ANDROIDWORLD: A DYNAMIC BENCHMARKING ENVIRONMENT FOR AUTONOMOUS AGENTS

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ABSTRACT

Autonomous agents that execute human tasks by controlling computers can enhance human productivity and application accessibility. However, progress in this field will be driven by realistic and reproducible benchmarks. We present ANDROIDWORLD, a fully functional Android environment that provides reward signals for 116 programmatic tasks across 20 real-world Android apps. Unlike existing interactive environments, which provide a static test set, ANDROIDWORLD dynamically constructs tasks that are parameterized and expressed in natural language in unlimited ways, thus enabling testing on a much larger and more realistic suite of tasks. To ensure reproducibility, each task includes dedicated initialization, success-checking, and tear-down logic, which modifies and inspects the device's system state.

We experiment with baseline agents to test ANDROIDWORLD and provide initial results on the benchmark. Our best agent can complete 30.6% of ANDROIDWORLD's tasks, leaving ample room for future work. Furthermore, we adapt a popular desktop web agent to work on Android, which we find to be less effective on mobile, suggesting future research is needed to achieve universal, cross-platform agents. Finally, we also conduct a robustness analysis, showing that task variations can significantly affect agent performance, demonstrating that without such testing, agent performance metrics may not fully reflect practical challenges. ANDROIDWORLD and the experiments in this paper are available at https://github.com/google-research/android_world.

1 INTRODUCTION

Autonomous agents that interpret natural language instructions and operate computing devices can provide enormous value to users by automating repetitive tasks, augmenting human intelligence, and accomplishing complex workflows. However, a key research challenge remains the realistic evaluation of these agents in real-world settings. Despite growing enthusiasm for building autonomous agents (Deng et al., 2023; Rawles et al., 2023; Zheng et al., 2024a; Koh et al., 2024; Kim et al., 2024; He et al., 2024; Gravitas, 2023; Wu et al., 2023; Xie et al., 2023) most existing approaches for evaluation compare an agent's actions at each step to a previously collected human demonstration (Deng et al., 2023; Rawles et al., 2023; Yang et al., 2023b; Zhang & Zhang, 2023; Lù et al., 2024; Zhang et al., 2024c; Yan et al., 2023; Li et al., 2024). Measuring performance in this way can be misleading because when performing tasks online in real environments agents can take multiple paths to solve tasks, environments may behave non-deterministically, and agents can dynamically learn from mistakes to correct their actions (Shinn et al., 2023; Liu et al., 2018b; Li et al., 2023b; Pan et al., 2024). For this reason, online evaluation of agents in realistic environments able to reward task outcome provides a gold standard for evaluation. While there is an emerging body of work to address this need across different environments (Zhou et al., 2023; Koh et al., 2024; Drouin et al.,

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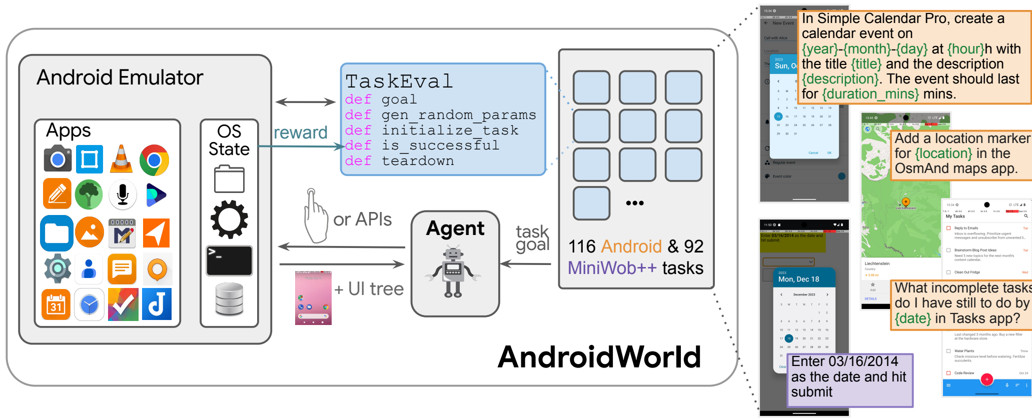

Figure 1: ANDROIDWORLD is an environment for building and testing autonomous agents.

2024; Lee et al., 2024; Xie et al., 2024; Bonatti et al., 2024; Zheng et al., 2024b), there is no comprehensive solution for mobile platforms, such as Android, which are used by billions of users and therefore represent environments in which automation agents may be very productively employed. We introduce ANDROIDWORLD to address this.

At its core, ANDROIDWORLD offers a reliable means of obtaining reward signals for tasks performed by agents in realistic mobile environments. Reward signals are quantitative metrics that indicate functional correctness of a task, i.e. is the stated goal achieved? For example, for the task "Send a text message to Jane confirming I'll be there," a positive reward indicates that the relevant message has been sent. Unlike simulated environments (Tassa et al., 2018; Shridhar et al., 2020) or games (Mnih et al., 2013; Silver et al., 2016; Vinyals et al., 2019; Wang et al., 2023b; Tan et al., 2024; Toyama et al., 2021), real-world apps and websites do not inherently offer explicit reward signals. While human (Rawles et al., 2023; Zheng et al., 2024a; Pan et al., 2024; Kinniment et al., 2023) or LLM-based (Chiang et al., 2024; Zheng et al., 2023; Liu et al., 2023; Du et al., 2023; Ma et al., 2023; Pan et al., 2024; He et al., 2024) judges can be employed to reward the outcome of a task, these approaches scale poorly or are not fully reliable, respectively. Alternatively, environments for autonomous agents which provide automated ground-truth rewards for complex workflows have been developed (Yao et al., 2023; Zhou et al., 2023; Koh et al., 2024; Xie et al., 2024; Bonatti et al., 2024). We find two problems with these environments. First, they are constrained to desktop computing environments, overlooking the mobile domain, which is of paramount importance given the ubiquity and diversity of mobile devices in the real world. Secondly, they are limited in their real-world diversity and scale. Crucially, unlike in real-world scenarios where conditions and task inputs vary widely, these environments support only static test specifications, meaning that when task parameters deviate, the reward signal is likely to break.

We seek to develop a comprehensive benchmark that addresses the limitations of the existing approaches above for evaluating automation agents in mobile environments. ANDROIDWORLD does this by spanning 20 Android apps on a total of 116 programmatic tasks to provide ground truth-rewards. Unlike existing test environments (MiniWoB++ (Shi et al., 2017) being a notable exception), each task in ANDROIDWORLD is dynamically instantiated using randomly-generated parameters, challenging agents with millions of unique task goals and conditions. While MiniWob++ consists of simple, synthetic websites, ANDROIDWORLD leverages actual Android applications. A main challenge that ANDROIDWORLD must address is how to ensure that reward signals are durable when using real-world applications and varying task parameters dynamically. ANDROIDWORLD's solves this by leveraging the extensive and consistent state management capabilities of the Android OS, using the same mechanisms that the apps themselves utilize to store and update data.

In addition to providing a comprehensive benchmark, ANDROIDWORLD is lightweight, requiring only 2 GB of memory and 8 GB of disk space, and is designed with convenience in mind. It connects agents to the Android OS by leveraging the Python library AndroidEnv (Toyama et al.,

Table 1: Comparison of different datasets and environments for benchmarking computer agents.

	Env?	# of apps or websites	# task templates	Avg # task instances	Reward method	Platform
GAIA	✗	n/a	466	1	text-match	None
MIND2WEB	✗	137	2350	1	None	Desktop Web
WEBLINX	✗	155	2337	1	None	Desktop Web
WEBVOYAGER	✗	15	643	1	LLM judge	Desktop Web
PIXELHELP	✗	4	187	1	None	Android
METAGUI	✗	6	1125	1	None	Android
MOTIF	✗	125	4707	1	None	Android (Apps+Web)
AITW	✗	357+	30378	1	None	Android (Apps+Web)
ANDROIDCONTROL	✗	833	15283	1	None	Android (Apps+Web)
OMNIACT	✗	60+	9802	1	None	Desktop (Apps+Web)
ANDROIDARENA	✗	13	221	1	Action match/LLM	Android (Apps+Web)
LLAMATOUCH	✗	57	496	1	Screen match	Android (Apps+Web)
MINIWOB++	✓	1	114	∞	HTML/JS state	Web (synthetic)
WEBSHOP	✓	1	12k	1	product attrs match	Desktop Web
WEBARENA	✓	6	241	3.3	url/text-match	Desktop Web
VISUALWEBARENA	✓	4	314	2.9	url/text/image-match	Desktop Web
WORKARENA	✓	1	29	622.4	cloud state	Desktop Web
MOBILE-ENV	✓	1	13	11.5	regex	Android (Apps)
B-MOCA	✓	4	6	1.9	regex	Android (Apps+Web)
MMINA	✓	14	1050	1	text-match	Desktop web
OSWORLD	✓	9	369	1	device/cloud state	Desktop (Apps+Web)
WINDOWSAGENTARENA	✓	11	154	1	device state	Desktop (Apps+Web)
AGENTSTUDIO	✓	9	205	1	device state	Desktop (Apps+Web)
ANDROIDWORLD	✓	20	116	∞	device state	Android (Apps+Web)

2021) to connect to the freely available Android Emulator.[1] In addition to the 116 Android tasks, we extend ANDROIDWORLD with web tasks by integrating the MiniWoB++ (Shi et al., 2017; Liu et al., 2018a) benchmark into it.

To demonstrate ANDROIDWORLD's usefulness as a benchmark, we build and release a multi-modal agent, M3A (Multimodal Autonomous Agent for Android), and establish state-of-the-art results on ANDROIDWORLD. We analyze M3A's performance using both multimodal and text-only input, and we observe that while multimodal perception can improve performance in some cases, it generally does not outperform the text-only approach. On ANDROIDWORLD, M3A achieves a 30.6% success rate, which surpasses that of a web agent adapted for Android but remains significantly lower than the human success rate of 80.0%. In pursuit of building robust UI control agents, our study includes comprehensive tests under varied real-world conditions, demonstrating significant performance variations primarily driven by changes in intent parameters.

We make the following contributions: (i) the creation of a new, highly diverse and realistic mobile UI control agent environment; (ii) establishment of benchmark performance with a state-of-the-art multimodal agent, and (iii) a careful analysis demonstrating the need to evaluate agents across variable task parameters and conditions due to the inherent stochasticity in both models and environments.

2 RELATED WORK

Table 1 compares existing evaluation environments for autonomous UI agents.

2.1 INTERACTIVE EVALUATION ENVIRONMENTS

Effective evaluation of autonomous agents requires benchmarks that mimic real-world scenarios, but also interactive environments that provide reward signals upon successful task completion (Rawles et al., 2023; Deng et al., 2023; Abramson et al., 2022; Ruan et al., 2023; Chen et al., 2021). Many existing benchmarking environments target web browsing. MiniWoB++ (Shi et al., 2017; Liu et al., 2018b) consists of small, synthetic HTML pages with parameterizable tasks which allow for un-

[1]The Android Emulator is packaged as part of Android Studio, which can be downloaded from https://developer.android.com/studio

limited task variability. WebShop (Yao et al., 2023) provides a simulated e-commerce environment, whereas WebArena (Zhou et al., 2023) and VisualWebArena (Koh et al., 2024) consist of simulated websites across up to six domains. WorkArena (Drouin et al., 2024) consists of 29 tasks for enterprise software. GAIA (Mialon et al., 2023) is a static dataset that tests an agent's ability to interact with live web environments. MMInA (Zhang et al., 2024e) is a multihop and multimodal benchmark designed to evaluate agents for compositional Internet tasks.

Towards building computer use agents, OSWorld (Xie et al., 2024), WindowsAgentArena (Bonatti et al., 2024), and AgentStudio (Zheng et al., 2024b) provide a test suite of tasks for desktop computer interfaces and custom execution-based evaluation scripts across 9, 11, and 9 apps, respectively. In the mobile domain, existing benchmarks are limited and do not capture the diversity of real-world mobile interactions, containing low-complexity tasks or on a limited number of applications. B-MoCA's (Lee et al., 2024) evaluation is based on 6 simple tasks (e.g., "Call 911", "turn on airplane mode") across 4 apps[2], validated using regular expressions. Mobile-Env (Zhang et al., 2024b) offers task reproducibility limited to 13 task templates for a single app (WikiHow).

While ANDROIDWORLD shares the mobile OS focus of B-MoCA and Mobile-Env, it is more comparable to OSWorld (and WindowsAgentArena, which builds on top of OSWorld) in terms of task complexity and the diversity of interactions it supports. ANDROIDWORLD enhances OSWorld's approach by dynamically constructing the start states of an agent's run and varying the task parameters in unlimited ways, thus allowing for a new type of evaluation under varying real-world conditions.

Other studies leverage human evaluation (Rawles et al., 2023; Zheng et al., 2024a; Bishop et al., 2024) for tasks where automatic evaluation is not available. Lastly, emerging research (Pan et al., 2024; He et al., 2024; Xing et al., 2024; Zheng et al., 2024b) explores the potential of multimodal models to generalize agent evaluations to new settings, though this area requires further research to achieve accuracy comparable to manually-coded rewards.

AndroidEnv (Toyama et al., 2021) provides a mechanism to manage communication with the Android emulator, similar to Playwright and Selenium for web environments. While ANDROIDWORLD leverages this functionality, it diverges in its reward system. AndroidEnv's approach requires modifying application source code and implementing task-specific logging statements, making it well-suited for gaming environments with easily verifiable success criteria. In contrast, ANDROIDWORLD implements a non-invasive reward mechanism, allowing it to create a benchmark suite for apps whose source code is unavailable and to reuse validation components across different apps. This approach enables ANDROIDWORLD to cover a broader range of real-world mobile tasks.

2.2 STATIC DATASETS FOR UI AUTOMATION

Datasets derived from human interactions provide proxy metrics that correlate with real-world agent performance (Li et al., 2020; Burns et al., 2021; Deng et al., 2023; Rawles et al., 2023). On mobile platforms, AitW (Rawles et al., 2023), AndroidControl (Li et al., 2024), PixelHelp (Li et al., 2020), AndroidArena (Xing et al., 2024), LlamaTouch (Zhang et al., 2024d), UGIF (Venkatesh et al., 2022), and MoTIF (Burns et al., 2021) consist of demonstrations across Android apps and mobile websites, with screens often represented via accessibility trees. In contrast, desktop web environments typically utilize the DOM for representing website content, with Mind2Web (Deng et al., 2023), OmniAct (Kapoor et al., 2024) and others, across various desktop websites. Mobile-based datasets frequently involve more complex actions, such as scrolling, which are not as useful in DOM-based desktop interactions where the entire action space is readily accessible. Additionally, API-centric datasets like API-Bank (Li et al., 2023a), ToolTalk (Farn & Shin, 2023), and ToolBench (Xu et al., 2023) assess agents' capabilities to manipulate computer systems via APIs.

2.3 INTERACTIVE AGENTS

Prior to today's foundation models, traditional approaches to developing user interface-operating agents primarily used reinforcement learning and behavioral cloning to simulate interactions like mouse clicks and keyboard typing (Liu et al., 2018b; Li et al., 2020; Shvo et al., 2021; Gur et al., 2022a; Humphreys et al., 2022). More recent work leverages off-the-shelf foundational models (Gemini, 2023; OpenAI, 2023; Touvron et al., 2023) with in-context learning (ICL) and fine-tuning

[2]Based on what reported in the Experiments Section of the B-MoCA manuscript as of October 1st, 2024.

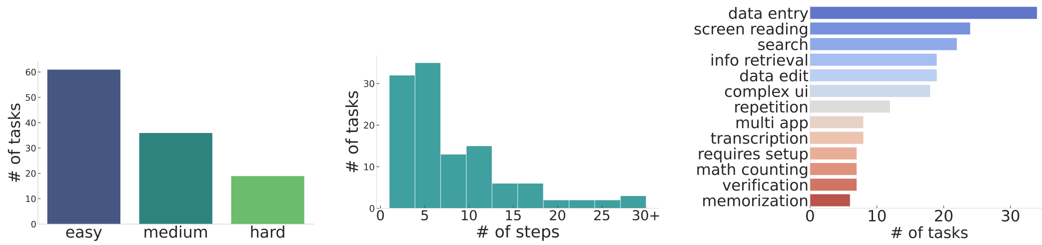

Figure 2: Annotators performed the tasks assigned to them, assigned a difficulty level (2a) and estimated the number of steps required to complete each task (2b), using the action space available to an agent. For each task, they selected relevant category tags from a predefined list (2c).

applied to mobile (Rawles et al., 2023; Hong et al., 2023; Wang et al., 2023a; Yan et al., 2023; Zhang & Zhang, 2023; Bishop et al., 2024; Zhang et al., 2023), desktop web (Zheng et al., 2024a; Deng et al., 2023; Zhou et al., 2023; Koh et al., 2024; Cheng et al., 2024; Lai et al., 2024; You et al., 2024), and desktop OS (Wu et al., 2024; Zhang et al., 2024a; Xie et al., 2024). Recent work explores agents that reflect on system state (Shinn et al., 2023; Yao et al., 2022; Madaan et al., 2024) by leveraging exploration, self-evaluation, and retry-capabilities for continual learning and adaptation (Li et al., 2023b; Yang et al., 2023b; Pan et al., 2024; Wu et al., 2024; Gao et al., 2023; Murty et al., 2024).

3 ANDROIDWORLD

3.1 ANDROID FOR AUTONOMOUS AGENTS

Android is an ideal environment for developing autonomous agents. It is the most widely-used OS globally[3] and is highly flexible for research, while providing an open world of the Web[4] and over 2M apps for agents to operate in. Using emulation, an Android environment is easy to deploy, does not require specialized hardware, and can be run on a laptop. Android Virtual Devices or emulator images are well suited for research as they are self-contained, easy to distribute, and configurable.

Compared to desktops, mobile environments like Android present unique challenges for computer-use agents. While mobile UIs are simpler due to smaller screens, their action space is more complex, requiring intricate gestures (e.g., navigating carousels, long-pressing, multi-finger zooming) and often more steps to complete tasks. Unlike web-browser-only environments, Android, as an OS, offers greater flexibility, including function-calling APIs (e.g., sending texts) alongside standard UI actions (click, scroll, type).

3.2 THE OBSERVATION AND ACTION SPACE

ANDROIDWORLD provides an interface for agents to receive observations and execute actions on Android. It uses AndroidEnv (Toyama et al., 2021) and the Android Device Bridge to facilitate interaction between Android and the agent. The observation space consists of a full-resolution screenshot and a UI tree representation developed for accessibility purposes. The action space is similar to that which humans use, consisting of gestures (i.e., tapping, swiping), typing, and navigation buttons (i.e., go home and go back). In addition to these naturalistic actions, ANDROIDWORLD exposes a limited set of function calling APIs, such as `send_text_message`, to help agents accomplish goals. Appendix C provides more details on the observation format and action space.

3.3 REPRODUCIBLE AND PARAMETERIZED TASKS

ANDROIDWORLD consists of a suite of 116 tasks, spread across 20 diverse applications (see Appendix D for more details). These tasks simulate practical, everyday activities, including note-

[3] https://gs.statcounter.com/os-market-share

[4] Mobile is the most popular platform for accessing the web; https://gs.statcounter.com/platform-market-share/desktop-mobile/worldwide/

Table 2: Selected tasks with code describing validation logic.

Task	Validation code
In Simple Calendar Pro, create a calendar event on {event.year}-{event.month}-{event.day} at {event.hour}h with the title '{event.title}' and the description '{event.description}'. The event should last for {event.duration} mins.	`event_exists(event)`
Send a text message to {phone_number} with message: {message}.	`message_exists(phone_number, message, messaging_db)`
Create a new drawing in Simple Draw Pro. Name it {file_name}. Save it in the Pictures folder.	`file_exists(file_path)`
Create a timer with {hours} hours, {minutes} minutes, and {seconds} seconds. Do not start the timer.	`timer_displays(time, ui_hierarchy)`
Create a new note in Markor named {file_name} with the following text: {text}. Share the entire content of the note with the phone number {number} via SMS.	`(file_exists(file_name, content=text) + message_exists(phone_number, message)) / 2.0`
Turn on WiFi and open {app_name}.	`(wifi_enabled() + app_launched(app_name))/2.0`

taking, scheduling appointments, communicating through messaging, and interacting with system utilities. The suite consists of open-source apps and built-in Android system apps, such as Settings and Contacts. As rated by humans, the tasks vary in difficulty, duration, and categories (Figure 2).

To achieve a high degree of reproducibility in real-world scenarios, ANDROIDWORLD precisely controls the OS and app states in several ways. The Android OS is fixed, consisting of a Pixel 6 emulator running Android 13. At the start of each task, ANDROIDWORLD resets the device timestamp to October 15th, 2023 at 15:34 UTC, ensuring consistent time-dependent behaviors across all executions. All applications in ANDROIDWORLD are fully-functional and consists of both open-source apps and OS-level apps included with Android. For the open-source apps, ANDROIDWORLD maintains a constant environment by installing a fixed version of each app, acquired from F-Droid.[5] OS-level apps' versions are determined by the Android OS, which is also fixed. To maintain a reproducible environment, ANDROIDWORLD utilizes apps that do not require login/authentication and can store their application data on device.

In addition to managing the states of apps and operating systems, ANDROIDWORLD precisely defines and controls the state during task execution. Each task has its own unique setup, reward determination logic, and teardown procedures (see Appendix D.2 and D.3 for more details), ensuring a fully reproducible suite of tasks.

Automatic task *parameterization* is a critical mechanism, unique to ANDROIDWORLD, to evaluate agents on a much larger and more realistic suite of tasks than current benchmarks support. Achieving this requires significantly more effort than randomly generating new task parameters because it involves developing evaluation logic that remains valid across different task instantiations. It is exactly through its careful state management that in addition to reproducibility AndroidWorld ensures that the reward mechanisms function correctly. Task parameters, initialized randomly at the start of each task based on a controlled random seed, dictate the initial state and influence reward outcomes. Similar to MiniWoB++ (Shi et al., 2017; Liu et al., 2018a), ANDROIDWORLD consists of a practically infinite set of varying initial conditions and success criteria.

This approach enables finer-grained analyses of agent adaptability, essential for real-world deployment. Beyond robustness testing, dynamic task construction supports online learning, particularly reinforcement learning (Shi et al., 2017; Liu et al., 2018a; Humphreys et al., 2022; Gur et al., 2022a), while also streamlining train/test dataset generation for supervised learning (Humphreys et al., 2022; Shaw et al., 2023; Furuta et al., 2023).

3.4 DURABLE REWARDS FROM SYSTEM STATE

ANDROIDWORLD provides reward signals primarily by managing application state using the Android Debug Bridge (`adb`), while also incorporating UI element validation where appropriate. With

[5] https://f-droid.org/

adb, ANDROIDWORLD has complete access to system resources including the file system, application databases, and system settings. For tasks where system state inspection is impractical, ANDROIDWORLD validates task completion by examining UI elements on screen. Determining reward signals from system state has several benefits. It is highly accurate because an application's state can be quickly inspected and manipulated using the same mechanisms that the app itself utilizes. Using the underlying system state is much more durable than matching superficial UI changes. Additionally, it facilitates easy re-use across disparate apps, which tend to use the same underlying caching mechanisms. For instance, logic for checking existence of a specific file is used across many unrelated applications, including those for file management, note-taking, and media playback. For applications leveraging SQLite databases, a common pattern, ANDROIDWORLD implements evaluators that verify the existence of new and deleted rows. Table 2 shows examples of the validators in ANDROIDWORLD. See Table 6 for a comprehensive list of all tasks in the suite. Table 5 provides selected examples with additional implementation details.

3.5 TASK COMPOSABILITY

Inferring task success from system state enables accurate, reusable evaluations and simplifies creating *composite* tasks by combining existing ones. For instance, "Create a calendar event with details and text the details to contact" merges two standalone tasks, facilitated by hermetic initialization and success detection. Composite tasks are more challenging due to their complexity but provide partial rewards for subtask completion, aiding hill climbing. The last two rows of Table 2 show validation code for composite tasks.

3.6 INTEGRATING MINIWOB++

We implement MiniWoB++ in the ANDROIDWORLD framework and term it MobileMiniWoB++. Each MobileMiniWoB++ task is instantiated using the standard ANDROIDWORLD interface, inheriting from `TaskEval` base class, and contains methods like `initialize_state` and `is_successful`. Since MiniWoB++ leverages JavaScript for task configuration and success detection, we built a WebView app to communicate between Python and the app.

MobileMiniWoB++ introduces modifications in both observations and actions compared to the original benchmark. For example, HTML5 <input> elements are rendered with native Android UI widgets like the date-picker (see Figure 4), enhancing the realism of the tasks. MobileMiniWoB++ uses the same observation space as the Android tasks (accessibility tree and screenshot). Notably, it does not include the DOM as in the original implementation. The action space from ANDROIDWORLD is retained. We manually review and test each task to ensure they are solvable. We excluded twelve of the original tasks that failed to render correctly on Android, presented compatibility issues with the touch interface, or required near real-time interaction, which poses challenges on emulators. Overall, ANDROIDWORLD supports 92 MiniWoB++ tasks. See Appendix C.3 for more details.

4 ANDROIDWORLD AS A COMPUTER-CONTROL BENCHMARK

To test ANDROIDWORLD's applicability for autonomous agents, we develop and test a state-of-the-art agent and its variants across all 20 apps and 116 tasks, as well as on MobileMiniWoB++.

4.1 COMPUTER USE AGENTS

4.1.1 M3A

We develop a multimodal autonomous agent for Android, M3A. It is zero-shot, integrating ReAct-style (Yao et al., 2022) and Reflexion-style (Shinn et al., 2023) prompting to consume user instructions and screen content, reason, take actions, and update its decision-making based on the outcome of its actions.

In the first stage, M3A generates an action, represented in JSON, and reasoning for that action. To generate this output, the agent is provided with a list of available action types, guidelines for operating the phone, and a list of UI elements derived from the Android accessibility tree's leaf nodes. The agent receives the current screenshot and a Set-of-Mark (SoM) (Yang et al., 2023a)

Table 3: Success Rates (SR) on ANDROIDWORLD and MobileMiniWoB++.

Agent	Input	Base model	$SR_{\text{AndroidWorld}}$	$SR_{\text{MobileMiniWoB++}}$
Human	*screen*	*N/A*	*80.0*	*100.0*
SeeAct (Zheng et al., 2024a)	SoM (screen + a11y tree)	GPT-4 Turbo	15.5	66.1
M3A-Simple	a11y tree	Gemma 2	3.4	35.5
M3A-Simple	a11y tree	Gemini 1.5 Pro	14.7	55.2
M3A-Simple	a11y tree	GPT-4 Turbo	19.8	**67.7**
M3A	a11y tree	Gemma 2	9.5	45.6
M3A	a11y tree	Gemini 1.5 Pro	19.4	57.4
M3A	SoM (screen + a11y tree)	Gemini 1.5 Pro	22.8	40.3
M3A	a11y tree	GPT-4 Turbo	**30.6**	59.7
M3A	SoM (screen + a11y tree)	GPT-4 Turbo	25.4	**67.7**

annotated screenshot, which includes bounding boxes with numeric labels on the top-left corner for each UI element (see screenshot in Figure 5). The agent attempts to execute outputted action by referencing the specific mark (if applicable). In addition to the multimodal agent, we have developed a text-only variant that consumes the screen represented using the accessibility tree and selects the relevant action in JSON format.

After executing an action, M3A reflects on its effect by observing any state changes that may have occurred. During this stage, the agent is provided with available action types, general operating guidelines, the actual action taken, and its reasoning, as well as before-and-after UI states, represented by UI element representations and screenshots with SoM annotations. We request the agent to provide a concise summary of this step, including the intended action, success or failure, potential reasons for failure, and recommendations for subsequent actions. This summary will serve as the action history and be used for future action selection. See Appendix E for more details on the agent.

In addition to the full agent, we develop M3A-SIMPLE to measure the performance that can be achieved with minimal prompting, without guidelines or reflection mechanisms. This helps quantify the impact of more advanced prompting techniques and domain-specific guidance.

4.1.2 SEEACT BASELINE

We implement a baseline agent based on SeeAct (Zheng et al., 2024a), which was originally designed for GPT-4V for web navigation. Specifically, we implement the best-performing variant, $\text{SeeAct}_{\text{choice}}$, which grounds actions via textual choices. We implement SeeAct for the Android environment to evaluate how an existing model that performs well on web tasks (Deng et al., 2023) can be adapted and applied to Android.

To accommodate the Android environment, we adapt SeeAct in several ways. Firstly, we augment the action space from the original SeeAct implementation to support actions needed for mobile, including scroll, long press, navigate home and back, and open app actions. Secondly, in lieu of the DOM, which is not available for Android apps, we utilize the accessibility tree to construct candidate UI actions. Due to the lack of the DOM representation, we do not use the bespoke ranker model from the original implementation. However, we observe that after applying a filtering heuristic to remove non-interactable elements, the majority of screens contains less than 50 candidate elements. See Appendix E.6 for more details on the implementation.

4.2 EXPERIMENTAL RESULTS

We evaluate M3A, M3A-SIMPLE, and SeeAct on ANDROIDWORLD and MobileMiniWoB++. We set the seed to 30 and the temperature to 0 to aid reproducibility. Each task has a maximum allowed number of steps (detailed in Appendix F), typically set to twice the number of steps needed by human annotators to complete the task. We use Gemini 1.5 Pro, GPT-4 Turbo, and the open-source Gemma 2 27B (Team et al., 2024) as base models. For MobileMiniWoB++, we evaluate on a subset of 62 tasks, consistent with recent studies (Zheng et al., 2024c; Kim et al., 2024; Gur et al., 2022b).

Table 3 presents the success rates (SR) for the agents and human performance on both task suites. Although the agents have far from human performance, they demonstrate out-of-the-box capabilities in operating mobile UIs, exhibiting basic understanding and control capabilities of UIs. They can perform a variety of actions, including long-press, scrolling to search for information, and revising their plan if actions do not work out. The best performance is obtained by M3A when using GPT-4. On ANDROIDWORLD the SoM-based variant is less performant, while on MobileMiniWoB++ it performs best. A similar result was obtained in recent work on computer agents for desktop applications (Xie et al., 2024). We posit SoM plays a more critical role in MobileMiniWoB++ tasks due to the often incomplete accessibility tree, compared to that of native Android apps.

The simplified agent variant M3A-SIMPLE shows a significant performance drop on ANDROIDWORLD tasks (19.8% vs 30.6% with GPT-4), indicating that additional prompting techniques and domain-specific guidance are beneficial for navigating the complexity of Android interactions. However, on MobileMiniWoB++ tasks, M3A-SIMPLE achieves comparable performance (67.7%), suggesting that these simpler tasks may not benefit as much from sophisticated prompting strategies. The open-source Gemma model's lower performance (9.5% on ANDROIDWORLD, 45.6% on MobileMiniWoB++) compared to proprietary models likely stems from its smaller parameter count, though exact comparisons are difficult as the parameter counts for GPT-4 and Gemini are not public.

4.3 ANALYSIS

Agents have difficulty understanding mobile UIs, often failing to detect visual cues that are essential for task completion (see Figure 6a). Additionally, agents struggle with certain UI patterns and affordances, and when they make reasoning mistakes (see Figure 6b), they often lack the capability to explore and adapt as humans do (see Figure 6c). Moreover, agents sometimes struggle with tasks that simply involve confirming system states, e.g., confirming the WiFi is turned on, suggesting challenges in both task and screen understanding.

The agents struggle with grounding, particularly when executing precise interactions, such as manipulating text (see Figure 7) or operating sliders, and they are often unable to recover from mistyping errors. In addition, for tasks that demand memory, such as performing transcriptions across apps, multiplying numbers, or scrolling, the agents struggle as they are unable to "remember" content.

SeeAct performs less effectively than M3A on the ANDROIDWORLD task suite and similarly on MobileMiniWoB++, reflecting its optimization for web rather than mobile environments. It struggles with mobile-specific actions like long-presses and swipes, and often fails to select appropriate actions due to not incorporating screen elements during action generation. Memory-intensive tasks are particularly challenging, as SeeAct only caches actions without remembering outcomes, leading to repetitive, ineffective behaviors such as endless scrolling. This lack of quick error recovery often results in task termination once maximum steps are reached.

Finally, we note that large foundation models significantly increase latency, taking three times longer than humans on average to complete tasks. On average, M3A takes 3.9 minutes to complete a task, with the text-only version taking 2.5 minutes.

5 ROBUSTNESS ANALYSIS

To understand agent robustness, we analyze M3A's performance across different random seeds, which generate different task parameters (e.g., calendar appointments, expense categories) and can consequently require different UI interaction patterns (e.g., scrolling to access hidden elements, handling varying numbers of elements to modify, or adapting to different input types and lengths). Across three seeds, we observe significant performance variations: 27.6%, 26.3% and 33.2% (mean 29.0%), obtained using M3A with GPT-4 Turbo with accessibility trees as input. Note that for consistency with existing literature we maintain the single-seed results in Table 3.

To better understand the sources of this variability, we evaluate agent robustness under two conditions: (1) identical tasks with the same parameters and (2) tasks with different parameter combinations, which change the initial state and task definition. We perform this analysis on a representative subset of ANDROIDWORLD tasks that span different interaction patterns and complexity levels (listed in Appendix E.4). Due to computational constraints, we conduct 20 trials for each task using our strongest agent configuration - M3A using the accessibility tree and GPT-4.

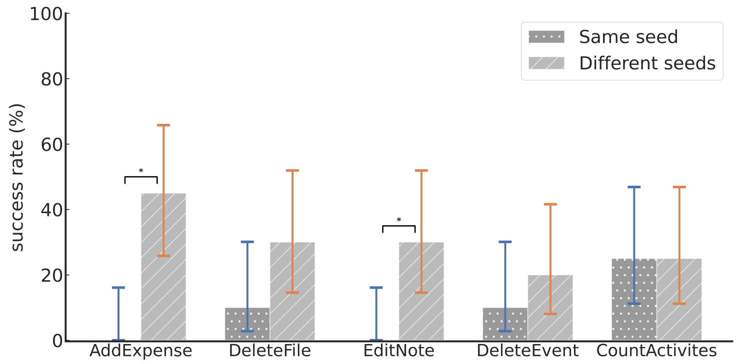

Figure 3: Success rate variation across tasks due to the parametrization built into ANDROIDWORLD. Using a fixed seed, the agent appears completely incapable of solving some tasks due to "bad luck" with the seed. In contrast, under different task parameterizations, we observe the agent can solve the tasks fairly often. Wilson binomial proportion confidence intervals (95%) are shown for the different seed group (orange) and the same seed group (blue). The different seed group has higher variance than the same seed group. Significant differences, with p-value $<$ 0.05, are indicated by "*".

Figure 3 shows our results. With a constant seed, the agent fails on add and edit tasks and rarely solves delete tasks, primarily due to UI operation challenges. Surprisingly, performance varies even with a fixed seed, suggesting model non-determinism affects reliability. Performance varies significantly more with different seeds, with statistically significant differences for add expense and edit note tasks. The high intra-task variation indicates the model's sensitivity to task parameters. Section E.5 provides an analysis on how specific parameter variations impact agent performance.

This sensitivity aligns with observations in RL research (Henderson et al., 2018; Raffin et al., 2021; Colas et al., 2018), suggesting performance is best represented by the mean across seeds. We believe ANDROIDWORLD's support for such analysis will become increasingly valuable as more efficient models are developed. Finally, we note the observation of non-zero rewards under some seeds points to potential enhancements through RL-like mechanisms in future work.

To assess AndroidWorld's robustness to OS variations, we tested on a Pixel 5 (Android 12) alongside our primary setup (Pixel 6, Android 13). The agent achieved a 28.4% success rate, with performance variations akin to those from random seed changes, suggesting it maintained its capabilities despite differing UI layouts and device types.

These experiments underscore the importance of testing agents under varied conditions, a capability that ANDROIDWORLD effectively supports.

6 CONCLUSION

We introduced ANDROIDWORLD, a realistic and robust agent environment for Android that enables the development and evaluation of autonomous agents across a wide range of tasks and apps. ANDROIDWORLD provides a reproducible task suite consisting of 116 tasks across 20 apps, with each task dynamically generated using random parameters to challenge agents with millions of unique goals. By releasing ANDROIDWORLD and establishing benchmark performance with M3A, we aim to accelerate research and development in this area, ultimately leading to the creation of computer use agents capable of operating effectively in real-world environments. Further, the dynamic nature of ANDROIDWORLD opens up new research opportunities for online learning algorithms in computer use agents.

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APPENDIX A LIMITATIONS

ANDROIDWORLD currently supports open-source Android apps (>1M downloads) and built-in system apps. While testing on trending apps would be desirable, we found open-source apps often present harder challenges due to their less-optimized UIs. Popular apps typically offer more shortcuts and UI affordances, while open-source apps may require more complex interaction patterns. For example, in Figure 6c, the agent fails by repeatedly searching for a non-existent "delete-all" button instead of recognizing the need to delete notes individually.

APPENDIX B ETHICAL CONSIDERATIONS

Malicious use There is a risk that malicious actors could engineer agents to bypass security measures like CAPTCHAs or engage in activities like spamming. Additionally, they could alter prompts or screen outputs to further harmful objectives.

Societal impact Automation agents may transform societal norms, disrupt employment, and modify human behavior. While they can enhance efficiency, this improvement could pose risks if exploited by malevolent forces.

APPENDIX C ANDROIDWORLD ENVIRONMENT

C.1 OBSERVATION SPACE

In ANDROIDWORLD, the Android screen is represented using a `State` class, which includes the following attributes:

- **Pixels**: An RGB array representing the current screen capture of the device. The screenshot resolution is $2400 \times 1080 \times 3$.
- **Accessibility tree**: A raw representation of the accessibility tree.[6] This UI tree provides a detailed snapshot of all UI elements currently displayed on the screen. We utilize an accessibility forwarding app from AndroidEnv (Toyama et al., 2021), which leverages gRPC to transmit the accessibility tree data efficiently to the device.
- **UI elements**: A list of processed UI elements extracted from the children of the accessibility tree. Each `UIElement` contains attributes such as text, content description, bounding boxes, and various state flags (e.g., clickable, scrollable, focused).

Since Android observations and actions are asynchronous, changes resulting from actions may take some time to manifest. Therefore, instead of using an RL-based interface, which assumes a tight coupling between actions and observations, we design an interface for the agent tailored for asynchronous interaction. This interface implements a `get_state` method responsible for capturing the current state of the environment, typically after executing an action. This method includes an optional `wait_to_stabilize` flag, which, when enabled, employs heuristics to ensure the UI elements are not in a transient state, thus providing a stable and accurate snapshot of the environment.

[6] Represented using all current windows; `https://developer.android.com/reference/android/view/accessibility/AccessibilityWindowInfo`

C.2 ACTION SPACE

Actions are stored using a Python dataclass and executed using `adb`. The action space includes:

- Direct UI Actions:
  - Click-based actions (click, long press): Simulates touch events at specified coordinates
  - Text input: Simulates typing in focused text fields
  - Navigation: Sends home/back key events
  - Scrolling: Executes swipes in four directions (up, down, left, right)
  - App launching: Starts specified applications
- Task Management Actions:
  - Status: Reports if task is in-progress, complete, or infeasible
  - Answer: Provides responses, which are needed for information retrieval tasks
- System Actions:
  - Wait: No-op useful for loading screens and UI transitions
  - Unknown: No-op for handling internal errors

```
ACTION_TYPES = {
    # UI Manipulation
    "CLICK": "click",
    "SCROLL": "scroll",
    "INPUT_TEXT": "input_text",
    "NAVIGATE_HOME": "navigate_home",
    "NAVIGATE_BACK": "navigate_back",
    "KEYBOARD_ENTER": "keyboard_enter",
    "OPEN_APP": "open_app",
    "LONG_PRESS": "long_press",

    # Control Flow
    "STATUS": "status",     # Reports task completion state
    "WAIT": "wait",        # Handles UI transitions
    "ANSWER": "answer",    # For information retrieval tasks
    "UNKNOWN": "unknown"   # No-op for internal errors
}

@dataclasses.dataclass()
class JSONAction:
  """Represents a parsed JSON action.

  # Example
  result_json = {'action_type': 'click', 'x': %d, 'y': %d}
  action = JSONAction(**result_json)

  Attributes:
    action_type: The action type.
    index: The index to click, if action is a click. Either an index or a <x, y>
      should be provided. See x, y attributes below.
    x: The x position to click, if the action is a click.
    y: The y position to click, if the action is a click.
    text: The text to type, if action is type.
    direction: The direction to scroll, if action is scroll.
    goal_status: If the status is a 'status' type, indicates the status of the goal.
    app_name: The app name to launch, if the action type is 'open_app'.
  """
  action_type: str
  index: int = None
  x: int = None
  y: int = None
  text: str = None
  direction: str = None
  goal_status: str = None
  app_name: str = None
```

Listing 1: Pseudo-code representation of the action space.

In addition to the UI-based action space described above, AndroidWorld provides a set of high-level APIs for direct device interaction (i.e., sending SMS messages, opening web pages, managing contacts). While the core action space focuses on fundamental UI control capabilities, these supplementary APIs found in `env/tools.py` enable future research into hybrid interaction approaches that combine both UI-based and programmatic device control.

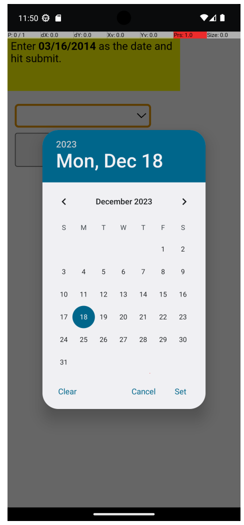


Figure 4: Native Android UI widget rendering for HTML5 <input> element.

C.3 MOBILEMINIWOB++

Authors manually completed all tasks in MobileMiniWoB++, implemented as a WebView app, to verify solvability on a mobile interface. MobileMiniWoB++ differs from MiniWoB++ due to the touch-based interface, which required different approaches for certain tasks. For instance, highlighting text from the `highlight-text` tasks involves using Android's long-press and cursor-moving functionalities. HTML5 <input> elements are natively rendered with native Android UI widgets like the date-picker (see Figure 4).

Our implementation of MiniWoB++ contains 92 tasks in total. We exclude the following tasks: `chase-circle` (requires near-realtime movement, unachievable by humans on emulators), `moving-items` (too hard to click in emulator), `drag-cube` (drags will scroll the screen, moving the task out of view), `drag-items-grid` (elements are not interactable on Android), `drag-items` (elements are not interactable on Android), `drag-shapes` (drags will scroll the screen, moving the task out of view), `drag-sort-numbers` (elements are not interactable on Android), `text-editor` (cannot underline everything, weird glitch), `number-checkboxes` (not correctly rendered: only three columns), `use-slider-2` (slider implementation not working), `use-spinner` (slider implementation not working), and `click-menu` (the menu responsiveness breaks and the task does not behave as intended).

APPENDIX D ANDROIDWORLD BENCHMARK DETAILS

D.1 APP SELECTION

Our selection of apps (summarized in Table 4) was guided by three main factors: use case, popularity, and the need for consistency and reproducibility.

Use case and categories We analyzed popular app categories in app stores, focusing on productivity, communication, and multimedia. Selected apps had to meet criteria such as not requiring a login and storing data locally on the device. Additionally, we considered apps from categories that the authors commonly used, ensuring the selection was representative of real-world Android usage.

Popularity We used download statistics from the Google Play Store to gauge app popularity, selecting apps with over 1 million downloads. Most of the selected apps exceeded this threshold. Less popular apps were also included if they featured common UI patterns and affordances, ensuring they are indicative of typical Android app usage. For instance, Simple Calendar Pro, though less downloaded, has a UI comparable to the widely-used Google Calendar app.

Table 4: List of ANDROIDWORLD apps and number of tasks for each one.

App name	Description	# tasks
Simple Calendar Pro	A calendar app for creating, deleting, and managing events and appointments.	17
Settings	The Android system settings app for managing device settings such as Bluetooth, Wi-Fi, and brightness.	15
Markor	A note-taking app for creating, editing, deleting, and managing notes and folders.	14
Broccoli - Recipe App	A recipe management app for adding, deleting, and organizing recipes.	13
Pro Expense	An expense tracking app for adding, deleting, and managing expenses.	9
Simple SMS Messenger	An SMS app for sending, replying to, and resending text messages.	7
OpenTracks	A sport tracking app for recording and analyzing activities, durations, and distances.	6
Tasks	A task management app for tracking tasks, due dates, and priorities.	6
Clock	An app with stopwatch and timer functionality.	4
Joplin	A note-taking app.	4
Retro Music	A music player app.	4
Simple Gallery Pro	An app for viewing images.	4
Camera	An app for taking photos and videos.	3
Chrome	A web browser app.	3
Contacts	An app for managing contact information.	3
OsmAnd	A maps and navigation app with support for adding location markers, favorites, and saving tracks.	3
VLC	A media player app for playing media files.	3
Audio Recorder	An app for recording and saving audio clips.	2
Files	A file manager app for the Android filesystem, used for deleting and moving files.	2
Simple Draw Pro	A drawing app for creating and saving drawings.	1

Consistency and reproducibility All apps were sourced from F-Droid, an open-source Android app repository. This allowed us to manage app versions precisely by selecting and distributing specific APKs. We use the newest version of each app at the time of download.

D.2 TASK CLASSIFICATION AND GENERATION

We categorize tasks into two types: those with side-effects and those without. Tasks with side-effects are those that modify the internal state of the device or applications, such as turning off Wi-Fi or creating a calendar event. These tasks are implemented as distinct Python classes, each with its own parameter generation, initialization, evaluation, and teardown methods.

Below we show an example of the task evaluation for a `SendSms` task, which involves sending and validating a text message. The pseudocode illustrates the task initialization, success check, and parameter generation methods. Each task has its own random parameter generation method and success logic.

```python
class SendSms(TaskEval):
  """Task sending and validating a text message has been sent.

  It checks the SMS telephony database, which is located at:
  /data/data/com.android.providers.telephony/databases/mmssms.db."""

  template = (
      "Send a text message using Simple SMS Messenger to "
      "{number} with message: {message}"
  )

  def initialize_task(self, env: interface.AsyncEnv) -> None:
    """Sets up the initial state of the task."""
    super().initialize_task(env)
    clear_sms_database(env.base_env)

  def is_successful(self, env: interface.AsyncEnv) -> float:
    """Checks if the SMS was sent successfully."""
    super().is_successful(env)
    messages = get_messages(env.base_env)
    return check_message_exists(
        phone_number=self.params["number"],
        body=self.params["message"],
    )
```

```python

  def teardown(self, env: interface.AsyncEnv) -> None:
    """Clears the SMS database."""
    super().teardown(env)
    clear_sms_database(env.base_env)

  @classmethod
  def generate_random_params(cls) -> dict[str, Any]:
    number = generate_random_number()
    message = generate_random_message()
    return {
        "number": number,
        "message": message,
    }
```

D.3 INFORMATION RETRIEVAL TASKS

Tasks without side-effects are Information Retrieval tasks, requiring the agent to answer a question based on the device or app's current state. For these tasks, instead of a Python class, we create a protobuf structure to specify the prompt, parameter values, and initialization and validation logic. We decided to use a structured data format with the belief that it would allow us to define new information retrieval tasks by simply adding new entries, making it easier to scale up the number of tasks without needing to write and maintain Python classes for each one.

Initialization is defined per app, including only the state relevant to the prompt's answer and exclusion conditions for generating random states. This ensures that no random state contains information that could alter the expected answer. The initial state and prompt are parameterized using random values from the specified task parameters. For validation, we define the expected answer format within the prompt and use a few supported functions ("count", "sum", "identity") to generate the answer from the initial state.

Once an app and its specific logic are programmed, new tasks can be generated using an LLM to generate the task's protobuf. The process is not automatic and requires human review. Common issues with LLM-generated tasks include missing fields, hallucinated fields, incompatible parameter generation, insufficient parameter usage, and non-specific task prompts. We observed that the complexity of the proto structure correlates with an increase in generated task issues. Despite these challenges, we found that editing LLM-generated protobufs can be more efficient than writing a complete task from scratch.

Below we show a simplified version of the task definition for the `SimpleCalendarEventsOnDate` task which involves checking which events are on a certain date. It specifies the relevant event, the exclusion conditions for any noisy event, how to determine success, and possible parameter values to be chosen at random that will be used to fill out the task definition.

```
tasks {
  name: "SimpleCalendarEventsOnDate"
  prompt: "What events do I have {date} in Simple Calendar Pro? Answer with the titles only. If there are
     multiple titles, format your answer as a comma separated list."
  complexity: 1
  relevant_state {
    // Defines information for the goal events.
    state: {
      calendar {
        events {
          start_date: "{date}"
          start_time: "{time}"
          duration: "{duration}"
          title: "{title}"
        }
      }
    }
    // Non-goal events.
    exclusion_conditions {
      field: "start_date"
      operation: EQUAL_TO
      value: "{date}"
    }
  }
  success_criteria {
    expectations {
      field_transformation {
        operation: IDENTITY
        field_name: "title"
      }
      match_type: STRING_MATCH
```

```
    }
  }

  task_params {
    name: "time"
    possible_values: "11:00am"
    // ...
  }

  task_params {
    name: "date"
    possible_values: "October 15 2023"
    //...
  }
  task_params {
    name: "duration"
    possible_values: "30 m"
    // ...
  }
  task_params {
    name: "title"
    possible_values: "Data Dive"
    // ...
  }
}
```

D.4 Humans for task analysis

During development, we recruited six volunteers with proficient programming skills to analyze task difficulty, duration, and category. Each human was assigned an equal portion of tasks and tasked with identifying bugs during this annotation phase. This process resulted in the discovery and resolution of over 30 bugs.

To evaluate human performance, we enlisted two software engineers to complete the tasks using an Android emulator. Participants were provided with task descriptions and attempted to achieve the goals based on their interpretations. Each participant had one attempt per task. The majority of errors stemmed from misinterpretations or minor errors, such as entering an incorrect file extension. Other errors occurred when participants encountered unfamiliar user interfaces, impeding their ability to solve the tasks on their first attempt.

In both exercises, we informed participants about the intended use of the collected data. Participants were not required to enter any personal information in the tested tasks.

D.5 Task examples

Table 5 lists some additional examples of tasks and highlights which task attributes can be parameterized in unlimited ways.

Appendix E AndroidWorld agent details

E.1 M3A observations

AndroidWorld consumes the raw screen pixels, the screen shot with Set-of-Mark (SoM) (Yang et al., 2023a) annotations, and a list of UI elements on screen.

```
Here is a list of descriptions for some UI elements on the current screen:

UIelement0: UIElement(text="VLC", content_description=None, class_name="android.widget.EditText",
bbox_pixels=BoundingBox(x_min=98, x_max=886, y_min=146, y_max=311), ...)
UIelement1: UIElement(text=None, content_description="Clear search box", class_name="android.widget.
      ImageButton",
bbox_pixels=BoundingBox(x_min=886, x_max=1023, y_min=160, y_max=297), ...)
UIelement2: UIElement(text="15:11", content_description="15:11", class_name="android.widget.TextView",
bbox_pixels=BoundingBox(x_min=50, x_max=148, y_min=1, y_max=128), ...)
... More elements listed ...

... Guidelines on action selection emitted ...

Now output an action from the above list in the correct JSON format, following the reason why you do that.
      Your answer should look like:

Reason: ...
Action: {"action_type":...}
```

Listing 2: The prompt format pertaining to screen representation with UI elements.

Table 5: Examples of ANDROIDWORLD tasks. We list the task nickname, the task template indicating which task attributes can be parameterized, the initialization logic that is executed before the task starts and pseudo code describing the success evaluation.

Task nickname	Task template	Initialization logic	Success evaluation code
VlcCreatePlaylist	Create a playlist in VLC, titled "{playlist_name}" with the following files, in order: {files}	Create new mpeg files: files + "noise" files that should not be added. Add them to VLC videos folder.	`execute_sql(vlc_query) == files`
RecipeAddMultiple RecipesFromImage	Add the recipes from recipes.jpg in Simple Gallery Pro to the recipe app.	Write a receipt file with recipes to Simple Gallery.	`sql_rows_exist(expected_recipes)`
MarkorEditNote	Edit {file_name} in Markor. {file_operation}.	Generate file with starting content, along with "noise" files not relevant to goal. *Note:* `file_operation` *can be to add a footer, header, or update note content.*	`file_exists(file_name, content=expected_content)`
ExpenseAddSingle	Add the following expenses into pro expense: {expense_csv}	Add to the app's SQLite database the expense that should be deleted, along with "noise" expenses that should not be deleted.	`sql_rows_exist(expense_obj)`
SimpleCalendarDelete EventsOnRelativeDay	In Simple Calendar Pro, delete all events scheduled for this {day_of_week}.	add to the app's SQLite database calendar events on specified day, along with "noise" events that should not be deleted.	`!sql_rows_exist(expected_events)`
FilesDeleteFile	Delete the file {file_name} from the Android filesystem located in the {subfolder} folder within the sdk_gphone_x86_64 storage area.	Generate specified file, along with "noise" files that should not be deleted.	`!file_exists(file_name)`
SportsTrackerActivities CountForWeek	How many {category} activities did I do this week in the OpenTracks app? Express your answer as a single integer.	add to the app's SQLite database activities for the specified category, along with "noise" activities.	`int(agent_response) == expected_count`

E.2 M3A ACTIONS

For the SoM prompting, the screen is annotated based on the UI elements extracted from the accessibility tree, which form the agent's action space. Figure 5 shows one example.

E.3 ERROR ANALYSIS

We analyze M3A errors based on broader categories we observe during evaluation.

Perceptual errors Perceptual errors are caused when the model fails to recognize crucial elements on the screen necessary for task completion.

For the task below, the model does not recognize that the "All-day" checkbox is currently not checked (see Figure 6a):

> *In Simple Calendar Pro, create a recurring calendar event titled 'Review session for Budget Planning' starting on 2023-10-15 at 14h. The event recurs weekly, forever, and lasts for 60 minutes each occurrence. The event description should be 'We will understand software updates. Remember to confirm attendance.'*

Reasoning errors Reasoning errors occur when the model misinterprets the task requirements or the current state, leading to incorrect actions.

For example, in the task below, the model mistakenly believes the note name has already been entered, so it types the note text into the "Name" field and cannot recover from this error (see Figure 6b):

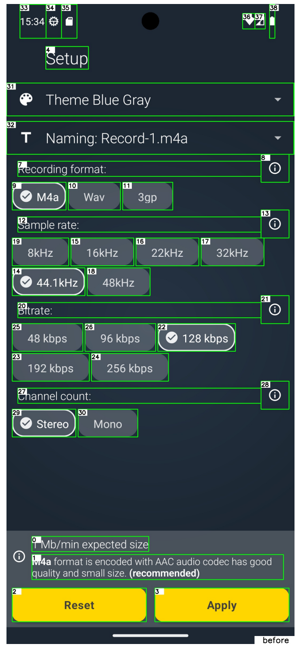
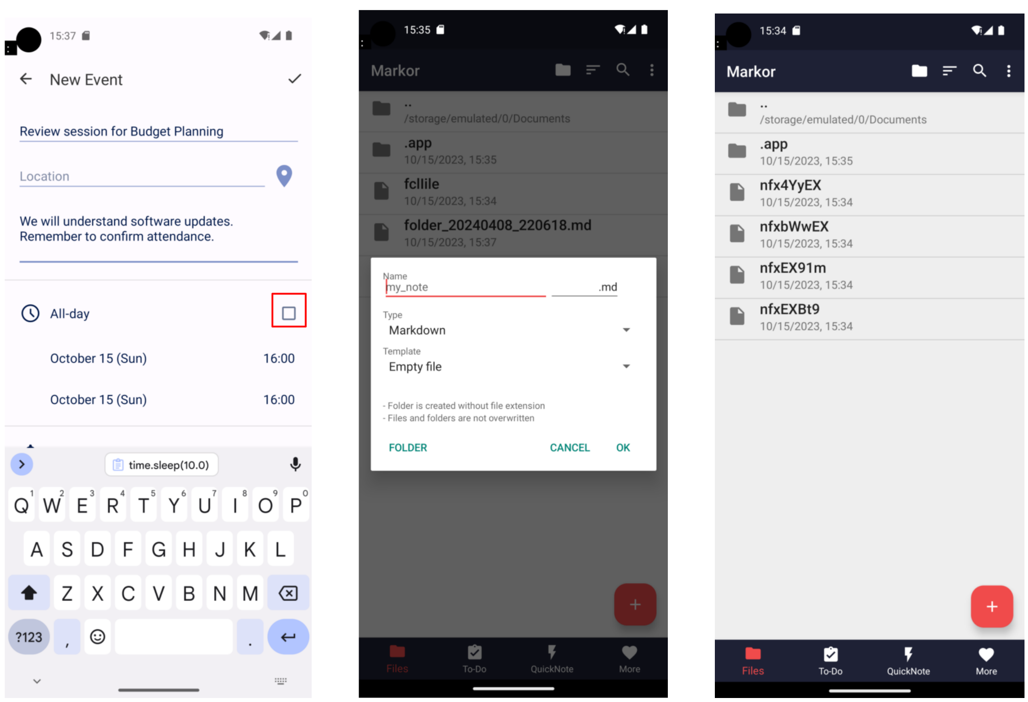


Figure 5: Set-of-marks overlaid on an Android screen.



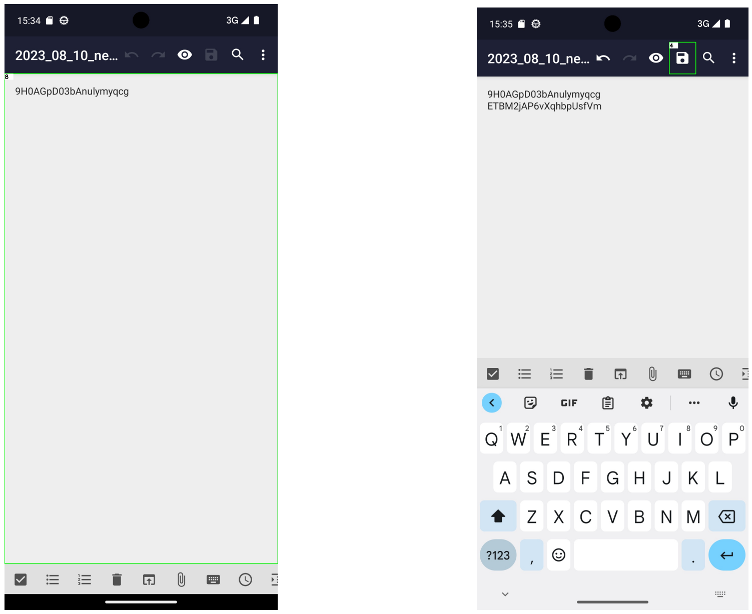
(a) Perceptual error. Red square highlights issue.

(b) Reasoning error. The agent's next action is to start entering the note's contents, which is incorrect because it needs to enter the note's name first.

(c) Missing knowledge error. To delete all notes, the agent mistakenly looks for an option to delete all the notes at once, rather than trying to do it note-by-note.

Figure 6: Screens illustrating perceptual, reasoning and missing knowledge errors.

Create a new note in Markor named ipsum_mNcKd36pDq.txt with the following text: ...



(a) Error on initial click. (b) Error with text entered and saving.

Figure 7: Screens illustrating grounding errors.

Here is the agent's reasoning trace:

> *The user wants to create a new note with a specific name and text. The name of the note has already been entered, so all that needs to be done is to enter the text and click on the OK button.*

Missing knowledge errors Missing knowledge errors occur when the model lacks the necessary understanding of the application's UI to complete a task efficiently.

For example, in the task below, the agent does not know how to delete all files at once. It looks for an option to do that instead of deleting each file one by one (see Figure 6c):

> *Delete all files in the current directory.*

Grounding errors Grounding errors occur when the model fails to correctly interact with the UI elements based on their spatial or contextual positioning.

For the task below, the agent needs to update the Markor note by prepending text to the existing text. Figure 7 illustrates the errors the agent makes. It clicks the entire text field area, highlighted in green, which automatically places the cursor after the current text, resulting in the new text being appended after the current content.

> *Update the Markor note '2023_08_10_neat_wolf.txt' by adding the following text, along with a new blank line before the existing content: "ETBM2jAP6vXqhbpUsfVm", and rename it to 'sure_ocean_uRnI.txt'.*

Then, in the next screen, the text has been entered after the existing content, and the agent clicks the save button.

E.4 Agent robustness experiments

We ran the agent on the following tasks (the nicknames shown in the figures in parentheses):

- `MarkorEditNote` (EditNote)

- `ExpenseAddSingle` (AddExpense)
- `SimpleCalendarDeleteEventsOnRelativeDay` (DeleteEvent)
- `FilesDeleteFile` (DeleteFile)
- `SportsTrackerActivitiesCountForWeek` (CountActivities)

More details about these tasks can be found in Table 5.

E.5 AGENT STRUGGLES DUE TO TASK PARAMETERIZATION

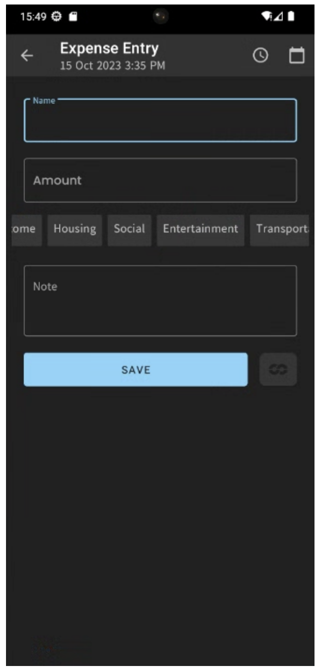


Figure 8: The expense entry interface features a horizontally scrollable category selector. When certain parameterization seeds require selecting categories that are not initially visible (e.g., "Food""), the agent fails to discover the scrolling interaction required to access them.

The variance in success rates (Figure 3) across different seeds demonstrates how task parameterization fundamentally changes task difficulty. For instance, in the `ExpenseAddSingle` task, the seed determines which expense category must be selected (see UI in Figure 8). When the seed specifies readily on-screen visible categories (e.g., "Housing", "Social"), the agent can complete the task. However, when the seed requires categories that are only accessible via horizontal scrolling (e.g., "Food", "Other"), the agent consistently fails due to its inability to discover and execute this UI interaction pattern.

Similarly, the `MarkorEditNote` task's difficulty varies based on the seed-determined variant: adding text to the top of a note, adding text to the bottom, or replacing existing text. The "replace" variant requires a more complex sequence of UI interactions (long-press, text selection, deletion, then text entry) compared to the simpler "header" variant. This explains both the complete failure under fixed seeds that happen to select challenging variants, and the higher but variable success rates when using different seeds that allow the agent to encounter various task parameterizations.

E.6 SEEACT DETAILS

We modify the SeeAct prompt (Zheng et al., 2024a) to reflect that the environment is Android by inputting elements from the accessibility tree and supporting additional actions (e.g., scrolling). Below we include the updated prompt. We annotate the system, user, and assistant roles that are each provided to the OpenAI API.

```

> Role: SYSTEM
Imagine that you are imitating humans operating an Android device for a task step by step. At each stage, you can see the Android screen like humans by a screenshot and know the previous actions before the current step decided by yourself through recorded history. You need to decide on the first following action to take. You can tap on an element, long-press an element, swipe, input text, open an app, or use the keyboard enter, home, or back key. (For your understanding, they are like 'adb shell input tap', 'adb shell input swipe', 'adb shell input text', 'adb shell am start -n', and 'adb shell input keyevent'). One next step means one operation within these actions. Unlike humans, for typing (e.g., in text areas, text boxes), you should try directly typing the input or selecting the choice, bypassing the need for an initial click. You should not attempt to create accounts, log in or do the final submission. Terminate when you deem the task complete or if it requires potentially harmful actions.

> Role: USER
You are asked to complete the following task: <GOAL>

Previous Actions:
<PREVIOUS ACTIONS>

The screenshot below shows the Android screen you see. Follow the following guidance to think step by step before outlining the next action step at the current stage:

(Current Screen Identification)
Firstly, think about what the current screen is.

(Previous Action Analysis)
Secondly, combined with the screenshot, analyze each step of the previous action history and their intention one by one. Particularly, pay more attention to the last step, which may be more related to what you should do now as the next step. Specifically, if the last action involved a INPUT TEXT, always evaluate whether it necessitates a confirmation step, because typically a single INPUT TEXT action does not make effect. (often, simply pressing 'Enter', assuming the default element involved in the last action, unless other clear elements are present for operation).

(Screenshot Details Analysis)
Closely examine the screenshot to check the status of every part of the screen to understand what you can operate with and what has been set or completed. You should closely examine the screenshot details to see what steps have been completed by previous actions even though you are given the textual previous actions. Because the textual history may not clearly and sufficiently record some effects of previous actions, you should closely evaluate the status of every part of the screen to understand what you have done.

(Next Action Based on Android screen and Analysis)
Then, based on your analysis, in conjunction with human phone operation habits and the logic of app design, decide on the following action. And clearly outline which element on the Android screen users will operate with as the first next target element, its detailed location, and the corresponding operation.

To be successful, it is important to follow the following rules:
1. You should only issue a valid action given the current observation.
2. You should only issue one action at a time
3. For handling the select dropdown elements on a screen, it's not necessary for you to provide completely accurate options right now. The full list of options for these elements will be supplied later.

> Role: ASSISTANT
<AGENT RESPONSE TO ABOVE>

> Role: USER
(Reiteration)
First, reiterate your next target element, its detailed location, and the corresponding operation.

(Multichoice Question)
Below is a multi-choice question, where the choices are elements on the screen. All elements are arranged in the order based on their height on the screen, from top to bottom (and from left to right). This arrangement can be used to locate them. From the screenshot, find out where and what each one is on the screen, taking into account both their text content and details. Then, determine whether one matches your target element. Please examine the choices one by one. Choose the matching one. If multiple options match your answer, choose the most likely one by re-examining the screenshot, the choices, and your further reasoning. If you would like to perform a swipe action, you can optionally select the choice where you will swipe.

A. "Home" icon
B. "Phone" icon
C. "Messages" icon
D. "Chrome" icon
E. "Search" icon
...
If none of these elements match your target element, please select Z. None of the other options match the correct element.

(Final Answer)
Finally, conclude your answer using the format below. Ensure your answer is strictly adhering to the format provided below. Please do not leave any explanation in your answers of the final standardized format part, and this final part should be clear and certain. The element choice, action, and value should be in three separate lines.

Format:

ELEMENT: The uppercase letter of your choice. (No need for TERMINATE, KEYBOARD ENTER, WAIT, ANSWER, OPEN APP, NAVIGATE HOME, NAVIGATE BACK; and optional for SWIPE.)

ACTION: Choose an action from {CLICK, INPUT TEXT, LONG PRESS, NAVIGATE BACK, TERMINATE, KEYBOARD ENTER, SWIPE, WAIT, ANSWER, OPEN APP, NAVIGATE HOME}.

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VALUE: Provide additional input based on ACTION.

The VALUE means:
If ACTION == INPUT TEXT, specify the text to be typed.
If ACTION == SWIPE, specify the direction: up, down, left, right.
If ACTION == OPEN APP, provide the name of the app to be opened.
If ACTION == ANSWER, specify the text of your answer to respond directly to a question or request for
      information.
For CLICK, LONG PRESS, KEYBOARD ENTER, NAVIGATE HOME, NAVIGATE BACK, WAIT, and TERMINATE, write "None".
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APPENDIX F ANDROIDWORLD TASK LIST

The table below lists all tasks in ANDROIDWORLD. The maximum number of steps per task ("S") were determined based on human performance analysis, allowing agents approximately twice the number of steps typically required by human annotators to complete each task while preventing infinite loops.

Task completion tasks (e.g., send a message or edit a note) are abbreviated as "TC" and information retrieval tasks are abbreviated as "IR".

Name	**Template**	**Task type**	**Validation method**	**S**	**Apps**
Audio Recorder Record Audio	Record an audio clip using Audio Recorder app and save it.	TC	Filesystem	12	audio recorder
Audio Recorder Record Audio With File Name	Record an audio clip and save it with name "{file_name}" using Audio Recorder app.	TC	Filesystem	20	audio recorder
Browser Draw	Open the file task.html in Downloads in the file manager; when prompted open it with Chrome. Then create a drawing using the three colors shown at the top and hit submit.	TC	UI-elements	20	files, chrome
Browser Maze	Open the file task.html in Downloads in the file manager; when prompted open it with Chrome. Then navigate the X to the bottom-right cell, by using the direction buttons.	TC	UI-elements	20	files, chrome
Browser Multiply	Open the file task.html in Downloads in the file manager; when prompted open it with Chrome. Then click the button 5 times, remember the numbers displayed, and enter their product in the form.	TC	UI-elements	22	files, chrome
Camera Take Photo	Take one photo.	TC	Filesystem	10	camera
Camera Take Video	Take one video.	TC	Filesystem	10	camera
Clock Stop Watch Paused Verify	Pause the stopwatch.	TC	UI-elements	10	clock
Clock Stop Watch Running	Run the stopwatch.	TC	UI-elements	10	clock
Clock Timer Entry	Create a timer with {hours} hours, {minutes} minutes, and {seconds} seconds. Do not start the timer.	TC	UI-elements	10	clock
Contacts Add Contact	Create a new contact for {name}. Their number is {number}.	TC	Database query	12	contacts

Name	Template	Task type	Validation method	S	Apps
Contacts New Contact Draft	Go to the new contact screen and enter the following details: First Name: {first}, Last Name: {last}, Phone: {phone}, Phone Label: {phone_label}. Do NOT hit save.	TC	UI-elements	12	contacts
Expense Add Multiple	Add the following expenses into the pro expense: {expense_list}	TC	Database query	40	expense
Expense Add Multiple From Gallery	Add the expenses from expenses.jpg in Simple gallery to pro expense.	TC	Database query	20	gallery, expense
Expense Add Multiple From Markor	Go through the transactions in my_expenses.txt in Markor. Log the reimbursable transactions in the pro expense.	TC	Database query	30	markor, expense
Expense Add Single	Add the following expenses into the pro expense: {expense_info}	TC	Database query	12	expense
Expense Delete Duplicates	Delete all but one of any expenses in pro expense that are exact duplicates, ensuring at least one instance of each unique expense remains.	TC	Database query	12	expense
Expense Delete Duplicates2	Delete all but one of any expenses in pro expense that are exact duplicates, ensuring at least one instance of each unique expense remains.	TC	Database query	18	expense
Expense Delete Multiple	Delete the following expenses from pro expense: {expense_list}.	TC	Database query	20	expense
Expense Delete Multiple2	Delete the following expenses from pro expense: {expense_list}.	TC	Database query	34	expense
Expense Delete Single	Delete the following expenses from pro expense: {expense_name}.	TC	Database query	10	expense
Files Delete File	Delete the file {file_name} from the Android filesystem located in the {subfolder} folder within the sdk_gphone_x86_64 storage area.	TC	Filesystem	10	files
Files Move File	Move the file {file_name} from {source_folder} within the sdk_gphone_x86_64 storage area to the {destination_folder} within the same sdk_gphone_x86_64 storage area in the Android filesystem.	TC	Filesystem	20	files
Markor Add Note Header	Update the Markor note {file_name} by adding the following text, along with a new blank line before the existing content: "{header}".	TC	Filesystem	12	markor
Markor Change Note Content	Update the content of {file_name} to "{updated_content}" in Markor.	TC	Filesystem	12	markor
Markor Create Folder	Create a new folder in Markor named {folder_name}.	TC	Filesystem	10	markor
Markor Create Note	Create a new note in Markor named {file_name} with the following text: {text}	TC	Filesystem	16	markor

Name	Template	Task type	Validation method	S	Apps
Markor Create Note And Sms	Create a new note in Markor named {file_name} with the following text: {text}. Share the entire content of the note with the phone number {number} via SMS using Simple SMS Messenger	TC	Filesystem, database query	18	markor, sms
Markor Create Note From Clipboard	Create a note in Markor named {file_name}. Perform a paste operation in the note and save the note.	TC	Filesystem	14	markor
Markor Delete All Notes	Delete all my notes in Markor.	TC	Filesystem	14	markor
Markor Delete Newest Note	Delete the newest note in Markor.	TC	Filesystem	10	markor
Markor Delete Note	Delete the note in Markor named {file_name}.	TC	Filesystem	10	markor
Markor Edit Note	Edit {file_name} in Markor. {edit_subcommand}	TC	Filesystem	12	markor
Markor Merge Notes	Merge the contents of Markor notes {file1_name}, {file2_name} and {file3_name} (in the same order) into a new Markor note named {new_file_name} and save it. Add a new line between the content of each note.	TC	Filesystem	78	markor
Markor Move Note	In Markor, move the note {file_name} from {source_folder} to {destination_folder}.	TC	Filesystem	14	markor
Markor Transcribe Receipt	Create a file in Markor, called receipt.md with the transactions from the receipt.png. Use Simple Gallery to view the receipt. Please enter transactions in csv format including the header ”Date, Item, Amount”.	TC	Filesystem	18	gallery, markor
Markor Transcribe Video	Transcribe the contents of video {video_name} by watching it in VLC player (located in Download) and writing the sequence of strings shown on each frame to the text file {file_name} in Markor as a comma separated list. For example, if the first frame shows the text ”edna” and the second frame shows the text ”pineapple”, then the text file should contains only the following text: ”edna, pineapple”.	TC	Filesystem	20	markor, vlc
Notes Is Todo	Is the note titled ’{title}’ in the Joplin app marked as a todo item? Respond with either ’True’ if it is a todo or ’False’ if not.	IR	String match	10	joplin
Notes Meeting Attendee Count	How many attendees were present in the meeting titled ’{title}’ in the Joplin app? Express your answer as just a single number.	IR	String match	10	joplin

Name	Template	Task type	Validation method	S	Apps
Notes Recipe Ingredient Count	What quantity of {ingredient} do I need for the recipe '{title}' in the Joplin app? Express your answer in the format ⟨amount⟩ ⟨unit⟩ without using abbreviations.	IR	String match	10	joplin
Notes Todo Item Count	How many to-dos do I have in the '{folder}' folder in the Joplin app? Express your answer as just a single number.	IR	String match	10	joplin
Open App Task Eval	Open the {app_name} app. Clear any pop-ups that may appear by granting all permissions that are required.	TC	System API	10	camera, clock, contacts, settings, dialer
Osm And Favorite	Add a favorite location marker for {location} in the OsmAnd maps app.	TC	Filesystem	13	osmand
Osm And Marker	Add a location marker for {location} in the OsmAnd maps app.	TC	Filesystem	20	osmand
Osm And Track	Save a track with waypoints Ruggell, Liechtenstein, Bendern, Liechtenstein in the OsmAnd maps app in the same order as listed.	TC	Filesystem	120	osmand
Recipe Add Multiple Recipes	Add the following recipes into the Broccoli app: {recipe_list}	TC	Database query	68	recipe
Recipe Add Multiple Recipes From Image	Add the recipes from recipes.jpg in Simple gallery to the Broccoli recipe app.	TC	Database query	26	markor, recipe
Recipe Add Multiple Recipes From Markor	Add the recipes from recipes.txt in Markor to the Broccoli recipe app.	TC	Database query	48	gallery, recipe
Recipe Add Multiple Recipes From Markor2	Add the recipes from recipes.txt in Markor that take 10 mins to prepare into the Broccoli recipe app.	TC	Database query	52	recipe
Recipe Add Single Recipe	Add the following recipes into the Broccoli app: {recipe_list}	TC	Database query	24	recipe
Recipe Delete Duplicate Recipes	Delete all but one of any recipes in the Broccoli app that are exact duplicates, ensuring at least one instance of each unique recipe remains	TC	Database query	10	recipe
Recipe Delete Duplicate Recipes2	Delete all but one of any recipes in the Broccoli app that are exact duplicates, ensuring at least one instance of each unique recipe remains	TC	Database query	24	recipe
Recipe Delete Duplicate Recipes3	Delete all but one of any recipes in the Broccoli app that are exact duplicates, ensuring at least one instance of each unique recipe remains	TC	Database query	34	recipe
Recipe Delete Multiple Recipes	Delete the following recipes from Broccoli app: {recipe_list}	TC	Database query	24	recipe

Name	Template	Task type	Validation method	S	Apps
Recipe Delete Multiple Recipes With Constraint	Delete the recipes from Broccoli app that use {ingredient} in the directions.	TC	Database query	40	recipe
Recipe Delete Multiple Recipes With Noise	Delete the following recipes from Broccoli app: {recipe_list}	TC	Database query	34	recipe
Recipe Delete Single Recipe	Delete the following recipes from Broccoli app: {recipe_list}	TC	Database query	10	recipe
Recipe Delete Single With Recipe With Noise	Delete the following recipes from Broccoli app: {recipe_list}	TC	Database query	20	recipe
Retro Create Playlist	Create a playlist in Retro Music titled "{title}" with the following songs, in order: {song_list}	TC	Database query	24	music
Retro Playing Queue	Add the following songs, in order, {song_list} to my playing queue in Retro music.	TC	Database query	32	music
Retro Playlist Duration	Create a playlist in Retro Music titled "{title}" with a duration between 45 and 50 minutes using the provided songs.	TC	Database query	30	music
Retro Save Playlist	Create a playlist in Retro Music titled "{title}" with the following songs, in order: {song_list}. Then export the playlist to the Downloads directory on the device.	TC	Database query	50	music
Save Copy Of Receipt Task Eval	Copy {file_name} in DCIM and save a copy with the same name in Download	TC	Filesystem	16	gallery
Simple Calendar Add One Event	In Simple calendar, create a calendar event on {year}-{month}-{day} at {hour}h with the title '{event_title}' and the description '{event_description}'. The event should last for {duration_mins} mins.	TC	Database query	34	calendar
Simple Calendar Add One Event In Two Weeks	In Simple calendar, create a calendar event in two weeks from today at {hour}h with the title '{event_title}' and the description '{event_description}'. The event should last for {duration_mins} mins.	TC	Database query	20	calendar
Simple Calendar Add One Event Relative Day	In Simple calendar, create a calendar event for this {day_of_week} at {hour}h with the title '{event_title}' and the description '{event_description}'. The event should last for {duration_mins} mins.	TC	Database query	34	calendar
Simple Calendar Add One Event Tomorrow	In Simple calendar, create a calendar event for tomorrow at {hour}h with the title '{event_title}' and the description '{event_description}'. The event should last for {duration_mins} mins.	TC	Database query	26	calendar

Name	Template	Task type	Validation method	S	Apps
Simple Calendar Add Repeating Event	In Simple calendar, create a recurring calendar event titled '{event_title}' starting on {year}-{month}-{day} at {hour}h. The event recurs {repeat_rule}, forever, and lasts for {duration_mins} minutes each occurrence. The event description should be '{event_description}'.	TC	Database query	28	calendar
Simple Calendar Any Events On Date	Do I have any events {date} in Simple calendar? Answer with the titles only. If there are multiples titles, format your answer in a comma separated list.	IR	Database query	10	calendar
Simple Calendar Delete Events	In Simple calendar, delete all the calendar events on {year}-{month}-{day}	TC	Database query	14	calendar
Simple Calendar Delete Events On Relative Day	In Simple calendar, delete all events scheduled for this {day_of_week}.	TC	Database query	12	calendar
Simple Calendar Delete One Event	In Simple calendar, delete the calendar event on {year}-{month}-{day} at {hour}h with the title '{event_title}'	TC	Database query	12	calendar
Simple Calendar Event On Date At Time	What is on my schedule for {date} at {time} in Simple calendar? Answer with the titles only. If there are multiples titles, format your answer in a comma separated list.	IR	Database query	10	calendar
Simple Calendar Events In Next Week	What events do I have in the next week in Simple calendar? Answer with the titles only. If there are multiples titles, format your answer in a comma separated list.	IR	Database query	10	calendar
Simple Calendar Events In Time Range	Do I have any events between {start_time} and 8pm {date} in Simple calendar? Answer with the titles only. If there are multiples titles, format your answer in a comma separated list.	IR	Database query	10	calendar
Simple Calendar Events On Date	What events do I have {date} in Simple calendar? Answer with the titles only. If there are multiple titles, format your answer as a comma separated list.	IR	Database query	10	calendar
Simple Calendar First Event After Start Time	What is my first event after {time} {date} in Simple calendar? Answer with the titles only. If there are multiples titles, format your answer in a comma separated list.	IR	Database query	10	calendar
Simple Calendar Location Of Event	What is the location of my {title} event in Simple calendar? Answer with the location only.	IR	Database query	10	calendar
Simple Calendar Next Event	What is my next upcoming event in Simple calendar? Answer with the title only. If there are multiples titles, format your answer in a comma separated list.	IR	Database query	10	calendar

Name	Template	Task type	Validation method	S	Apps
Simple Calendar Next Meeting With Person	When is my next meeting with {person} in Simple calendar? Express your answer in the format ⟨month name⟩ ⟨day⟩ ⟨year⟩ ⟨hour in 24-hour format⟩:⟨minutes⟩.	IR	Database query	10	calendar
Simple Draw Pro Create Drawing	Create a new drawing in Simple Draw Pro. Name it {file_name}. Save it in the Pictures folder within the sdk_gphone_x86_64 storage area.	TC	Filesystem	18	simpledrawpro
Simple Sms Reply	Reply to {number} with message: {message} in Simple SMS Messenger	TC	Database query	12	sms
Simple Sms Reply Most Recent	Reply to the most recent text message using Simple SMS Messenger with message: {message}	TC	Database query	12	sms
Simple Sms Resend	Resend the message I just sent to {name} in Simple SMS Messenger	TC	Database query	12	sms
Simple Sms Send	Send a text message using Simple SMS Messenger to {number} with message: {message}	TC	Database query	12	sms
Simple Sms Send Clipboard Content	Send a message to {number} with the clipboard content in Simple SMS Messenger	TC	Database query	12	sms
Simple Sms Send Received Address	Text the address of the event to {name1} that {name2} just sent me in Simple SMS Messenger	TC	Database query	18	sms
Sports Tracker Activities Count For Week	How many {category} activities did I do this week in the OpenTracks app? Express your answer as a single integer.	IR	String match	10	sportstracker
Sports Tracker Activities On Date	What activities did I do {date} in the OpenTracks app? Answer with the category only. If there are multiples categories, format your answer in a comma separated list.	IR	String match	20	sportstracker
Sports Tracker Activity Duration	How long was my {category} activity {date} in the OpenTracks app? Express your answer in minutes as a single integer.	IR	String match	12	sportstracker
Sports Tracker Longest Distance Activity	What was the longest distance covered in a {category} activity in the OpenTracks app this week? Express your answer in meters as a single integer.	IR	String match	10	sportstracker
Sports Tracker Total Distance For Category Over Interval	What was the total distance covered for {category} activities in the OpenTracks app from {start_date} to {end_date}? Express your answer in meters as a single integer.	IR	String match	22	sportstracker
Sports Tracker Total Duration For Category This Week	What was the total duration of {category} activities in the OpenTracks app this week? Express your answer in minutes as a single integer.	IR	String match	16	sportstracker
System Bluetooth Turn Off	Turn bluetooth off.	TC	System API	10	settings

Name	Template	Task type	Validation method	S	Apps
System Bluetooth Turn Off Verify	Turn bluetooth off.	TC	System API	10	settings
System Bluetooth Turn On	Turn bluetooth on.	TC	System API	10	settings
System Bluetooth Turn On Verify	Turn bluetooth on.	TC	System API	10	settings
System Brightness Max	Turn brightness to the max value.	TC	System API	10	settings
System Brightness Max Verify	Turn brightness to the max value.	TC	System API	10	settings
System Brightness Min	Turn brightness to the max value.	TC	System API	10	settings
System Brightness Min Verify	Turn brightness to the max value.	TC	System API	10	settings
System Copy To Clipboard	Copy the following text to the clipboard: {clipboard_content}	TC	System API	10	n/a
System Wifi Turn Off	Turn wifi off.	TC	System API	10	settings
System Wifi Turn Off Verify	Turn wifi off.	TC	System API	10	settings
System Wifi Turn On	Turn wifi on.	TC	System API	10	settings
System Wifi Turn On Verify	Turn wifi on.	TC	System API	10	settings
Tasks Completed Tasks For Date	Which tasks have I completed for {date} in Tasks app? Answer with the titles only. If there are multiples titles, format your answer in a comma separated list.	IR	String match	10	tasks
Tasks Due Next Week	How many tasks do I have due next week in Tasks app? Express your answer as a single integer.	IR	String match	12	tasks
Tasks Due On Date	What tasks do I have due {date} in Tasks app? Answer with the titles only. If there are multiples titles, format your answer in a comma separated list.	IR	String match	10	tasks
Tasks High Priority Tasks	What are my high priority tasks in Tasks app? Answer with the titles only. If there are multiples titles, format your answer in a comma separated list.	IR	String match	10	tasks
Tasks High Priority Tasks Due On Date	Which tasks with high priority are due {date} in the Tasks app? Answer with the title only. If there are multiples titles, format your answer in a comma separated list.	IR	String match	10	tasks
Tasks Incomplete Tasks On Date	What incomplete tasks do I have still have to do by {date} in Tasks app? Answer with the titles only. If there are multiples titles, format your answer in a comma separated list.	IR	String match	10	tasks

Name	**Template**	**Task type**	**Validation method**	**S**	**Apps**
Turn Off Wifi And Turn On Bluetooth	Turn off WiFi, then enable bluetooth	TC	String match	20	settings
Turn On Wifi And Open App	Turn on Wifi, then open the {app_name} app	TC	String match	20	settings
Vlc Create Playlist	Create a playlist titled {title}" with the following files in VLC (located in Internal Memory/VLCVideos), in order: {video_names}	TC	String match	28	vlc
Vlc Create Two Playlists	Create a playlist titled "{title1}" with the following files in VLC (located in Internal Memory/VLCVideos), in order: {video_names1}. And then, create a playlist titled "{title2}" with the following files in VLC, in order: {video_names2}.	TC	String match	48	vlc