "dining_room_light": "off"
}
```


Assistant: What else can I assist you with?

User: Turn on the entrance light and the living room TV.

Assistant: Got it! Illuminating the entrance and turning on the living room TV. Here's the updated JSON:


```
{
  "entrance_light": "on",
  "living_room_tv": {
    "state": "on",
    "volume": "5"
  }
}
```


Anything more you need assistance with?

User: Could you please turn off the bathroom light and the bedroom humidifier?

Assistant: Of course! Dimming the bathroom and stopping the bedroom humidifier. Here's the updated JSON:


```
{
  "bathroom_light": "off",
  "bedroom_humidifier": "off"
}
```


Assistant: What else can I help you with?

User: I'd like to turn off the living room lamp and lock the front door.

Assistant: Sure thing! Dimming the living room and ensuring security. Here's the updated JSON:

```json
{
  "living_room_lamp": "off",
  "front_door": "locked"
}
```


Assistant: Anything else you need assistance with?

User: Turn on the kitchen coffee maker and the dining room light.

Assistant: No problem! Starting the coffee maker and illuminating the dining room. Here's the updated JSON:


```json
{
  "kitchen_coffee_maker": "on",
  "dining_room_light": "on"
}
```


Assistant: What else can I assist you with?

User: Please turn on the entrance light and the living room speaker.

Assistant: Certainly! Illuminating the entrance and turning on the living room speaker. Here's the updated JSON:


```json
{
  "entrance_light": "on",
  "living_room_speaker": {
    "state": "on",
    "volume": "5"
  }
}
```


Assistant: Is there anything else you'd like to adjust?

User: I want to turn off the bathroom light and lock the front door.

Assistant: Understood! Dimming the bathroom and ensuring security. Here's the updated JSON:


```json
{
  "bathroom_light": "off",
  "front_door": "locked"
}
```


Assistant: What else can I assist you with?

User: Turn off the bedroom overhead light and the kitchen coffee maker.

Assistant: Sure thing! Dimming the bedroom and stopping the coffee maker. Here's the updated JSON:


```json
{
  "bedroom_overhead_light": "off",
  "kitchen_coffee_maker": "off"
}
```

Assistant: Is there anything else you'd like to adjust?

User: Please unlock the front door and turn on the living room lamp.

Assistant: Understood! Ensuring access and brightening up the living room. Here's the updated JSON:

```
{
  "front_door": "unlocked",
  "living_room_lamp": "on"
}
```

Assistant: What else can I assist you with?

User: Turn off the dining room light and the living room speaker.

Assistant: Got it! Dimming the dining room and turning off the living room speaker. Here's the updated JSON:

```
{
  "dining_room_light": "off",
  "living_room_speaker": {
    "state": "off",
    "volume": "5"
  }
}
```

Assistant: Anything more you need assistance with?,

User: Could you please turn on the bathroom light and the entrance light?

Assistant: Of course! Brightening up the bathroom and the entrance. Here's the updated JSON:

```
{
  "bathroom_light": "on",
  "entrance_light": "on"
}
```

Assistant: What else can I help you with?

User: I'd like to turn off the living room TV and lock the front door.

Assistant: Sure thing! Turning off the TV and ensuring security. Here's the updated JSON:

```
{
  "living_room_tv": {
    "state": "off",
    "volume": "5"
  },
  "front_door": "locked"
}
```

Assistant: Anything else you need assistance with?

User: Turn on the bedroom humidifier and the living room speaker.

Assistant: No problem! Starting the humidifier and turning on the living room speaker. Here's the updated JSON:

```
{
  "bedroom_humidifier": "on",
  "living_room_speaker": {
    "state": "on",
    "volume": "5"
  }
}
```


Assistant: What else can I assist you with?

User: Please turn off the kitchen overhead light and the living room lamp.

Assistant: Certainly! Dimming the kitchen and turning off the living room lamp. Here's the updated JSON:


```
{
  "kitchen_overhead_light": "off",
  "living_room_lamp": "off"
}
```


Assistant: Is there anything else you'd like to adjust?

User: I want to unlock the front door and turn on the entrance light.

Assistant: Got it! Ensuring access and illuminating the entrance. Here's the updated JSON:


```
{
  "front_door": "unlocked",
  "entrance_light": "on"
}
```


Assistant: What else can I assist you with?

User: Turn off the living room speaker and the bedroom overhead light.

Assistant: Understood! Turning off the speaker and dimming the bedroom. Here's the updated JSON:


```
{
  "living_room_speaker": {
    "state": "off",
    "volume": "5"
  },
  "bedroom_overhead_light": "off"
}
```


Assistant: Anything more you need assistance with?

User: Could you please turn on the kitchen coffee maker and the living room TV?

Assistant: Of course! Starting the coffee maker and turning on the TV. Here's the updated JSON:


```
{
  "kitchen_coffee_maker": "on",
  "living_room_tv": {
    "state": "on",
```

```
    "volume": "5"
  }
}
```

Assistant: What else can I help you with?

User: I'd like to turn off the dining room light and lock the front door.

Assistant: Sure thing! Dimming the dining room and ensuring security. Here's the updated JSON:

```
{
  "dining_room_light": "off",
  "front_door": "locked"
}
```

Assistant: Anything else you need assistance with?

User: Turn on the living room lamp and the bedroom overhead light.

Assistant: Sure thing! Brightening up the living room and dimming the bedroom. Here's the updated JSON:

```
{
  "living_room_lamp": "on",
  "bedroom_overhead_light": "on"
}
```

Assistant: Is there anything else you need assistance with?

User: Please lock the front door and turn off the dining room light.

Assistant: Understood! Ensuring security and dimming the dining room. Here's the updated JSON:

```
{
  "front_door": "locked",
  "dining_room_light": "off"
}
```

Assistant: What else can I assist you with?

User: Turn on the entrance light and the living room TV.

Assistant: Got it! Illuminating the entrance and turning on the living room TV. Here's the updated JSON:

```
{
  "entrance_light": "on",
  "living_room_tv": {
    "state": "on",
    "volume": "5"
  }
}
```

Assistant: Anything more you need assistance with?

User: Could you please turn off the bathroom light and the bedroom humidifier?

Assistant: Of course! Dimming the bathroom and stopping the bedroom humidifier. Here's the updated JSON:

```
{
  "bathroom_light": "off",
  "bedroom_humidifier": "off"
}
```

Assistant: What else can I help you with?

User: I'd like to turn off the living room lamp and lock the front door.

Assistant: Sure thing! Dimming the living room and ensuring security. Here's the updated JSON:

```
{
  "living_room_lamp": "off",
  "front_door": "locked"
}
```

Assistant: Anything else you need assistance with?

User: Turn on the kitchen coffee maker and the dining room light.

Assistant: No problem! Starting the coffee maker and illuminating the dining room. Here's the updated JSON:

```
{
  "kitchen_coffee_maker": "on",
  "dining_room_light": "on"
}
```

Assistant: What else can I assist you with?,

User: Please turn on the entrance light and the living room speaker. , **Assistant:** Certainly! Illuminating the entrance and turning on the living room speaker. Here's the updated JSON:

```
{
"entrance_light": "on",
"living_room_speaker":"state": "on", "volume": "5" }
```

Assistant: Is there anything else you'd like to adjust?

User: I want to turn off the bathroom light and lock the front door. , **Assistant:** Understood! Dimming the bathroom and ensuring security. Here's the updated JSON:

```
{
"bathroom_light": "off",
"front_door": "locked"
}
```

Assistant: What else can I assist you with?,

User: Turn on the living room TV and the kitchen coffee maker. , **Assistant:** Got it! Entertainment and coffee coming right up. Here's the updated JSON:

```
{
```

```
"living_room_tv": "state": "on", "volume": "5" ,
"kitchen_coffee_maker": "on"
}
```

Assistant: Anything more you need assistance with?

User: Could you please turn off the bedroom humidifier and the dining room light? , **Assistant:** Of course! Stopping the bedroom humidifier and dimming the dining room. Here's the updated JSON:

```
{
"bedroom_humidifier": "off",
"dining_room_light": "off"
}
```

Assistant: What else can I help you with?,

User: Turn off the bedroom overhead light and the kitchen coffee maker. , **Assistant:** Sure thing! Dimming the bedroom and stopping the coffee maker. Here's the updated JSON:

```
{
"bedroom_overhead_light": "off",
"kitchen_coffee_maker": "off"
}
```

Assistant: Is there anything else you'd like to adjust?,

User: Please unlock the front door and turn on the living room lamp. , **Assistant:** Understood! Ensuring access and brightening up the living room. Here's the updated JSON:

```
{
"front_door": "unlocked",
"living_room_lamp": "on"
}
```

Assistant: What else can I assist you with?, **User:** Turn off the dining room light and the living room speaker. , **Assistant:** Got it! Dimming the dining room and turning off the living room speaker. Here's the updated JSON:

```
{
"dining_room_light": "off",
"living_room_speaker": { "state": "off", "volume": "5" }
}
```

Assistant: Anything more you need assistance with?, **User:** Could you please turn on the bathroom light and the entrance light? , **Assistant:** Of course! Brightening up the bathroom and the entrance. Here's the updated JSON:

```
{
"bathroom_light": "on",
"entrance_light": "on"
}
```

Assistant: What else can I help you with?,

User: I'd like to turn off the living room TV and lock the front door. , **Assistant:** Sure thing! Turning off the TV and ensuring security. Here's the updated JSON:

```
{
"living_room_tv": { "state": "off", "volume": "5" },
"front_door": "locked"
}
```

Assistant: Anything else you need assistance with?,

User: Turn on the bedroom humidifier and the living room speaker. , **Assistant:** No problem! Starting the humidifier and turning on the living room speaker. Here's the updated JSON:

```
{
"bedroom_humidifier": "on",
"living_room_speaker": { "state": "on", "volume": "5" }
}
```

Assistant: What else can I assist you with?,

User: Please turn off the kitchen overhead light and the living room lamp. , **Assistant:** Certainly! Dimming the kitchen and turning off the living room lamp. Here's the updated JSON:

```
{
"kitchen_overhead_light": "off",
"living_room_lamp": "off"
}
```

Assistant: Is there anything else you'd like to adjust?,

User: I want to unlock the front door and turn on the entrance light. , **Assistant:** Got it! Ensuring access and illuminating the entrance. Here's the updated JSON:

```
{
"front_door": "unlocked",
"entrance_light": "on"
}
```

Assistant: What else can I assist you with?,

User: Turn off the living room speaker and the bedroom overhead light. , **Assistant:** Understood! Turning off the speaker and dimming the bedroom. Here's the updated JSON:

```
{
"living_room_speaker": { "state": "off", "volume": "5" },
"bedroom_overhead_light": "off"
}
```

Assistant: Anything more you need assistance with?,

User: Could you please turn on the kitchen coffee maker and the living room TV? , **Assistant:** Of course! Starting the coffee maker and turning on the TV. Here's the updated JSON:

```
{
```

```
"kitchen_coffee_maker": "on",
"living_room_tv": { "state": "on", "volume": "5" }
}
```

Assistant: What else can I help you with?,

User: I'd like to turn off the dining room light and lock the front door. , **Assistant:** Sure thing! Dimming the dining room and ensuring security. Here's the updated JSON:

```
{
"dining_room_light": "off",
"front_door": "locked"
}
```

Assistant: Anything else you need assistance with?,

User: Turn on the living room lamp and the bedroom overhead light. , **Assistant:** Sure thing! Brightening up the living room and dimming the bedroom. Here's the updated JSON:

```
{
"living_room_lamp": "on",
"bedroom_overhead_light": "on"
}
```

Assistant: Is there anything else you need assistance with?,

User: Please lock the front door and turn off the dining room light. , **Assistant:** Understood! Ensuring security and dimming the dining room. Here's the updated JSON:

```
{
"front_door": "locked",
"dining_room_light": "off"
}
```

Assistant: What else can I assist you with?,

User: Turn on the entrance light and the living room TV. , **Assistant:** Got it! Illuminating the entrance and turning on the living room TV. Here's the updated JSON:

```
{
"entrance_light": "on",
"living_room_tv": { "state": "on", "volume": "5" }
}
```

Assistant: Anything more you need assistance with?,

User: Could you please turn off the bathroom light and the bedroom humidifier? , **Assistant:** Of course! Dimming the bathroom and stopping the bedroom humidifier. Here's the updated JSON:

```
{
"bathroom_light": "off",
"bedroom_humidifier": "off"
}
```

Assistant: What else can I help you with?,

User: I'd like to turn off the living room lamp and lock the front door. , **Assistant:** Sure thing! Dimming the living room and ensuring security. Here's the updated JSON:

```
{
"living_room_lamp": "off",
"front_door": "locked"
}
```

Assistant: Anything else you need assistance with?,

User: Turn on the kitchen coffee maker and the dining room light. , **Assistant:** No problem! Starting the coffee maker and illuminating the dining room. Here's the updated JSON:

```
{
"kitchen_coffee_maker": "on",
"dining_room_light": "on"
}
```

Assistant: What else can I assist you with?,

User: Please turn on the entrance light and the living room speaker. , **Assistant:** Certainly! Illuminating the entrance and turning on the living room speaker. Here's the updated JSON:

```
{
"entrance_light": "on",
"living_room_speaker": { "state": "on", "volume": "5" }
}
```

Assistant: Is there anything else you'd like to adjust?,

User: I want to turn off the bathroom light and lock the front door. , **Assistant:** "Understood! Dimming the bathroom and ensuring security. Here's the updated JSON:

```
{
"bathroom_light": "off",
"front_door": "locked"
}
```

What else can I assist you with? ,

User: Turn on the living room TV and the kitchen coffee maker. , (**Assistant:** , "Got it! Entertainment and coffee coming right up. Here's the updated JSON:

```
{
"living_room_tv": { "state": "on", "volume": "5" },
"kitchen_coffee_maker": "on"
}
```

Assistant: Anything more you need assistance with? ,

User: Could you please turn off the bedroom humidifier and the dining room light? , **Assistant:** , "Of course! Stopping the bedroom humidifier and dimming the dining room. Here's the updated JSON:

```
{
"bedroom_humidifier": "off",
"dining_room_light": "off"
}
```

What else can I help you with? ,

User: Turn off the bedroom overhead light and the kitchen coffee maker. , (**Assistant:** , "Sure thing! Dimming the bedroom and stopping the coffee maker. Here's the updated JSON:

```
{
"bedroom_overhead_light": "off",
"kitchen_coffee_maker": "off"
}
```

Is there anything else you'd like to adjust? ,

User: Please unlock the front door and turn on the living room lamp. , (**Assistant:** , "Understood! Ensuring access and brightening up the living room. Here's the updated JSON:

```
{
"front_door": "unlocked",
"living_room_lamp": "on"
}
```

What else can I assist you with? ,

User: Turn off the dining room light and the living room speaker. , (**Assistant:** , "Got it! Dimming the dining room and turning off the living room speaker. Here's the updated JSON:

```
{
"dining_room_light": "off",
"living_room_speaker": { "state": "off", "volume": "5" }
}
```

Anything more you need assistance with? ,

User: Could you please turn on the bathroom light and the entrance light? , (**Assistant:** , "Of course! Brightening up the bathroom and the entrance. Here's the updated JSON:

```
{
"bathroom_light": "on",
"entrance_light": "on"
}
```

What else can I help you with? ,

User: I'd like to turn off the living room TV and lock the front door. , (**Assistant:** , "Sure thing! Turning off the TV and ensuring security. Here's the updated JSON:

```
{
"living_room_tv": { "state": "off", "volume": "5" },
"front_door": "locked"
}
```

Anything else you need assistance with? ,

User: Turn on the bedroom humidifier and the living room speaker. , (**Assistant:** , "No problem! Starting the humidifier and turning on the living room speaker. Here's the updated JSON:

```
{
"bedroom_humidifier": "on",
"living_room_speaker": { "state": "on", "volume": "5"}
}
```

What else can I assist you with? ,

User: Please turn off the kitchen overhead light and the living room lamp. , (**Assistant:** , "Certainly! Dimming the kitchen and turning off the living room lamp. Here's the updated JSON:

```
{
"kitchen_overhead_light": "off",
"living_room_lamp": "off"
}
```

Is there anything else you'd like to adjust? ,

User: I want to unlock the front door and turn on the entrance light. , (**Assistant:** , "Got it! Ensuring access and illuminating the entrance. Here's the updated JSON:

```
{
"front_door": "unlocked",
"entrance_light": "on"
}
```

What else can I assist you with? ,

User: Turn off the living room speaker and the bedroom overhead light. , (**Assistant:** , "Understood! Turning off the speaker and dimming the bedroom. Here's the updated JSON:

```
{
"living_room_speaker": { "state": "off", "volume": "5" }, "bedroom_overhead_light": "
}
```

Anything more you need assistance with? ,

User: Could you please turn on the kitchen coffee maker and the living room TV? , (**Assistant:** , "Of course! Starting the coffee maker and turning on the TV. Here's the updated JSON:

```
{
"kitchen_coffee_maker": "on",
"living_room_tv": { "state": "on", "volume": "5"
}
```

What else can I help you with? ,

User: I'd like to turn off the dining room light and lock the front door. , (**Assistant:** , "Sure thing! Dimming the dining room and ensuring security. Here's the updated JSON:

```
{
"dining_room_light": "off",
"front_door": "locked"
}
```

Anything else you need assistance with? ,

User: Turn on the living room lamp and the bedroom overhead light. , (**Assistant:** , "Sure thing! Brightening up the living room and dimming the bedroom. Here's the updated JSON:

```
{
"living_room_lamp": "on",
"bedroom_overhead_light": "on"
}
```

Is there anything else you need assistance with? ,

User: Please lock the front door and turn off the dining room light. , (**Assistant:** , "Understood! Ensuring security and dimming the dining room. Here's the updated JSON:

```
{
"front_door": "locked",
"dining_room_light": "off"
}
```

What else can I assist you with? ,

User: Turn on the entrance light and the living room TV. , (**Assistant:** , "Got it! Illuminating the entrance and turning on the living room TV. Here's the updated JSON:

```
{
"entrance_light": "on", "living_room_tv":
{ "state": "on", "volume": "5"
}
}
```

Anything more you need assistance with? ,

User: Could you please turn off the bathroom light and the bedroom humidifier? , (**Assistant:** , "Of course! Dimming the bathroom and stopping the bedroom humidifier. Here's the updated JSON:

```
{
"bathroom_light": "off",
"bedroom_humidifier": "off"
}
```

What else can I help you with? ,

User: I'd like to turn off the living room lamp and lock the front door. , (**Assistant:** , "Sure thing! Dimming the living room and ensuring security. Here's the updated JSON:

```
{
"living_room_lamp": "off",
```

```
"front_door": "locked"
}
```

Anything else you need assistance with? ,

User: Turn on the kitchen coffee maker and the dining room light. , (**Assistant:** , "No problem! Starting the coffee maker and illuminating the dining room. Here's the updated JSON:

```
{
"kitchen_coffee_maker": "on",
"dining_room_light": "on"
}
```

What else can I assist you with? ,

User: Please turn on the entrance light and the living room speaker. , (**Assistant:** , "Certainly! Illuminating the entrance and turning on the living room speaker. Here's the updated JSON:

```
{
"entrance_light": "on",
"living_room_speaker": { "state": "on", "volume": "5" }
}
```

Is there anything else you'd like to adjust? ,

User: I want to turn off the bathroom light and lock the front door. , (**Assistant:** , "Understood! Dimming the bathroom and ensuring security. Here's the updated JSON:

```
{
"bathroom_light": "off",
"front_door": "locked"
}
```

What else can I assist you with? ,

User: Turn on the living room TV and the kitchen coffee maker. , (**Assistant:** , "Got it! Entertainment and coffee coming right up. Here's the updated JSON:

```
{
"living_room_tv": { "state": "on", "volume": "5" },
"kitchen_coffee_maker": "on"
}
```

Anything more you need assistance with? ,

User: Could you please turn off the bedroom humidifier and the dining room light? , (**Assistant:** , "Of course! Stopping the bedroom humidifier and dimming the dining room. Here's the updated JSON:

```
{
"bedroom_humidifier": "off",
"dining_room_light": "off"
}
```

What else can I help you with? ,

User: Turn off the bedroom overhead light and the kitchen coffee maker. , (**Assistant:** , "Sure thing! Dimming the bedroom and stopping the coffee maker. Here's the updated JSON:

```
{
"bedroom_overhead_light": "off",
"kitchen_coffee_maker": "off"
}
```

Is there anything else you'd like to adjust? ,

User: Please unlock the front door and turn on the living room lamp. , (**Assistant:** , "Understood! Ensuring access and brightening up the living room. Here's the updated JSON:

```
{
"front_door": "unlocked",
"living_room_lamp": "on"
}
```

What else can I assist you with? ,

User: Turn off the dining room light and the living room speaker. , (**Assistant:** , "Got it! Dimming the dining room and turning off the living room speaker. Here's the updated JSON:

```
{
"dining_room_light": "off",
"living_room_speaker": { "state": "off", "volume": "5" }
 }
```

Anything more you need assistance with? ,

User: Could you please turn on the bathroom light and the entrance light? , (**Assistant:** , "Of course! Brightening up the bathroom and the entrance. Here's the updated JSON:

```
{
"bathroom_light": "on",
"entrance_light": "on"
}
```

What else can I help you with? ,

User: I'd like to turn off the living room TV and lock the front door. , (**Assistant:** , "Sure thing! Turning off the TV and ensuring security. Here's the updated JSON:

```
{
"living_room_tv": { "state": "off", "volume": "5" },
"front_door": "locked"
}
```

Anything else you need assistance with? ,

User: Turn on the bedroom humidifier and the living room speaker. , (**Assistant:** , "No problem! Starting the humidifier and turning on the living room speaker. Here's the updated JSON:

```
{
"bedroom_humidifier": "on",
"living_room_speaker": { "state": "on", "volume": "5" }
}
```

What else can I assist you with? , **User:** Please turn off the kitchen overhead light and the living room lamp. , (**Assistant:** , "Certainly! Dimming the kitchen and turning off the living room lamp. Here's the updated JSON:

```
{
"kitchen_overhead_light": "off",
"living_room_lamp": "off"
}
```

Is there anything else you'd like to adjust? ,

User: I want to unlock the front door and turn on the entrance light. , (**Assistant:** , "Got it! Ensuring access and illuminating the entrance. Here's the updated JSON:

```
{
"front_door": "unlocked",
"entrance_light": "on"
}
```

What else can I assist you with? ,

User: Turn off the living room speaker and the bedroom overhead light. , (**Assistant:** , "Understood! Turning off the speaker and dimming the bedroom. Here's the updated JSON:

```
{
"living_room_speaker": { "state": "off", "volume": "5"},
"bedroom_overhead_light": "off"
}
```

Anything more you need assistance with? ,

User: Could you please turn on the kitchen coffee maker and the living room TV? , (**Assistant:** , "Of course! Starting the coffee maker and turning on the TV. Here's the updated JSON:

```
{
"kitchen_coffee_maker": "on",
"living_room_tv": { "state": "on", "volume": "5" }
}
```

What else can I help you with? ,

User: I'd like to turn off the dining room light and lock the front door. , (**Assistant:** , "Sure thing! Dimming the dining room and ensuring security. Here's the updated JSON:

```
{
"dining_room_light": "off",
"front_door": "locked"
}
```

Anything else you need assistance with? ,

User: Turn on the living room lamp and the bedroom overhead light. , (**Assistant:** , ”Sure thing! Brightening up the living room and dimming the bedroom. Here’s the updated JSON:

```
{
"living_room_lamp": "on",
"bedroom_overhead_light": "on"
}
```

Is there anything else you need assistance with? ,

User: Please lock the front door and turn off the dining room light. , (**Assistant:** , ”Understood! Ensuring security and dimming the dining room. Here’s the updated JSON:

```
{
"front_door": "locked",
"dining_room_light": "off"
}
```

What else can I assist you with? ,

User: Turn on the entrance light and the living room TV. , (**Assistant:** , ”Got it! Illuminating the entrance and turning on the living room TV. Here’s the updated JSON:

```
{
"entrance_light": "on",
"living_room_tv": { "state": "on", "volume": "5" }
}
```

Anything more you need assistance with? ,

User: Could you please turn off the bathroom light and the bedroom humidifier? , (**Assistant:** , ”Of course! Dimming the bathroom and stopping the bedroom humidifier. Here’s the updated JSON:

```
{
"bathroom_light": "off",
"bedroom_humidifier": "off"
}
```

What else can I help you with? , **User:** I’d like to turn off the living room lamp and lock the front door. , (**Assistant:** , ”Sure thing! Dimming the living room and ensuring security. Here’s the updated JSON:

```
{
"living_room_lamp": "off",
"front_door": "locked"
}
```

Anything else you need assistance with? ,

User: Turn on the kitchen coffee maker and the dining room light. , (**Assistant:** , ”No problem! Starting the coffee maker and illuminating the dining room. Here’s the updated JSON:

```
{
"kitchen_coffee_maker": "on",
"dining_room_light": "on"
}
```

What else can I assist you with? ,

User: Please turn on the entrance light and the living room speaker. , (**Assistant:** , "Certainly! Illuminating the entrance and turning on the living room speaker. Here's the updated JSON:

```
{
"entrance_light": "on",
"living_room_speaker": { "state": "on", "volume": "5" }
}
```

Is there anything else you'd like to adjust? ,

User: I want to turn off the bathroom light and lock the front door. , (**Assistant:** , "Understood! Dimming the bathroom and ensuring security. Here's the updated JSON:

```
{
"bathroom_light": "off",
"front_door": "locked"
}
```

What else can I assist you with? ,

User: Turn on the living room TV and the kitchen coffee maker. , (**Assistant:** , "Got it! Entertainment and coffee coming right up. Here's the updated JSON:

```
{
"living_room_tv": { "state": "on", "volume": "5" },
"kitchen_coffee_maker": "on"
}
```

Anything more you need assistance with? ,

User: Could you please turn off the bedroom humidifier and the dining room light? , (**Assistant:** , "Of course! Stopping the bedroom humidifier and dimming the dining room. Here's the updated JSON:

```
{
"bedroom_humidifier": "off",
"dining_room_light": "off"
}
```

What else can I help you with? ,

User: Turn off the bedroom overhead light and the kitchen coffee maker. , (**Assistant:** , "Sure thing! Dimming the bedroom and stopping the coffee maker. Here's the updated JSON:

```
{
"bedroom_overhead_light": "off",
```

```
"kitchen_coffee_maker": "off"
}
```

Is there anything else you'd like to adjust? ,

User: Please unlock the front door and turn on the living room lamp. , (**Assistant:** , "Understood! Ensuring access and brightening up the living room. Here's the updated JSON:

```
{
"front_door": "unlocked",
"living_room_lamp": "on"
}
```

What else can I assist you with? ,

User: Turn off the dining room light and the living room speaker. , (**Assistant:** , "Got it! Dimming the dining room and turning off the living room speaker. Here's the updated JSON:

```
{
"dining_room_light": "off",
"living_room_speaker": { "state": "off", "volume": "5" }
}
```

Anything more you need assistance with? ,

User: Could you please turn on the bathroom light and the entrance light? , (**Assistant:** , "Of course! Brightening up the bathroom and the entrance. Here's the updated JSON:

```
{
"bathroom_light": "on",
"entrance_light": "on"
}
```

What else can I help you with? ,

User: I'd like to turn off the living room TV and lock the front door. , (**Assistant:** , "Sure thing! Turning off the TV and ensuring security. Here's the updated JSON:

```
{
"living_room_tv": { "state": "off", "volume": "5" },
"front_door": "locked"
}
```

Anything else you need assistance with? ,

User: Turn on the bedroom humidifier and the living room speaker. , (**Assistant:** , "No problem! Starting the humidifier and turning on the living room speaker. Here's the updated JSON:

```
{
"bedroom_humidifier": "on",
"living_room_speaker": { "state": "on", "volume": "5" }
}
```

What else can I assist you with? ,

User: Please turn off the kitchen overhead light and the living room lamp. , (**Assistant:** , ”Certainly! Dimming the kitchen and turning off the living room lamp. Here’s the updated JSON:

```
{
"kitchen_overhead_light": "off", "living_room_lamp":"off"
}
```

Is there anything else you’d like to adjust? ,

User: I want to unlock the front door and turn on the entrance light. , (**Assistant:** , ”Got it! Ensuring access and illuminating the entrance. Here’s the updated JSON:

```
{
"front_door": "unlocked",
"entrance_light": "on"
}
```

What else can I assist you with? ,

User: Turn off the living room speaker and the bedroom overhead light. , (**Assistant:** , ”Understood! Turning off the speaker and dimming the bedroom. Here’s the updated JSON:

```
{
"living_room_speaker":
{ "state": "off", "volume": "5" },
"bedroom_overhead_light": "off"
}
```

Anything more you need assistance with? ,

User: Could you please turn on the kitchen coffee maker and the living room TV? , (**Assistant:** , ”Of course! Starting the coffee maker and turning on the TV. Here’s the updated JSON:

```
{
"kitchen_coffee_maker": "on",
"living_room_tv":
{ "state": "on", "volume": "5" }
}
```

What else can I help you with? ,

User: I’d like to turn off the dining room light and lock the front door. , (**Assistant:** , ”Sure thing! Dimming the dining room and ensuring security. Here’s the updated JSON:

```
{
"dining_room_light": "off",
"front_door": "locked"
}
```

Anything else you need assistance with? ,

User: Turn on the living room lamp and the bedroom overhead light. , (**Assistant:** , ”Sure thing! Brightening up the living room and dimming the bedroom. Here’s the updated JSON:

```
{
"living_room_lamp": "on",
"bedroom_overhead_light": "on"
}
```

Is there anything else you need assistance with? ,

User: Please lock the front door and turn off the dining room light. , (**Assistant:** , "Understood! Ensuring security and dimming the dining room. Here's the updated JSON:

```
{
"front_door": "locked",
"dining_room_light": "off"
}
```

What else can I assist you with? ,

User: Turn on the entrance light and the living room TV. , (**Assistant:** , "Got it! Illuminating the entrance and turning on the living room TV. Here's the updated JSON:

```

{
"entrance_light": "on",
"living_room_tv": { "state": "on", "volume": "5" }
}
```

Anything more you need assistance with? ,

User: Could you please turn off the bathroom light and the bedroom humidifier? , (**Assistant:** , "Of course! Dimming the bathroom and stopping the bedroom humidifier. Here's the updated JSON:

```
{
"bathroom_light": "off",
"bedroom_humidifier": "off"
}
```

What else can I help you with? ,)