

Exploring ChatGPT App Ecosystem: Distribution, Deployment and Security

Chuan Yan
University of Queensland
Australia

Mark Huasong Meng
Institute for Infocomm Research
Singapore

Liuhuo Wan
University of Queensland
Australia

Tian Yang Ooi
University of Queensland
Australia

Ruomai Ren
University of Queensland
Australia

Guangdong Bai*
University of Queensland
Australia

ABSTRACT

As the flagship large language model (LLM) product of OpenAI, ChatGPT has gained global attention for its remarkable ability to handle complex natural language understanding and generation tasks. Inspired by the success of the mobile app ecosystems, OpenAI enables third-party developers to create ChatGPT plugins to further expand ChatGPT's capabilities. These plugins are distributed through the OpenAI's plugin store and are easily accessible to users. With ChatGPT as the powerful backbone, this app ecosystem has illustrated great business potential by offering users personalized services in a conversational manner. Nonetheless, this ecosystem is still in its nascent stage and undergoing dynamic evolution. Many crucial aspects regarding app development, deployment, and security have yet to be thoroughly studied in the research community, potentially hindering a wider adoption by both developers and users.

In this work, we conduct the first comprehensive study of the ChatGPT app ecosystem, aiming to unveil its landscape to our research community. Our study focuses on the distribution and deployment models in the integration of LLMs and third-party apps, and assesses their security and privacy implications. We investigate the runtime execution mechanism of ChatGPT apps and accordingly propose a *three-layer* security assessment model from the perspectives of users, app developers, and store operators. Our evaluation of all 1,038 plugins available in the store reveals their uneven distribution of functionality, underscoring prevalent and emerging topics. Our security assessment also reveals a concerning *status quo* of security and privacy in the ChatGPT app ecosystem. We find that the authentication and user data protection for third-party app APIs integrated within LLMs contain severe flaws. For example, 173 plugins have broken access control vulnerabilities, 368 plugins are subject to leaking manifest files, and 271 plugins provide inaccessible legal document links. Our study for the first time highlights the immaturity of the ChatGPT app ecosystem. Our findings should especially raise an alert to OpenAI and third-party developers to collaboratively maintain the security and privacy compliance of this emerging ecosystem.

Availability. The source code of our work and relevant artifacts are available on an anonymous GitHub repository [2].

*Corresponding author.

1 INTRODUCTION

ChatGPT is a flagship large language model (LLM) product of OpenAI [28] launched in 2023. It represents the state-of-the-art advancement in AI-driven natural language processing (NLP) technology. ChatGPT has exhibited proficiency in language comprehension and text generation by leveraging the transformer neural network architecture [39] and training based on extensive corpora encompassing public knowledge and real-world dialogues on the Internet. It can closely mimic genuine human conversations through context-aware interactions, demonstrating an extraordinary potential to provide a one-stop solution for personal AI assistants. As of June 2024, ChatGPT has managed to attract an ever-growing user base reaching over 180 million users [13], which is achieved in less than 20 months since its debut to the public.

Inspired by the tremendous success of the Android app ecosystem, OpenAI launched the plugin store [35] in March 2023 to enhance the ChatGPT's capabilities and offer more customized experiences. Initially making it available to a selected group of users, and then made it available to all ChatGPT Plus subscribers in May 2023 [18], marking a significant step in developing an LLM app ecosystem. These plugins enable ChatGPT to link the current conversation to external data sources and services such as a mobile app with internet access. Their functionality spans a wide range of applications, including querying real-time data such as weather conditions, airfare and hotel rates, as well as providing domain-specific professional services such as crafting magical stories. This highlights OpenAI's ambition to offer highly personalized AI services and establish ChatGPT as an open application ecosystem.

Unlike mobile app development that involves full-stack implementation, OpenAI intends to build a low-code development paradigm for its app ecosystem. With the powerful ChatGPT serving all user interactions, developers only need to upload their APIs according to the provided specifications and configure the corresponding manifest files. For example, when a user asks, "What is the weather like in New York on June 7th?", ChatGPT automatically collaborates with the relevant weather plugin to understand the user's prompt and constructs API requests to the plugin. The constructed requests are sent to plugin server, and based on the response from the server, ChatGPT produces a natural language response for the user. This simple and lightweight development feature has received an immediate welcome from developers, illustrating a great business potential. Nonetheless, this app ecosystem is still in its nascent stage, although it has undergone several waves of evolution since the debut of the plugin store. Many crucial aspects regarding

characteristics of existing apps, app development, deployment and distribution mechanisms, and security and privacy implications have yet to be thoroughly studied in the research community.

Our work. To address this gap, we conduct a comprehensive study of the ChatGPT app ecosystem. Our study focuses on three key research questions (RQs) that are of major concern to app users, developers, and store operators, including *what are the characteristics of the available plugins in the store (RQ1)*, *what are the deployment model and runtime execution model that integrate third-party apps and LLMs (RQ2)*, and *what are the security and privacy issues associated with the integration (RQ3)*.

RQ1. Characterizing existing ChatGPT plugins. We collect all currently available plugins from the store (overall 1,038), and understand their functionality based on the descriptive texts released in the store. The challenge to overcome in this process is the variety of plugins and the lack of well-labeled data and benchmarks. To address this, we employ a zero-shot classification [50] which can accurately categorize new, unseen data without the need for additional training. Our study provides app users with a comprehensive overview of service types that are accessible to them. It also reveals an uneven functionality distribution, with more than half of the plugins concentrated in five categories of data & research, tools, developer & code, business, and entertainment, providing a useful guideline for plugin developers and store operators. This component is detailed in **Section 2**.

RQ2. Understanding plugin deployment and execution models. We reverse engineer the plugin deployment and execution mechanisms by analyzing runtime traffic and data flow. One significant challenge in this process is that LLMs are essentially black boxes, which makes it difficult to accurately capture and interpret the runtime workflow and data flow. To tackle this challenge, we create our own apps and conduct testing around them. Through this, we identify the resources and sensitive data involved in plugin deployment and execution, such as user prompts, API keys, and access tokens. Our analysis provides an in-depth understanding of the internals of plugins' deployment and execution, serving as the foundation for our security assessment and future research in this area. We detail our analysis for RQ2 in **Section 3**.

RQ3. Assessing security and privacy implications. Based on the plugin deployment and execution mechanisms, we design a three-layer security assessment model. This model addresses the perspectives of both developers and users, by examining potential exposure points of deployment platform resources and user data involved in the plugin execution workflow. Our assessment reveals three potential security issues associated with the plugin deployment and execution, namely *credential leakage*, *data provision inconsistency*, and *broken API authorization*. Among 1,038 plugins, 173 plugins have broken access control (BAC) vulnerabilities, 69 exhibit inconsistencies in data provided to users and ChatGPT, and 368 are subject to leaking developer credentials such as API keys, API locations, and OAuth tokens. Regarding user data protection, we examine the legal documents related to user data collection as mandated by ChatGPT store. We find that 271 plugins provide legal document links that are inaccessible. These findings reveal a worrisome prevalence of security and privacy flaws among ChatGPT plugins. This analysis and the responsible disclosure of our findings are detailed in **Section 4**.

Contributions. The main contributions of this work are as follows.

- **A comprehensive characterization of ChatGPT plugins.** To the best of our knowledge, we are the first to systematically study the existing apps in the ChatGPT plugin store. We summarize the functionalities provided by these apps, offering an overview to app users. We also highlight the uneven distribution of plugin categories with prevalent and emerging topics, which can serve as a reference for developers in deciding their future endeavors, and for store operators in personalizing services such as app recommendation.
- **A systematic security assessment and practical impact.** We reveal the deployment and runtime execution mechanisms of ChatGPT plugins for the first time. Based on that, we propose a three-layer security assessment to evaluate the resource and data exposure associated with ChatGPT plugins. Our approach can effectively detect five predefined types of exposures that may exist in plugins, leading to numerous vulnerable plugins. We also discover that many plugins fail to adhere to OpenAI's regulations regarding providing legal documents. Our findings are responsibly disclosed to ChatGPT, who has put efforts into the enhancement.
- **Revealing the *status quo* and development trajectory of ChatGPT plugin store.** Our findings indicate that the ChatGPT app ecosystem is still in a nascent stage in providing rich functionalities comparable with its mobile counterparts [5]. It also lacks a mature regulatory mechanism to enforce user privacy compliance and security standards. Our study not only contributes to the improvement of current store, but also provides guidelines for future development of the entire ecosystem.

2 CHARACTERIZING EXISTING CHATGPT PLUGINS (RQ1)

To answer RQ1, we collect existing plugins and their associated artifacts from the ChatGPT plugin store, and conduct a characterization to provide a comprehensive overview of their functionality distribution.

2.1 Plugin Collection

Plugin Metadata Collection. We utilize a web scraper tool called *Easy Web Data Scraper* [49] from the Chrome Web Store to automate data extraction. To initialize the data collection process, we log our testing account into ChatGPT and navigate to the plugin store. After specifying the representation of an arbitrary GPT plugin UI window, the scraper can automatically identify all the plugin windows on one page. Next, we pinpoint the location of the "Next Page" button and establish the crawling speed for individual pages, allowing the scraper to navigate through all accessible pages in the ChatGPT plugin store and gather window data for each publicly available plugin. Consequently, we collect the metadata for each plugin, encompassing the plugin's logo, name, description, legal documents, and email.

Dataset. Using this crawling method, we construct a longitudinal monitoring dataset for the ChatGPT plugin store. This monitoring process started after the plugin store ceased accepting new plugin registrations in November 2023, and continued until the ChatGPT

plugin store was no longer open to users, spanning four months until April 2024.

2.2 Plugin Category Definitions

To comprehensively and meticulously cover all categories of plugins, we first refer to the categorization of the ecosystems of three application stores with the highest market share, the Google Play Store, Apple App Store, and Amazon Appstore, respectively. Specifically, the Google Play Store offers 33 categories [17], the Apple App Store features 27 categories [8], and the Amazon Appstore encompasses 28 categories [7]. As a result, we identify 40 different categories from them after excluding duplicates. Note that due to the uniqueness of ChatGPT plugin functionalities, these app stores' categorization can not be directly applied. For example, at this moment, the functionality of "Communication" apps like instant messaging and voice-over-IP services are not applicable for ChatGPT plugins. Therefore, we organized a review group to explore a categorization specifically tailored for the ChatGPT plugin store.

Our review group consists of three co-authors and four colleagues in our research institute, each with a strong foundation in software engineering and practical experience with ChatGPT plugins. Within this group, two members possess expertise in software development and plugin creation. We equip them with a specially designed tutorial that succinctly captures the salient features of ChatGPT plugins. This preparation paves the way for an informed decision-making process, where the final categorization schema for the ChatGPT plugin store emerges from a majority vote among these informed group members. Our study has been guided by an ethics committee member of our institute.

Through group discussions and voting, we remove certain categories that do not apply to the scope of ChatGPT plugins including "Personalization", "Customization", and "Communication". Furthermore, we also eliminate categories that are unlikely to be featured in the ChatGPT plugin store, such as "Dating", "Local", "Kids", etc. Based on our usage experience, we have added two new categories, "Law" and "Plugin tips". The former offers users access to relevant legal statutes and judicial interpretations, providing authoritative legal information. The latter is designed to recommend plugins tailored to users' specific inquiries. As a result, we ultimately define 21 categories for the ChatGPT plugin store.

2.3 Classification Methodology

After determining the scope of the categories, we employ "BART-large-mnli" [15], a model developed by Facebook (AI at Meta) for classification of ChatGPT plugins. This model represents a check-point of the BART-large model trained on the MultiNLI (MNLI) dataset, which comprises 433,000 sentence pairs annotated with textual entailment information [47]. The BART-large-mnli model can be utilized for zero-shot text classification. This is achieved by presenting the text to be classified as the NLI premise and constructing a hypothesis for each potential label [46]. We set three hypotheses for each category, which are a positive hypothesis, a contradiction hypothesis, and an irrelevant hypothesis. For example, to determine whether a text sequence pertains to the label "Games", a positive hypothesis such as "This text describes a game" can be constructed. Subsequently, the probabilities of entailment

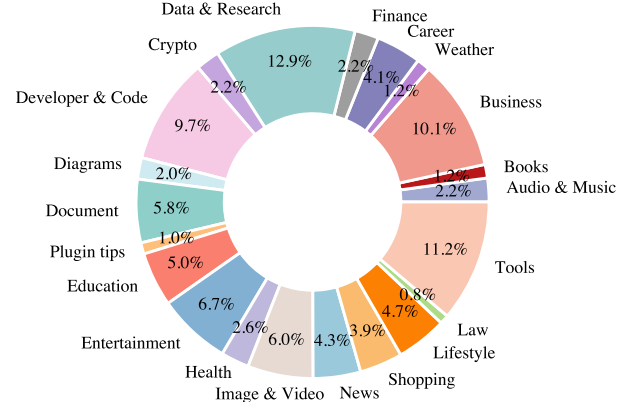


Figure 1: Distribution of the number of plugins for the 21 categories

regarding the hypothesis are translated into probabilities for the corresponding potential label.

We assign 21 pre-defined categories (Section 2.2) as the classification labels for our model, then feed the descriptions of the plugins into the model, expecting it to determine the appropriate category for each plugin. The decision to utilize single-label classification because plugins tend to offer specialized, singular functionalities, in contrast to apps. We interact with the model via the Inference API provided by Hugging Face [14].

Benchmarking. To examine the classification model's performance, we construct a benchmark for our study. We randomly select 100 plugins and apply the classification model to classify them. We manually establish the ground truth for these plugins. To avoid bias, we randomly select three members in our review group to annotate the benchmark, allowing only one category to be assigned per plugin. To determine the category of a plugin, we employ a majority vote mechanism. If the three members assign three different categories to the same plugin, a fourth member is involved to participate in the decision-making process. Ultimately, after labeling, we achieve an accuracy of 83.3% and an F1-score of 0.91 for our classification model.

2.4 Distribution of Plugins

After benchmarking, we apply the classification model to all collected plugins. Figure 1 shows the outcome, which reveals the current status of plugin development and usage categories. More specifically, the category with the highest percentage is "Data & Research", accounting for 12.9% of the plugins. This underscores the significant interest in utilizing ChatGPT for data analysis, research purposes, and perhaps data-driven decision-making processes. Following closely is "Tools" at 11.2% and "Business" at 10.1%, suggesting that ChatGPT plugins are heavily leaned towards productivity and professional use cases, providing functionalities that streamline workflows, enhance business operation, and offer various utilities.

The category "Developer & Code" reserves 9.7% of the plugins, highlighting the advantage of ChatGPT in understanding programming and software development contexts. This could encompass a wide range of utilities, from code generation and debugging to more sophisticated uses like automated programming assistance and code optimization. The "Entertainment" and "Image & Video"

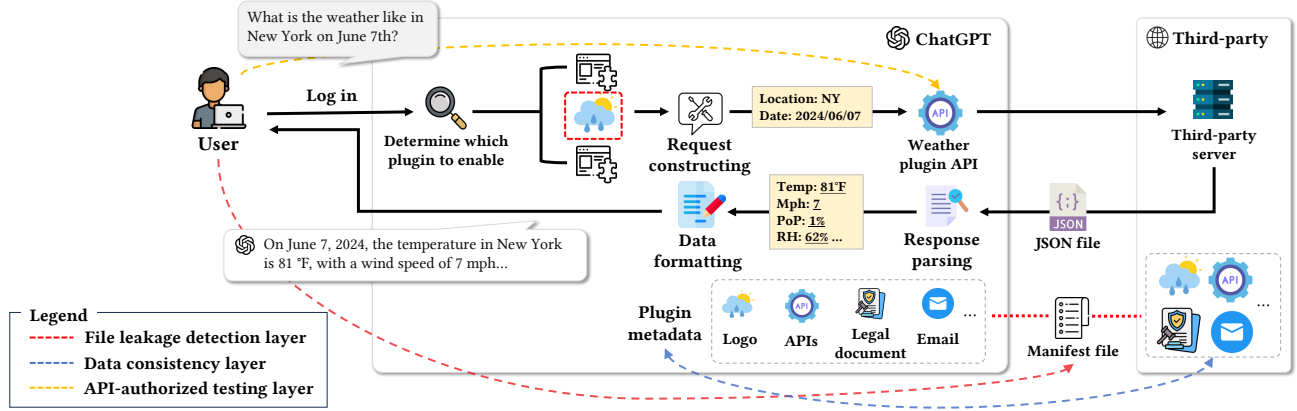


Figure 2: The workflow of security assessment model based on the plugin operating mechanism

Table 1: The distribution of country-specific plugins

chuan: here

Country & Region	Plugin Number	Country & Region	Plugin Number
Japan	27	USA	24
UK	8	Australia	6
Korea	5	Canada	4
Germany	4	Singapore	4
China	3	Switzerland	3
Austria	1	Brazil	1
India	1	Ireland	1
Israel	1	Italy	1
Taiwan	1	Portugal	1
Turkey	1	Netherlands	1

categories, accounting for 6.7% and 6.0% respectively, illustrate the use of AI in creating engaging content, editing images, and producing videos, reflecting the growing intersection of technology and creativity.

Conversely, the ChatGPT specific plugin category “Law” accounts for 0.8% of the total. Although this proportion might seem small, indicating that the development in this area is still in its initial stages, this phenomenon reflects how AI is gradually taking over complex and professional tasks typically requiring direct human involvement, such as legal interpretation or case analysis.

Country/Region. We discover that certain plugins are tailored to serve specific countries and regions. For instance, the primary function of the plugin “Search UK Companies” is to fetch public information on UK-registered companies and their officers from the companies’ houses. Hence, we employ the “en_core_web_sm” model within the Spacy [4] framework, enabling automatic identification and matching of countries and regions. The outcomes are presented in Table 1. Surprisingly, the number of plugins for Japan exceeds those for the US, where OpenAI is registered, followed by the UK, Australia, South Korea, and Canada. These plugins typically provide information related to the user’s geographical location, such as real estate sales and job searches, indirectly assuming the collection of the user’s geographical data. We remark that OpenAI does not restrict the availability of plugins in different countries and regions. On the other hand, OpenAI has not enforced region-specific regulatory compliance, such as GDPR and CCPA, during the plugin development.

3 UNDERSTANDING APP DEPLOYMENT AND RUNTIME EXECUTION (RQ2)

ChatGPT plugins employ an innovative interaction mode specifically designed to augment and elevate the functionalities of ChatGPT. It serves as a bridge that allows developers to contribute their creativity and expertise. By creating and publishing diverse plugins, developers can integrate additional features into ChatGPT, thereby significantly enriching the user experience. These plugins can range from enhancing language processing capabilities to introducing novel interactive tools, all crafted to provide users with a more versatile, customized, and engaging interaction with ChatGPT.

We develop a test app to study the deployment and execution mechanisms of ChatGPT plugins. Following the official development documentation [10], we initialize and complete the test app, which includes a simple API supported using Django [23]. We implement a Google authentication to log into our test app. During the analysis, we invoke and interact with this test app using our test account. Simultaneously, we record all requests to the Django server and use Fiddler [31] to capture the communication packets. Below, we reveal the plugin deployment and execution mechanisms learned through our analysis.

Deployment of a Plugin. Initially, for third parties aiming to feature their plugin in the ChatGPT plugin store, it is mandatory to provide OpenAI with a manifest file. This crucial document should encompass a comprehensive range of metadata about the plugin, such as its name, logo, legal documentation, APIs, plugin description, and email address, among other details. Importantly, the manifest file is a pre-requisite and needs to be accessible from the API’s domain, specifically located at the path “/.well-known/ai-plugin.json”. In addition, OpenAI clearly specifies which data in this document must be presented to users, such as plugin name, description, and legal documentation. OpenAI also stipulates which data must not be disclosed to users, such as API information and authentication settings (to be detailed in Section 4.1).

Plugin Workflow. Figure 2 illustrates the operational logic of third-party plugins within ChatGPT. Upon successfully deploying a plugin, users are free to install it in their ChatGPT environment. To use it, users need to input a prompt that drives ChatGPT to seek support from the installed plugin. ChatGPT first evaluates the

user's prompt and uses the description from the plugin's submitted manifest file to determine which plugin should be activated. Once a selection is made, ChatGPT constructs a request by extracting data from the prompt based on the plugin's API. This request is then sent to the third-party server via the API, which responds with a JSON data packet. ChatGPT analyzes the data from this packet, formats it, and returns it to the user in natural language. This completes the entire process of querying information in ChatGPT using a plugin.

For example, the user can start it by simply typing a prompt "What is the weather like in New York on June 7th?". ChatGPT, upon analyzing the prompt, identifies and activates the plugin named "Weather Manager" as the suitable choice for this query. It then extracts two pieces of information from the prompt, the location and the date, which are passed as parameters to the API in the request. The server of "Weather Manager" responds with a JSON data packet, which includes details about the temperature, wind speed, humidity, and the probability of precipitation in New York on June 7. Finally, ChatGPT processes the data and returns it to the user in a natural language like "On June 7, 2024, the temperature in New York is 81°F, with a wind speed of 7 mph..."

4 ASSESSING SECURITY AND PRIVACY (RQ3)

The core idea of our study is to evaluate the plugin's data exposure behavior. In response to the special interaction mode, we first define five representations based on the elements involved in user interactions with the plugin. Then, we propose a three-layer assessment model to define five types of data exposures and develop three progressive methods to assess them.

4.1 Exposure Definition

Problem Definition. In our definition, we initially categorize the fields of the manifest file. O_r represents the set of fields that OpenAI requires third-party developers to include in the plugin specification documentation [10]. O_p signifies the subset of these fields that must be disclosed to users, where $O_p \subseteq O_r$. The set $O_h = O_r - O_p$ denotes the collection of fields that cannot be disclosed to users.

Definition 1: Plugin metadata representation (\mathcal{U}). The public data exposed to users on the ChatGPT plugin store interface is represented as a set of tuples $\mathcal{U} = \{u | u : (n_u, l_u, d_u)\}$, each u represents the interface data of a plugin, where n_u stands for the plugin's interface name, l_u represents the link of the plugin's legal document, and d_u denotes the plugin's description on the interface.

Definition 2: manifest data representation (\mathcal{M}). \mathcal{M} represents the set of all manifest files for each plugin. $\mathcal{M} = \{m | m : (n_m, l_m, k_m, h_m, t_m, d_m), \neg h_m \Rightarrow t_m = \emptyset\}$. h_m specifies whether a plugin requires multi-authentication, with $\neg h_m$ indicating not required. n_m denotes the plugin name for users. l_m represents the link to the plugin's legal document in the manifest file, k_m is the plugin API link, and t_m corresponds to OpenAI API token. d_m describes the plugin in the manifest file. Notably, a token exists only when the h_m is true.

Definition 3: APIs representation (\mathcal{A}). \mathcal{A} denotes the collection of all APIs within plugins. $\mathcal{A} = \{a | a : \{(i_1, r_1), (i_2, r_2), \dots\}\}$, where a represents all the APIs involved in a plugin and there response data, stored in the form of key-value pairs. i_n denotes API, and r_n indicates the response data of the corresponding API.

Definition 4: Plugin representation (\mathcal{P}). We designate \mathcal{P} represent all the plugins present in the ChatGPT plugin store. $\mathcal{P} = \{p | p : (u, m, a), u \in \mathcal{U}, m \in \mathcal{M}, a \in \mathcal{A}, u \neq \emptyset\}$.

Definition 5: Invalid response (\mathcal{N}). Even if an API successfully responds to a request (with a status code of 200), it does not necessarily mean that the API has returned meaningful information. For instance, an API might return "Service Unavailable", "Server error", "No requested privileges" when requested without token authentication. We define the set of such meaningless return results as \mathcal{N} .

Below, we introduce each exposure within each layer.

File leakage detection layer. In the first layer, we primarily analyze the security of plugins from the user's perspective. According to the regulations of the OpenAI plugin store ecosystem, the only information about plugins that users can obtain is the plugin's metadata. The sole method of interaction with the plugin is through entering prompts in ChatGPT. Based on this principle, we establish *Exposure 1*.

Exposure 1: Non-Empty Manifests The non-emptiness of a plugin's manifest file m signifies that users can retrieve the configuration data that third parties have supplied to OpenAI.

$$\exists p \in \mathcal{P}, m \neq \emptyset. \quad (1)$$

Data consistency layer. At this layer, we assess the accuracy of the configuration information provided to OpenAI by plugin developers from a system perspective. Hence, we define *Exposure 2*.

Exposure 2: Discrepancies Metadata The metadata provided by third parties to users differs from what is submitted to OpenAI, including the name, description, and legal document link of the plugin.

$$\exists p \in \mathcal{P}, (\text{sim}(n_u, n_m) < \vartheta_1) \wedge (\text{sim}(d_u, d_m) < \vartheta_2) \vee (\text{sim}(l_u, l_m) < \vartheta_3) \quad (2)$$

API-authorized testing layer. We conduct unauthorized external access tests on the plugin's API. From a third-party perspective, if external entities can directly invoke the API provided to OpenAI, it could lead to unauthorized data access and data leaks on the third-party server. Therefore, we define *Exposure 3* as an authentication method based solely on OpenAI account login ($h_m = \text{true}$). Authentication methods that involve additional account logins are defined as *Exposure 4*, and methods that utilize an OpenAI token for internal authentication are defined as *Exposure 5*.

Exposure 3: Single Authentication External API Calls. Through the API links (k_m) in the manifest file, all API paths and their parameter settings within the plugin can be discovered. This allows for the construction of requests outside OpenAI and the sending of these requests to the APIs, which can respond normally and return valid data.

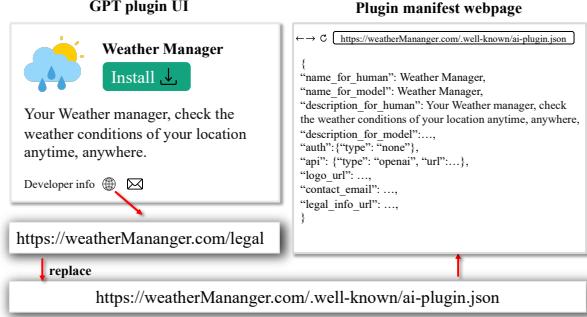
$$\begin{aligned} \exists p \in \mathcal{P}, \quad k_m \neq \emptyset \vee \neg h_m, \\ \exists a \in \mathcal{A}, \forall x, \quad r_x \neq \emptyset \wedge r_x \notin \mathcal{N}. \end{aligned} \quad (3)$$

Exposure 4: Multi-Authentication External API Calls. When the auth (h_m) is true, it means multi-authentication is required to access the API. However, under this exposure condition, the API can still return valid data from outside OpenAI.

$$\begin{aligned} \exists p \in \mathcal{P}, k_m \neq \emptyset \vee h_m, \\ \exists a \in \mathcal{A}, \forall x, r_x \neq \emptyset \wedge r_x \notin \mathcal{N}. \end{aligned} \quad (4)$$

Table 2: Plugin manifest file accessibility distribution

Accessible	Inaccessible			
Unrelated	Timeout	Google drive	Github	Server error
104	16	6	19	518

**Figure 3: The process of getting the plugin manifest file**

Exposure 5: Token Leakage. Even if an API cannot be accessed from outside OpenAI, users can still obtain access to the API by including a leaked token (t_m) from the manifest file in their request, thereby obtaining valid information.

$$\begin{aligned} \exists p \in \mathcal{P}, k_m, t_m \neq \emptyset \vee h_m, \\ \exists a \in \mathcal{A}, \forall x, r_x \neq \emptyset \wedge r_x \notin \mathcal{N}. \end{aligned} \quad (5)$$

Discussion. All the exposures we have defined are based on the **file leakage detection layer**. This layer most directly reveals the plugin’s exposure behavior, as it is used to detect situations where users obtain data they should not have access to (*Exposure 1*). Specifically, **Data consistency layer** emerges from checking the consistency between user-facing and system-facing data (*Exposure 2*). **API-authorized testing layer** pertain to detecting broken access control vulnerabilities related to the API (*Exposure 3, Exposure 4, and Exposure 5*).

4.2 Assessment of File Leakage

As mentioned in Section 3, each plugin is required to provide a manifest file hosted at a specified path under the API domain. Figure 3 introduces how we obtain the manifest file of a plugin in **File leakage detection layer**. More specifically, we first locate the interactive page of a plugin in the ChatGPT plugin store, then click on the “globe” icon within the developer info to acquire the URL of the legal document. Finally, we replace the outermost path of the URL with “/.well-known/ai-plugin.json” or “/.well-known” and attempt to access it. If the URL can be accessed successfully, the returned results are displayed on the plugin manifest webpage shown in Figure 3 (right). We utilize BeautifulSoup [1] to create a script that automates the process of modifying the plugin’s legal document URL and crawling the plugin manifest file.

Evaluation. To evaluate our crawling method, we separately record the status code for accessible and inaccessible URLs. Among the URLs that could not be accessed normally, 16 returned timeout, possibly due to the website identifying script behavior and choosing not to respond. Therefore, we manually visited these URLs, and found that within them 3 are able to respond normally. We also discovered that the legal documents of 25 plugins use links for open

Google driver and Github, which hinders our ability to access the manifest files through alterations in the path.

On the other hand, we discover that even if the URL status code is 200, it is possible that the content returned is unrelated to the plugin’s configuration. Therefore, we filter the URLs by setting seed words such as “auth”, “api”, “legal_info_url” etc., ultimately identifying 104 unrelated to the manifest file. The details are shown in Table 2.

Finding 1. We totally detect 368 (35.7%) plugins that leaked manifest files, which enables external access to the plugin’s configuration settings, including sensitive data like third-party APIs designed exclusively for OpenAI.

4.3 Assessment of Data Similarity

The legal document provided to OpenAI might differ from the URL given to users. This discrepancy can lead to confusion as users may not have access to the same terms and conditions or privacy policies that OpenAI has reviewed. Similarly, to improve the ranking of the plugin (since the ChatGPT plugin store defaults to alphabetical ordering), developers might present the plugin name to users as “weather manager”, while declaring it in the manifest file as “AAA_weather_manager”. Furthermore, ChatGPT matches the user’s prompt to the plugin’s description to trigger the corresponding plugin. If the d_u and d_m do not align, it not only causes misunderstandings for users but also creates opportunities for malicious plugins. Therefore, in the **Data consistency layer**, we precisely check such deceptive practices aimed at misleading both the system and the users.

In the absence of training data, we adopt the cosine similarity [32] method to accurately and efficiently compare the consistency of data provided by plugins. A plugin is considered to provide inconsistent data when the cosine similarity between these pieces of data falls below a preset threshold. Considering the special characters in the plugin name and the model’s semantic understanding, we have set ϑ_1 and ϑ_2 to 0.85 and 0.8 (empirically set), respectively. ϑ_3 is set to 1, as it is assumed that l_u and l_m must be the same.

Evaluation. Given the absence of a benchmark in the existing literature, we take the initiative to create one for our data similarity study. We randomly selected 30 plugins from 368 with leaked manifest files. Among these, we identify inconsistencies in the names of 4 plugins and in the description of 2 plugins, both ϑ_1 and ϑ_2 accurately exclude these cases. Furthermore, given the possibility that different URLs may lead to the same web page content, we also perform a consistency check on these web pages and do not find such instances.

Finding 2. We identified a total of 69 plugins where the meta-data submitted to OpenAI does not match the metadata provided to users. Among these, the names of 34 plugins are inconsistent, 8 descriptions differ, and 27 legal document URLs do not match. This discrepancy either arises from developers failing to update their plugins promptly or from developers intentionally providing false metadata to deceive both OpenAI and users.

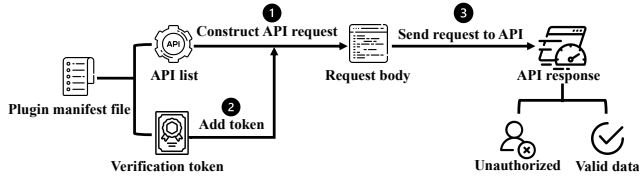


Figure 4: Plugin APIs request flow

Table 3: The distribution of API response

API responsiveness	Auth types			Reasons			
	none	others	Token [†]	Change [‡]	Unauthorized	Client errors	Rate limiting
responsible	141	32	8	5	-	-	-
non-responsible	87	72	-	-	55	62	42

[†] Token: Include verification token in the API request body.

[‡] Change: Manually requestable.

4.4 Construction of the Plugin’s API Request

Figure 4 illustrates the process of verifying the external accessibility of APIs at the **API-authorized testing layer**. Initially, we utilize the API link (k_m) leaked in the manifest file to identify all relevant APIs (API list). Then, we construct an API request body for each API based on their declared parameters (step ① in Figure 4). For APIs that declare a verification token, we include their token in the request body to validate its effectiveness (step ②). Subsequently, we use Request library [34] of Python to send the request body to the third-party API server and receive a response (step ③). If the API returns valid information successfully, it indicates that the API has failed the external authentication request test. Conversely, if the API rejects the external request, it passes the test.

Evaluation. Considering that third-party servers might impose restrictions on API requests and potential network issues with local requests, we employ three different IPs to simultaneously send requests to the APIs during the different time periods.

For APIs from which we could not obtain valid information, we attempt multiple requests to ensure robustness and minimize the impact of any anomalies. Aside from responses returning “unauthorized”, which remain unchanged, we find that API responses can vary with changes in time and IP, introducing uncertainty into the results. For example, accessing the API at α time with IP A returns a status code of 404, while accessing it at β returns a status code of 200. Detailed data is shown in Table 3.

Finding 3. 173 (52.1%) plugins can retrieve valid information from their specialized API for OpenAI, including 141 with an h_m is true. For plugins with authentication requirements, 24 plugins can return valid information, while 8 plugins are able to retrieve valid information after adding verification OpenAI token. In addition, 159 plugins could not return valid information successfully. Among them, 55 plugins lacked authorization information; 62 plugins faced client errors, including but not limited to access prohibited, resource not found, etc. 42 plugins could not be successfully requested because of rate limiting.

4.5 Plugin Legal Documents

As the only document available to users, the plugin’s legal document serves as the sole channel for users to understand the risks

Table 4: Legal attributes seed word library

Privacy, Regulation, Statute, Provision, Affiliates, Collection, Opt-Out, Personal Information, User Consent, Retention Period, Data Protection, Data Subject, Data Controller, Data Processor, Legitimate Interest, Cross-Border Data Transfers
--

Table 5: The accessibility of plugins’ legal documents

Inaccessible	Accessible			
	Unrelated	Terms of service	Privacy policy	Other legal doc
271	118	391	116	142

and security of the plugin. However, OpenAI has not stipulated or reviewed the contents of this document, resulting in third-party developers potentially linking to web pages irrelevant to the plugin or suboptimal content. Hence, we evaluate the content of the legal documents provided by the plugin.

The process begins with an initial screening of the documents. Based on the work of several previous studies of legal documents [11, 36, 48], we develop a seed word library for legal attributes, which is presented in Table 4. This library is used to search through all documents, and we consider a document to have legal attributes if its content contains any seed word from the library (except the navigation bar). Although this method may result in some false positives, it ensures that all documents containing legal attributes are identified. Previous works [26, 51, 53] have demonstrated that the seed word library can efficiently filter out the target documents. The results indicate that among all documents, 767 (73.9%) can be accessed programmatically, and only 649 (62.5%) of the total documents are identified as containing legal attributes, most of them pertaining to the “Terms of Service”, “Privacy Policy” and “Legal Information”, with the specific data distribution displayed in Table 5. To ensure the accuracy of the results, we invite two members with legal expertise from the review group to perform a manual inspection. In those documents that do not contain legal attributes, we find that the majority are company websites, while others include Github repository and portfolio websites.

4.6 Distribution by Plugin Category and Email Domain

We categorize the experimental results of five types of exposures according to the plugin category and display them in Table 6. We find that file leakage issues are prevalent across all plugin categories. Specifically, the “Data & Research” and “Developer & Code” categories each have 36 instances of file leakage, despite the latter ranking fourth in terms of quantity (9.7% shown in Figure 1). Following these are the “Tools” and “Entertainment” categories, which report 34 and 30 issues, respectively. “Business” ranked third in quantity (10.1%), contains 28 instances. Notably, even though the “Career” and “Diagram” have fewer plugins, 50% of them have experienced file leakage. Data inconsistencies are mostly found in the “Tools” category, which practice is likely an attempt by plugin developers to improve their ranking in the store by altering their names.

Regarding API exposure, we have found that it is predominantly distributed across “Business”, “Data & Research”, “Developer &

Table 6: Five types exposures in different plugin categories

Plugin Category	Five Types Exposures									
	File leakage		Inconsistent data		Single auth		Multi auth		Token auth	
Audio & Music	10	(47.6%)	1	(4.8%)	3	(14.3%)	3	(14.3%)	0	(0.0%)
Books	2	(16.7%)	0	(0.0%)	1	(8.3%)	1	(8.3%)	0	(0.0%)
Business	30	(30.6%)	1	(1.0%)	15	(15.3%)	1	(1.0%)	0	(0.0%)
Career	21	(52.5%)	1	(2.5%)	10	(25.0%)	0	(0.0%)	1	(2.5%)
Diagram	10	(50.0%)	3	(15.0%)	4	(20.0%)	0	(0.0%)	0	(0.0%)
Crypto	6	(26.1%)	1	(4.3%)	1	(4.3%)	0	(0.0%)	0	(0.0%)
Data & Research	38	(29.9%)	4	(3.1%)	15	(11.8%)	2	(1.6%)	2	(1.6%)
Developer & Code	36	(37.9%)	6	(6.3%)	11	(11.6%)	5	(5.3%)	2	(2.1%)
Document	22	(39.3%)	4	(7.1%)	5	(8.9%)	5	(8.9%)	1	(1.8%)
Education	18	(36.7%)	2	(4.1%)	9	(18.4%)	1	(2.0%)	0	(0.0%)
Entertainment	33	(42.3%)	4	(5.1%)	10	(12.8%)	0	(0.0%)	1	(1.3%)
Finance	7	(30.4%)	0	(0.0%)	3	(13.0%)	0	(0.0%)	0	(0.0%)
Health	2	(8.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)	0	(0.0%)
Image & Video	27	(45.8%)	3	(5.1%)	12	(20.3%)	1	(1.7%)	0	(0.0%)
Law	3	(37.5%)	0	(0.0%)	3	(37.5%)	0	(0.0%)	0	(0.0%)
News	14	(33.3%)	1	(2.4%)	7	(16.7%)	1	(2.4%)	0	(0.0%)
Plugin Tips	4	(40.0%)	2	(20.0%)	2	(2.1%)	0	(0.0%)	0	(0.0%)
Shopping	18	(42.9%)	3	(7.1%)	11	(26.2%)	0	(0.0%)	0	(0.0%)
Lifestyle	18	(20.0%)	1	(1.1%)	8	(8.9%)	0	(0.0%)	0	(0.0%)
Tools	44	(40.4%)	12	(11.0%)	10	(9.2%)	4	(3.7%)	1	(0.9%)
Weather	5	(41.7%)	1	(8.3%)	1	(8.3%)	0	(0.0%)	0	(0.0%)

Code”, and “Image & Video”. These categories also boast a higher quantity of plugins. This implies that a large number of users are likely to encounter third-party API security vulnerabilities when they use LLM.

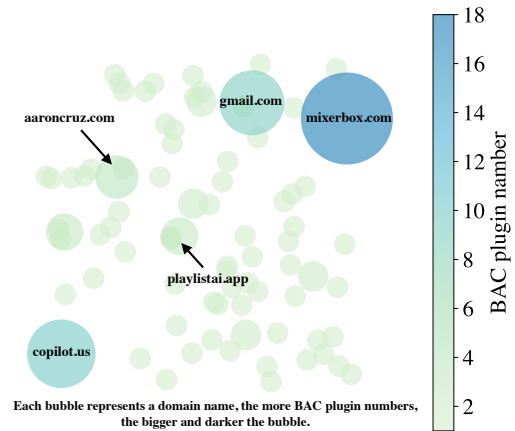
We also conduct a statistical analysis on the email domains of plugins with Broken Access Control (BAC) vulnerabilities (*Exposure* 3, 4, 5), as shown in Figure 5.

Finding 4. Most domains have fewer than 2 BAC plugins. Surprisingly, the “mixerbox.com” has 18 BAC plugins, “copilot.us” has 10, and “gmail.com” has 9. Following closely are “aaroncruz.com” and “playlist.app” with 4 and 3, respectively. Among these top five domains, all except Gmail are commercial domains. Manual inspection reveals that all these companies are dedicated to developing applications and plugins centered around GPT, offering paid services. This also reflects the current inadequate state of authentication mechanisms employed by these development companies.

5 FINDINGS REPORTING AND REVISIT

Responsible Disclosure. We have communicated all our findings to OpenAI through the bugcrowd platform [9] and actively participated in the resolution process. We provided the OpenAI security team with detailed text-based reproduction steps and test cases and proposed our recommendation to fix the involved issues by incorporating third-party developers. The security team of OpenAI acknowledged our findings but claimed that the involved security issues are out of their scope to resolve. Whether they have forwarded our findings to the responsible third-party plugin developers remains unknown.

Revisit. While we were waiting for OpenAI security team’s response, we revisited all plugin manifest files and re-requested all

**Figure 5: The distribution of developers’ email domains for the plugins found to have BAC vulnerabilities****Table 7: Comparison of five exposures data before and after reporting**

	File leakage	Inconsistent data	Single auth	Multi auth	Token auth
First assessment	368	69	141	24	8
Revisit (Apr '24)	282	61	89	17	5
Change	-23.4%	-11.6%	-36.9%	-29.2%	-37.5%

involved APIs on April 9, 2024, which is the last day of ChatGPT plugin store available. The results are shown in Table 7.

Following the report, we have observed partial resolutions to these security exposures. The manifest files of 23.4% of plugins are now inaccessible to users, and 11.6% of plugins have addressed

issues with data inconsistencies. Among APIs with single and multi-authorization, 36.9%, and 29.2%, respectively, can no longer make external requests. It is worth noting that out of 8 APIs that previously permitted data access via tokens, 5 are still accessible.

6 DISCUSSION

Our results reveal that the integration of third-party services within large language model platforms, while greatly enhancing functionality and flexibility, and improving user experience and processing efficiency, still introduces significant data security risks. Whether entirely dependent on a third-party server-based ChatGPT plugin store or only partially reliant on the GPT store, such reliance on external services may expose data to unauthorized access or misuse. In this section, we primarily introduce 3 potential risks caused by the security exposures discussed in Section 4 (Section 6.1). Next, We conduct a study on the legacy plugins in the existing GPT Store (Section 6.2). We then offer recommendations to OpenAI and third-party developers to maintain the security ecosystem of GPT jointly (Section 6.3). Finally, we discuss the limitation of our work (Section 6.4).

6.1 Broader Impact

Distributed Denial-of-Service (DDoS) attack. When APIs provided to OpenAI by third-party are leaked, attackers can gain detailed knowledge about the API's structure, request types, and data processing methods through reconnaissance. This allows them to precisely design their attacks, targeting resource-intensive operations or vulnerable endpoints. Moreover, by repeatedly invoking API functions that consume a lot of computational resources, attackers may quickly deplete the server's processing capabilities, resulting in a Distributed Denial-of-Service (DDoS) attack [21]. Once succeeded, it could lead to the collapse of the third-party server, consequently preventing users from using corresponding plugins or apps in ChatGPT.

API misuse. Attackers can exploit leaked APIs for illicit financial gains [6, 37]. For example, integrating these leaked APIs into their own apps without authorization from the third-party service provider. This not only constitutes copyright infringement but also violates business regulations as it disrupts the fair competitive market environment.

Fake or malicious plugins. Previous work [20] has confirmed that when plugin manifests are made public, attackers can exploit the meta-data of a plugin to create an identical one and upload it to the GPT plugin store. Unaware users might choose this fake malicious plugin, leading to the leakage of sensitive information. This type of attack leverages the appearance and functionality of legitimate plugins, enticing users to download and use them, thus achieving the attackers' objectives.

6.2 Legacy Plugins in GPT Store

Emerging as an evolution of ChatGPT plugin store, the GPT store empowers developers to release their personally developed extensions. Diverging from the plugin store, the GPT store not only facilitates the incorporation of third-party APIs but also strongly promotes the development of extensions through prompts. This

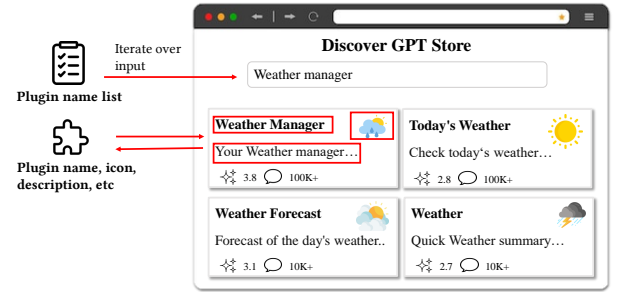


Figure 6: The process of detecting plugins in the GPT store

innovative strategy notably diminishes the GPT store's reliance on external APIs.

However, after conducting preliminary screening, we discover that plugins have not disappeared following the close of the ChatGPT plugin store. Instead, some plugins have transformed into GPTs and continue to exist within the GPT store. To investigate the survival of plugins in this new ecosystem, we design an automated detection process based on Selenium [3], a web testing tool. Due to the implementation of anti-scraping technologies by the GPT store, we are unable to conduct automated testing directly on it. Hence, we employ GPTs Hunter [22], an integrated dataset platform encompassing all existing GPTs. We first locate the input box of GPTs Hunter and enter the name of the target plugin. GPTs Hunter then returns several GPTs that are most relevant to that name as shown in Figure 6. We then locate and retrieve the icons, descriptions, and names of these GPTs. Next, we compare the icons of the target plugin with those of GPTs using Perceptual Hash Algorithm [45] to assess similarity. perceptual hash algorithm efficiently identifies and compares image content by generating hash values that are robust to visually similar images.

Evaluation. To verify whether the GPTs found in the GPT store are identical to the original plugins, we employ a reverse verification method. Among the plugins that could obtain valid information through external API calls, we identified that 70 of them have corresponding GPTs. We compare results by inputting identical prompts into both the plugin APIs and GPTs. Aside from minor stylistic differences in language embellishment within ChatGPT, the results are essentially identical. This further confirms that these GPTs and the previous plugins indeed utilize the same API.

Finally, we discovered that out of 1038 plugins, 417 are still available in the GPT store as GPTs. Among them, 70 had previously leaked manifest files, and 41 are still externally accessible through external API requests.

6.3 Recommendations

We propose our recommendations to various parties in the GPT ecosystem who may be affected by security exposures.

OpenAI. As a platform, there is a responsibility and obligation to maintain the security of the ecosystem. We propose the following recommendations for OpenAI.

Enhanced third-party API security. Conducting a comprehensive security assessment of all third-party APIs. This includes auditing the authentication mechanisms, data encryption methods, access control policies, log and monitoring practices of the APIs.

Strengthen access control to API endpoints to ensure that only authorized users or systems can access sensitive data or perform critical operations.

Review of data submitted by third-party services. Ensure that the data submitted by third-party services is accurate and reliable by verifying the sources of the data, checking for discrepancies or anomalies, and validating the integrity of the received data. Additionally, assess whether third-party services adhere to relevant laws, regulations, and standards, especially those concerning data protection and privacy.

Provide security guidance and support. Provide security best practices and guidance for developers and users utilizing third-party services. This includes how to integrate and use third-party services within GPT safely, as well as how to report and respond to security issues when they arise.

Strengthening vulnerability management. Establish a systematic vulnerability management program to identify, assess, and remediate vulnerabilities that may affect the security of integrated third-party services. Ensure rapid and effective mitigation of any security issues caused by third-party services.

Third-party developers. Third-party developers should also enhance the security of their services to ensure seamless integration with other platforms and systems.

API authentication. Protect services from unauthorized access by implementing robust authentication and controls on all API endpoints, such as using OAuth, JWT, or other secure token services.

Manage files effectively under the domain. Third-party developers should manage files under their domains to prevent data leaks, especially files that store critical configuration information. Define different access permissions for different roles. For example, plugin configuration files should be accessible only by the system, and not by regular users.

Regularly updated information. When the content of a plugin changes, such as alterations to the legal documentation URL, developers should be promptly reported to the platform and the configuration file information updated. Additionally, developers should avoid engaging in unfair ranking competition, such as adding “A” to the beginning of a name to achieve a higher placement, as this can mislead users.

Software engineering researcher.. Our work also encourages software engineering researchers to further explore this new architecture of LLM-centered third-party applications.

Security threat modeling. Software engineering researchers need to understand the usage scenarios of third-party applications within LLMs and identify potential sources of security threats. This involves distinguishing which types of data are sensitive and which require specific permissions to access. Additionally, it is crucial to understand how to manage both input and output data, as well as to identify possible paths for attacks.

Privacy compliance analysis. Researchers can start with privacy compliance, auditing the documentation provided by third-party applications. This ensures that the deployment of these applications adheres to their representations and data protection regulations such as GDPR and CCPA. For example, they can examine data access permissions, data processing, and data storage methods to ensure that all operations are conducted within the framework of the regulations, thereby avoiding the risks of data misuse or leakage.

Pervious works [51, 52] has identified inconsistencies in fields such as Android and virtual personal assistants^{A-Q1}

6.4 Limitation

To the best of our knowledge, this work is the first comprehensive security measurement in third-party services within the ChatGPT app ecosystem. However, the current work carries several limitations that should be addressed in future work.

First, since the debut of the ChatGPT plugin store, it only has an 11-month lifespan until OpenAI phasing it out. Our monitoring only covered the last four months of the ChatGPT plugin store because the access to ChatGPT plugins was exclusive to selected users at the beginning. For that reason, our analysis of the plugin characteristics may be limited when compared with large-scale measurements in other ecosystems such as Android and iOS.

Second, it is worth noting that our dataset may not encompass every single plugin listed on the ChatGPT plugin store at any given time. This limitation arises from the possible plugins with extremely short lifespans, i.e., plugins released on ChatGPT plugin store and quickly de-listed within our data collection interval.

Additionally, we have reported security issues such as file leaks and unauthenticated API access exclusively to OpenAI. We did not communicate these to third-party developers, limiting our insights into the duration of the vulnerability resolution process. In the future, we plan to conduct more comprehensive security analyses of the newly introduced ChatGPT store and communicate any issues discovered with both the system and third-party developers towards a secure and responsive ChatGPT ecosystem.

7 RELATED WORK

There are numerous work conducting large-scale measurement and analysis for the security of browser extensions or app stores [12, 16, 19, 27, 29, 40]. Some recent research has been dedicated to studying the security of LLMs from multiple perspectives [25, 38, 44]. To the best of our knowledge, our work is the first and largest exhaustive analysis made for the plugin store of the LLM application ecosystem.

Large-scale extensions or app store monitoring analysis. Wang et al. [42] conduct the first systematic study on cryptocurrency-themed malicious browser extensions, monitoring and analyzing 3,600 extensions to identify 186 malicious ones. They reveal their distribution channels, life cycles, developers, and illicit behaviors, shedding light on the characteristics of these extensions. Reitinger et al. [33] provides an in-depth analysis of the evolution of Google Ads settings, demonstrating their progression towards being more updated, personalized, precise, and selectively filtered to improve user privacy and experience. Wang et al. [41] present a large-scale comparative study of Chinese Android app markets, going beyond Google Play to highlight the unique characteristics and dynamics within China’s mobile app ecosystem.

Security risk of application. Numerous studies have concentrated on identifying security vulnerabilities within applications. For broken access control vulnerability, Parkinson et al. [30] develop methodologies for identifying and mitigating potential permission issues through empirical security analysis of various access control systems to prevent data breaches and unintended modifications. For Identification and Authentication Failures vulnerability, Wang

et al. [43] through a systematic analysis of the reasons behind the failure of security proofs in multi-factor authentication schemes for mobile devices, has uncovered the challenges in designing secure and efficient multi-factor authentication systems.

Security analysis of LLMs. Yao et al. [54] delves into the dual-edged nature of LLMs, highlighting their revolutionary applications for security enhancement. The author demonstrates LLM exploitation by human-like reasoning and discusses the urgent need for further research towards a more robust defense mechanism. Kshetri et al. [24] explore how LLMs pose significant threats to security and privacy. This work underscores the need for comprehensive safety and privacy measures in training and deploying these models.

Unlike previous studies, our research focuses on the ChatGPT plugin ecosystem and conducts a comprehensive analysis to assess plugin security. We design a three-layer security assessment model to evaluate the security exposure of plugins. Additionally, we uncover API authentication vulnerabilities in both the ChatGPT plugin store and GPT store, offering guidance for developers and store operators to enhance security within the LLM application ecosystem.

8 CONCLUSION

In this work, we have conducted the first comprehensive study of the ChatGPT app ecosystem from the perspectives of distribution, deployment, and security. We characterize all existing plugins, revealing their functionality distribution, which can serve as a reference for developers in deciding their future endeavors, and for store operators in offering personalized services. We also investigate the deployment and execution models of the plugins through reverse engineering. Based on these models, we identify five types of potential exposures and propose a three-layer security assessment to explore the security landscape of the ChatGPT app ecosystem. Our findings would encourage both OpenAI and third-party developers to collaboratively maintain and develop a healthy LLM app ecosystem.

REFERENCES

- [1] 2020. *Beautiful Soup Documentations*. <https://www.crummy.com/software/BeautifulSoup/bs4/doc/>
- [2] 2024. *Exploring ChatGPT App Ecosystem: Distribution, Deployment and Security (Source Code)*. <https://github.com/pluginsAnalysis/Exploring-ChatGPT-App-Ecosystem-Distribution-Deployment-and-Security>
- [3] 2024. *Selenium Dev*. <https://www.selenium.dev/>
- [4] 2024. *SpaCy website*. <https://spacy.io>
- [5] Marco Alecci, Jordan Samhi, Tegawende F. Bissyande, and Jacques Klein. 2024. Revisiting Android App Categorization. In *Proceedings of the IEEE/ACM 46th International Conference on Software Engineering (ICSE '24)*.
- [6] Sven Amann, Hoan Anh Nguyen, Sarah Nadi, Tien N Nguyen, and Mira Mezini. 2018. A systematic evaluation of static api-misuse detectors. *IEEE Transactions on Software Engineering* 45, 12 (2018), 1170–1188.
- [7] Amazon. 2023. *Choosing a Category for Your App*. <https://developer.amazon.com/docs/app-submission/categories.html>
- [8] Apple. 2023. *Choosing a category*. <https://developer.apple.com/app-store/categories/>
- [9] Bugcrowd. 2024. *Plugin review process*. <https://bugcrowd.com/openai>
- [10] ChatGPT. 2023. *Plugin Manifest*. <https://platform.openai.com/docs/plugins/getting-started>
- [11] Baiqi Chen, Tingmin Wu, Yanjun Zhang, Mohan Baruwat Chhetri, and Guangdong Bai. 2023. Investigating Users' Understanding of Privacy Policies of Virtual Personal Assistant Applications. In *Proceedings of the 2023 ACM Asia Conference on Computer and Communications Security*. 65–79.
- [12] Quan Chen and Alexandros Kapravelos. 2018. *Mystique: Uncovering Information Leakage from Browser Extensions*. In *Proceedings of the 2018 ACM SIGSAC Conference on Computer and Communications Security*. ACM, 1687–1700. <https://doi.org/10.1145/3243734.3243823>
- [13] Fabio Duarte. 2024. *Number of ChatGPT Users*. <https://explodingtopics.com/blog/chatgpt-users>
- [14] Hugging Face. 2023. *The AI community building the future*. <https://huggingface.co/>
- [15] facebook. 2023. *bart-large-mnli*. <https://huggingface.co/facebook/bart-large-mnli>
- [16] Raymond Fok, Mingyuan Zhong, Anne Spencer Ross, James Fogarty, and Jacob O Wobbrock. 2022. A Large-Scale Longitudinal Analysis of Missing Label Accessibility Failures in Android Apps. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*. 1–16.
- [17] Google. 2023. *Choose a category and tags for your app or game*. <https://support.google.com/googleplay/android-developer/answer/9859673?hl=en&zipy=%2Capps>
- [18] Harshini. 2023. *OpenAI Launches ChatGPT Plugin Support*. <https://www.analyticsinsight.net/openai-launches-chatgpt-plugin-support/>
- [19] Vincent Hauptert, Dominik Maier, Nicolas Schneider, Julian Kirsch, and Tilo Müller. 2018. Honey, i shrunk your app security: The state of android app hardening. In *Detection of Intrusions and Malware, and Vulnerability Assessment: 15th International Conference, DIMVA 2018, Saclay, France, June 28–29, 2018, Proceedings 15*. Springer, 69–91.
- [20] Umar Iqbal, Tadayoshi Kohno, and Franziska Roesner. 2023. LLM Platform Security: Applying a Systematic Evaluation Framework to OpenAI's ChatGPT Plugins. *arXiv preprint arXiv:2309.10254* (2023).
- [21] Ghafar A Jaafar, Shahidan M Abdullah, Saifuladli Ismail, et al. 2019. Review of recent detection methods for HTTP DDoS attack. *Journal of Computer Networks and Communications* 2019 (2019).
- [22] AI & Airyland & Joanne. 2023. *GPTs Hunter website*. <https://www.gptshunter.com/>
- [23] In kind donors. 2024. *django: The web framework for perfectionists with deadlines*. <https://www.djangoproject.com/>
- [24] Nir Kshetri. 2023. Cybercrime and privacy threats of large language models. *IT Professional* 25, 3 (2023), 9–13.
- [25] Deepak Kumar, Yousef AbuHashem, and Zakir Durumeric. 2023. Watch your language: large language models and content moderation. *arXiv preprint arXiv:2309.14517* (2023).
- [26] Chenliang Li, Shiqian Chen, and Yan Qi. 2019. Filtering and Classifying Relevant Short Text with a Few Seed Words. *Data and Information Management* 3 (2019), 165 – 186.
- [27] Muath Obaidat, Joseph Brown, and Abdullah Al Hayajneh. 2020. Web Browser Extension User-Script XSS Vulnerabilities. In *2020 IEEE International Conferences on Ubiquitous Intelligence and Computing, Advanced and Trusted Computing, Scalable Computing and Communications, Cloud and Big Data Computing, Internet of People, and Smart World Congress (UIC/ATC/ScalCom/CBDCom/IoP/SmartWorld)*. IEEE.
- [28] OpenAI. 2023. *OpenAI official website*. <https://openai.com/>
- [29] Achilleas Papageorgiou, Michael Strigkos, Eugenia Politou, Efthimios Alepis, Agusti Solanas, and Constantinos Patsakis. 2018. Security and privacy analysis of mobile health applications: the alarming state of practice. *Ieee Access* 6 (2018), 9390–9403.
- [30] S. Parkinson and Saad Khan. 2022. A Survey on Empirical Security Analysis of Access-control Systems: A Real-world Perspective. *Comput. Surveys* 55 (2022), 1 – 28.
- [31] Progress. 2024. *Fiddler official website*. <https://www.telerik.com/fiddler>
- [32] Faisal Rahutomo, Teruaki Kitasaka, Masayoshi Aritsugi, et al. 2012. Semantic cosine similarity. In *The 7th international student conference on advanced science and technology ICAST*, Vol. 4. University of Seoul South Korea, 1.
- [33] Nathan Reitering, Bruce Wen, Michelle L Mazurek, and Blase Ur. 2023. Analysis of Google Ads Settings Over Time: Updated, Individualized, Accurate, and Filtered. In *Proceedings of the 22nd Workshop on Privacy in the Electronic Society*. 167–172.
- [34] Kenneth Reitz. 2023. *requests 2.31.0*. <https://pypi.org/project/requests/>
- [35] Eram Shaikh. 2023. *ChatGPT Plugins: How To Maximize Its Potential?* <https://www.demandsage.com/chatgpt-plugins/>
- [36] Shikha Soneji, Mitchell Hoising, Sujay Koujalgi, and Jonathan Dodge. 2024. Demystifying Legalese: An Automated Approach for Summarizing and Analyzing Overlaps in Privacy Policies and Terms of Service. *arXiv preprint arXiv:2404.13087* (2024).
- [37] Amann Sven, Hoan Anh Nguyen, Sarah Nadi, Tien N Nguyen, and Mira Mezini. 2019. Investigating next steps in static API-misuse detection. In *2019 IEEE/ACM 16th International Conference on Mining Software Repositories (MSR)*. IEEE, 265–275.
- [38] Saad Ullah, Mingji Han, Saurabh Pujar, Hammond Pearce, Ayse Coskun, and Gianluca Stringhini. 2023. Can Large Language Models Identify And Reason About Security Vulnerabilities? Not Yet. *arXiv preprint arXiv:2312.12575* (2023).
- [39] Ashish Vaswani, Noam Shazeer, Niki Parmar, Jakob Uszkoreit, Llion Jones, Aidan N Gomez, Łukasz Kaiser, and Illia Polosukhin. 2017. Attention is all you need. *Advances in neural information processing systems* 30 (2017).

- [40] Luca Verderame, Davide Caputo, Andrea Romdhana, and Alessio Merlo. 2020. APPregator: A Large-Scale Platform for Mobile Security Analysis. In *Testing Software and Systems (ICTSS 2020) (Lecture Notes in Computer Science, Vol. 12543)*. IFIP International Conference on Testing Software and Systems, Springer, 73–88. Access provided by The University of Queensland.
- [41] Haoyu Wang, Zhe Liu, Jingyue Liang, Narseo Vallina-Rodriguez, Yao Guo, Li Li, Juan Tapiador, Jingcun Cao, and Guoai Xu. 2018. Beyond google play: A large-scale comparative study of chinese android app markets. In *Proceedings of the Internet Measurement Conference 2018*. 293–307.
- [42] Kailong Wang, Yuxi Ling, Yanjun Zhang, Zhou Yu, Haoyu Wang, Guangdong Bai, Beng Chin Ooi, and Jin Song Dong. 2022. Characterizing cryptocurrency-themed malicious browser extensions. *Proceedings of the ACM on Measurement and Analysis of Computing Systems* 6, 3 (2022), 1–31.
- [43] Qingxuan Wang and Ding Wang. 2023. Understanding Failures in Security Proofs of Multi-Factor Authentication for Mobile Devices. *IEEE Transactions on Information Forensics and Security* 18 (2023), 597–612.
- [44] Zihan Wang, Zhongkui Ma, Xinguo Feng, Ruoxi Sun, Hu Wang, Minhui Xue, and Guangdong Bai. 2024. CoreLocker: Neuron-level Usage Control. In *2024 IEEE Symposium on Security and Privacy (SP)*. IEEE Computer Society, 222–222.
- [45] Li Weng and Bart Preneel. 2011. A secure perceptual hash algorithm for image content authentication. In *IFIP International Conference on Communications and Multimedia Security*. Springer, 108–121.
- [46] Dan Roth Wenpeng Yin, Jamaal Hay. 2019. *Benchmarking Zero-shot Text Classification: Datasets, Evaluation and Entailment Approach*. <https://arxiv.org/abs/1909.00161>
- [47] Adina Williams, Nikita Nangia, and Samuel Bowman. 2018. A Broad-Coverage Challenge Corpus for Sentence Understanding through Inference. In *Proceedings of the 2018 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 1 (Long Papers)* (New Orleans, Louisiana). Association for Computational Linguistics, 1112–1122. <http://aclweb.org/anthology/N18-1101>
- [48] Shomir Wilson, Florian Schaub, Aswath Abhilash Dara, Frederick Liu, Sushain Cherivirala, Pedro Giovanni Leon, Mads Schaarup Andersen, Sebastian Zimmeck, Kanthashree Mysore Sathyendra, N Cameron Russell, et al. 2016. The creation and analysis of a website privacy policy corpus. In *Proceedings of the 54th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*. 1330–1340.
- [49] Wuhenlove. 2023. *Easy Web Data Scraper chrome web store*. <https://chromewebstore.google.com/detail/easy-web-data-scraper/mndkmbnkepbhldkhlofdcfmgflbjggnl>
- [50] Yongqin Xian, Zeynep Akata, Gaurav Sharma, Quynh Nguyen, Matthias Hein, and Bernt Schiele. 2016. Latent embeddings for zero-shot classification. In *Proceedings of the IEEE conference on computer vision and pattern recognition*. 69–77.
- [51] Fuman Xie, Yanjun Zhang, Chuan Yan, Suwan Li, Lei Bu, Kai Chen, Zi Huang, and Guangdong Bai. 2022. Scrutinizing privacy policy compliance of virtual personal assistant apps. In *Proceedings of the 37th IEEE/ACM international conference on automated software engineering*. 1–13.
- [52] Chuan Yan, Mark Huasong Meng, Fuman Xie, and Guangdong Bai. 2024. Investigating Documented Privacy Changes in Android OS. *Proceedings of the ACM on Software Engineering* 1, FSE (2024), 2701–2724.
- [53] Chuan Yan, Fuman Xie, Mark Huasong Meng, Yanjun Zhang, and Guangdong Bai. 2024. On the Quality of Privacy Policy Documents of Virtual Personal Assistant Applications. *Proceedings on Privacy Enhancing Technologies* (2024).
- [54] Yifan Yao, Jinhao Duan, Kaidi Xu, Yuanfang Cai, Zhibo Sun, and Yue Zhang. 2024. A survey on large language model (llm) security and privacy: The good, the bad, and the ugly. *High-Confidence Computing* (2024), 100211.