

Artificial intelligence (AI) technologies are emerging and affecting our lives in many aspects. However, the majority of individuals are merely *users* of AI with little capability to adapt AI to their own heterogeneous needs. Most software developer also encounter significant barrier to developing AI-powered applications. **To address this gap, I design, build, and study new interactive systems to empower end-users and non-AI-expert developers to configure, extend, and create AI-powered applications.**

My work approaches AI system research from a human-centered perspective, where I design and build new AI systems and techniques based on the insights from my studies of the capabilities, contexts, preferences, and needs of different user groups. As a human-computer interaction (HCI) researcher with background in natural language processing (NLP) and end-user software engineering, I apply HCI design, user research, and evaluation methods in designing new interfaces and interaction techniques to make AI techniques more accessible and more useful for end users and developers, while at the same time, developing new AI techniques that enable novel interactions.

My interdisciplinary research agenda has resulted in contributions across premier venues in HCI, NLP, and system research (e.g., CHI, UIST, CSCW, ACL, MobiSys, VL/HCC). My research has produced 15 major peer-reviewed publications and book chapters, with 10 first-authored. My first-authored work has been awarded two Best Paper [3,6] and a Best Paper Honorable Mention [1] awards and resulted in sustained collaborations with academic and industry partners (UCLA; UCSD; Yale; Microsoft Research; Verizon; J.P. Morgan). Over last 5 years, I helped raise over \$1 million in research grants to support my research.

Below, I summarize two areas in my work. The first focuses on the end-users, where I developed and deployed a multi-modal interactive-task-learning agent that allows them to teach new tasks and concepts using a combination of natural language instructions and demonstrations on the graphical user interfaces (GUIs) of existing apps [1–8]. The second focuses on non-expert software developers, lowering the barrier for them to build AI-powered systems [9,11,13,14]. My future research work will continue this trajectory of democratizing AI to empower individuals with two areas of emphasis: future of work with AI and the natural interaction modalities in AI development tools.

FACILITATING HUMAN-AI COLLABORATION IN INTERACTIVE TASK LEARNING

Enabling end-users to automate their tasks using intelligent agents has been a long-standing objective in both the HCI and the AI communities. Instead of letting the users learn programming tools and languages, I developed a new intelligent agent named SUGILITE [1] that learns the human’s natural way to instructing tasks and concepts.

SUGILITE uses a new multi-modal interactive task learning approach that enables end users to teach new tasks, concepts, personal preferences, and automation rules using a combination of natural language instructions and demonstrations on existing app GUIs. Compared to prior systems, SUGILITE made significant

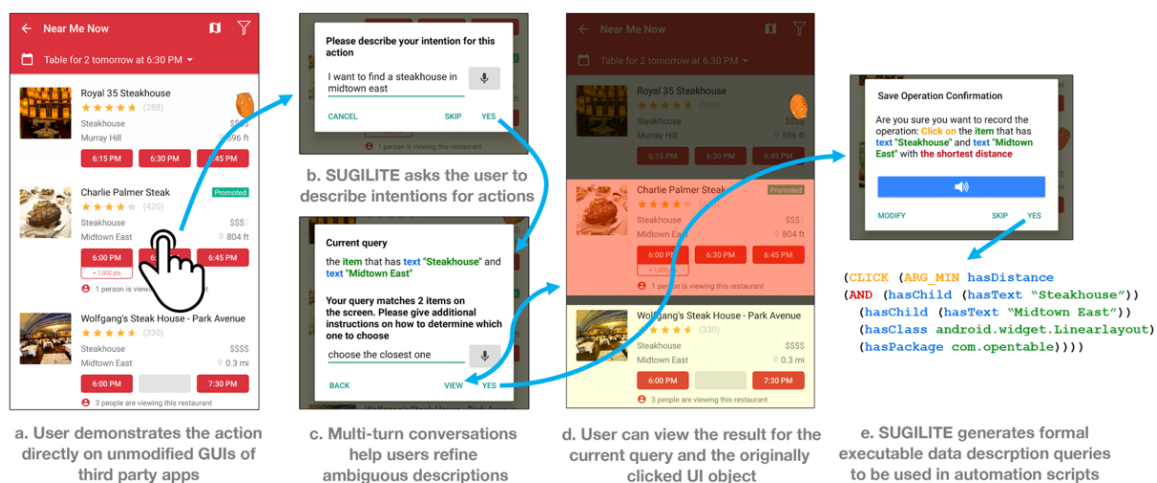


Figure 1. The screenshots of SUGILITE’s demonstration mechanism and its multi-modal mixed-initiative intent clarification process for the demonstrated actions.

progress in usability, applicability, generalizability, expressiveness, robustness, and shareability. SUGILITE has been open-sourced on GitHub, deployed in-situ through Google Play Store, and evaluated in several user studies.

SUGILITE feature novel intelligent interfaces and interaction techniques that facilitate the collaboration between the user and the agent. The multi-modal approach allows the user to first describe their intended task in natural language, and demonstrate new task procedures and concept on existing app GUIs. The utterances were grounded to the GUI demonstrations, allowing *mutual disambiguation* of the inputs from different modalities. The GUIs provide access to a large variety of computing services, information sources, and IoT devices [6] and encapsulate rich knowledge about the flows of the underlying tasks and the properties of relevant entities, so they can be used to bootstrap the domain-specific knowledge needed by the agent.

I created a mixed-initiative approach for users to disambiguate the intents of demonstrated actions [4]. After the user demonstrates an ambiguous action for generalization, the agent asks the user to clarify their actions in natural language in multiple turns of conversations. The system provides an interactive GUI-grounded visualization that highlights the agent's understanding of the user's utterances and prompts the user to explain specific aspects in their descriptions (Figure 1).

My work in SUGILITE introduced a new top-down lazy-evaluation dialog framework [8] for supporting concept and conditional instructions. The framework allows the user to start with saying an automation rule at a high level with ambiguous and vague concepts, procedures, and conditions. The agent then recursively resolves the ambiguities and vagueness in the initial instruction with the user through conversation, seeks clarifications from the user, and guides the user to define new concepts and procedures by demonstration if needed (Figure 2). I also designed a new multi-modal interface [3] that helps users discover, identify the causes of, and recover from conversational breakdowns using existing mobile app GUIs for grounding. This interface displays the system's understanding of

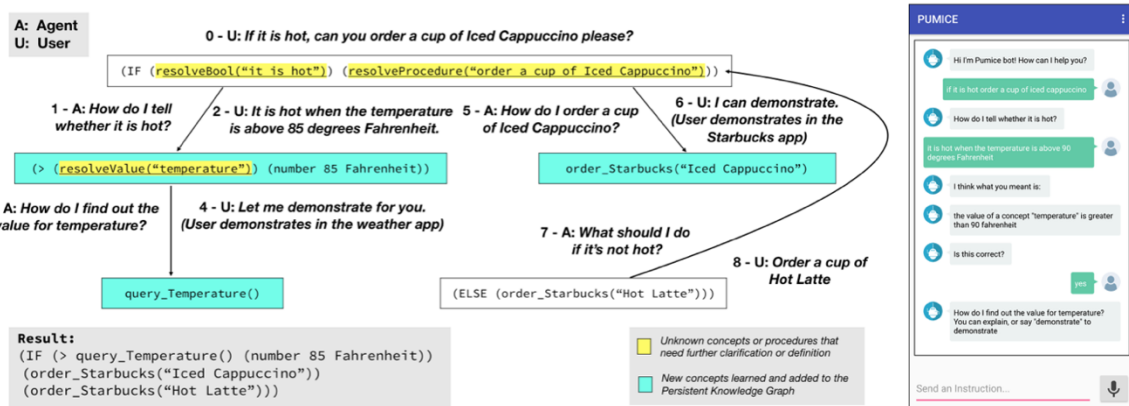


Figure 2. An example dialog structure when SUGILITE learns a new task that contains a conditional and new concepts. The numbers indicate the sequence of the utterances. The screenshot on the right shows the corresponding conversational interface.

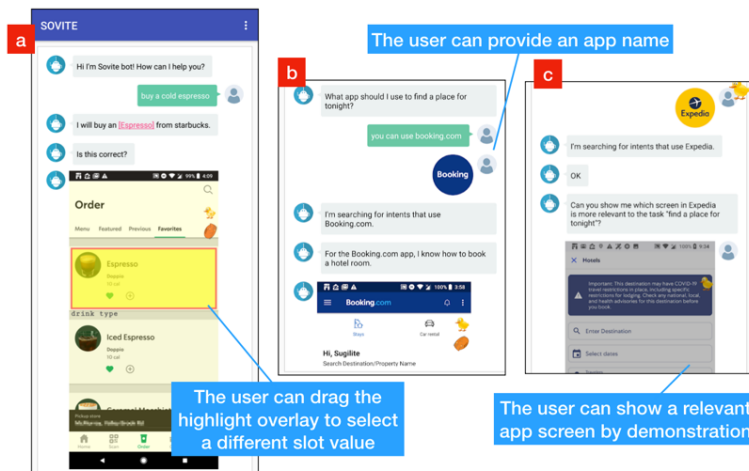


Figure 3. The interface for handling conversational breakdowns

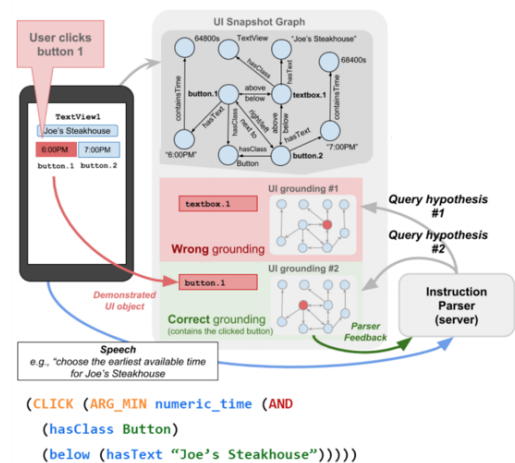


Figure 4. The UI Snapshot Graph for grounding natural language instructions to GUIs

user intents using GUI screenshots, allows the user to refer to third-party apps and their GUI screens in conversations as inputs for intent disambiguation, and enables the user to repair breakdowns using direct manipulation on these screenshots (Figure 3).

I created new AI-powered system capabilities that support the aforementioned interfaces. A key challenge in supporting the multi-modal task learning is to effectively ground the user’s natural language explanations to the corresponding GUI elements. I developed a new technique in SUGILITE that represents each GUI screen as a *UI Snapshot Graph* [4,7]. A floating semantic parser can parse the user’s natural language instruction into graph queries on this graph in a simple but flexible LISP-like functional query language. An iterative human-in-the-loop pipeline executes the query on the graph, verifies if the result matches the correct entity that the user originally demonstrated, and seeks additional input from the user if the result does not match, or matches more than one entity (Figure 4). The goal of this process is to generate a query that uniquely matches the target UI element and also reflects the user’s underlying intent.

This multi-modal GUI grounding approach allows SUGILITE to learn generalized procedures (e.g., to order *any* kind of beverage from Starbucks) from a demonstration of a specific instance of the task (e.g., ordering an iced cappuccino) [1]. SUGILITE achieves this by grounding the utterance (e.g., “order a cup of iced cappuccino”) to the data descriptions of the target UI elements (e.g., click on the menu item that has the text “Iced Cappuccino”) and the arguments of the demonstrated actions. It analyzes the hierarchical structure of GUI to extract the potential alternative values of the parameter (Figure 5). A similar GUI-grounding approach is also used for disambiguating the procedures to invoke [1] and for learning generalized concepts [8].

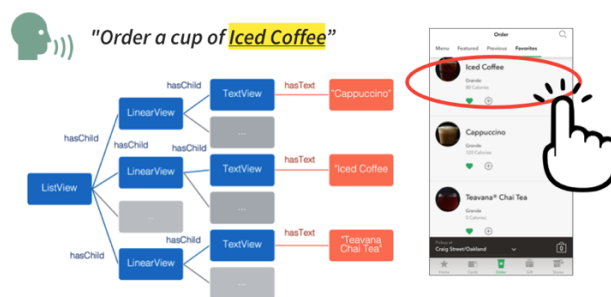


Figure 5. SUGILITE parameterizes the script using the hierarchical GUI structure

Another major barrier to the adoption of GUI-based interactive task learning agents has been the privacy concern in sharing the user-taught scripts, which may contain personal information like passwords, account numbers and balances. To address this, I developed a new mechanism [2] in SUGILITE for the privacy-preserving sharing of GUI-based demonstrational scripts. This mechanism can identify and obfuscate personal information at the time of sharing with minimal user intervention. It collects and aggregates hashed texts from app GUIs on users’ phones in everyday use. This aggregated data allows the system to identify fields in scripts with personal information, and obfuscate their values. At runtime, the obfuscated fields can be rebuilt locally using the script consumer’s apps, which helps preserve the shared scripts’ transparency, readability, robustness, and generalizability.

I developed a new technique for computationally modeling app GUIs and user GUI interactions, generating semantic embeddings for use in neural networks [10]. With the rise of data-driven computational methods for modeling GUI interactions, GUI screens have become not only interfaces for users to interact with the underlying computing services, but also valuable data sources that encode the task flow, the interactions, and the design patterns of the corresponding apps. My new self-supervised SCREEN2VEC technique can generate vector semantic representations for GUI Screens and components using their textual contents, visual design and layout patterns, and app-specific contexts without requiring manual human annotation efforts, addressing an important gap in the prior literature. The result vectors are shown to be effective and useful in many downstream tasks for modeling user tasks, querying GUI screens with natural language commands, and supporting embedding composability.

LOWERING THE BARRIER TO DEVELOPING AI-POWERED APPLICATIONS

I also created tools to support non-expert developers to build AI-powered applications. There are more than 27 millions of software developers in the world. Most of them do not have specialized expertise in AI domains, which prevents them from adopting the recent AI advances in their own application. My work seeks to lower the barrier to developing AI-powered applications through new interactive developer tools.

KITE [9] is a practical system I created that enables developers to bootstrap task-oriented conversational bots from existing mobile apps. Using traces of users using an app, KITE can automatically derive a task model, a graph of

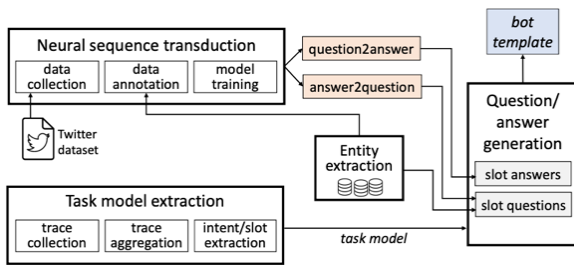


Figure 6. The processing pipeline of KITE's approach

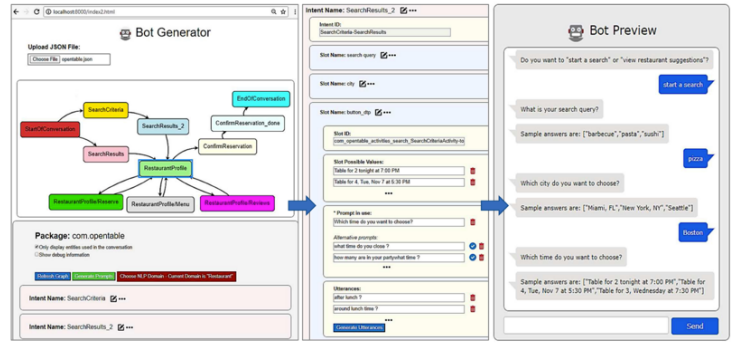


Figure 7. The interactive bot developing and testing interfaces of KITE

actions, and the associated inputs representing different task execution paths. On top of them, KITE generates a natural language interface for the task model with questions and answers using a Transformer-based neural network (Figure 6). The developer can then iteratively test and revise the auto-generated bot in KITE's interactive interface (Figure 7). KITE was not only evaluated in a lab study and published at MobiSys 2018, but also patented and is in the process of being incorporated into commercial products.

In collaboration with other teams of researchers, we developed three additional developer tools for AI-powered applications: GENO, PRIVACYSTREAM, and WIKIBRAIN. GENO [13] is a tool for adding the support for coordinated multi-modal voice inputs (e.g., moving *this event* to the next Monday) to existing web apps without requiring NLP and multi-modal interaction expertise. PRIVACYSTREAM [11] introduces a new Android developer framework for accessing and processing personal data (e.g., sensory inputs, location, contacts, photos) as a stream in a functional programming model, making it easier for developers to use personal data while simultaneously making it easier to analyze how that personal data is processed. WIKIBRAIN [14] democratized computation with Wikipedia knowledge for developers by providing simple access to the Wikipedia data and the state-of-art Wikipedia-based algorithms. All these tools have been open-sourced on GitHub and used by the communities of developers and researchers.

RESEARCH AGENDA

In the future, I plan to continue my line of research in **democratizing AI to empower individuals**. In this section, I outline two research themes that I am the most excited about.

End-User-Programmable AI Systems for the Future of Work

SUGILITE presents an example of supporting end user programming for task automation. For the next step, I am particularly interested in developing end-user-programmable AI systems to specifically address the challenges faced by the workforce in the era of “the fourth industrial revolution”. While the adoption of AI technologies have significantly increased the overall productivity of society, the gains have mostly gone to a small group at the top while many workers have been stagnated in wages or displaced by AI. I attribute much of this phenomenon to the *top-down* approach used in developing and deploying AI. While many workers, especially the rapidly expanding group of “gig workers”, participate in the corporate-provided AI infrastructures, they often act as interchangeable and replaceable components (e.g., Uber drivers, Instacart shoppers, data annotators) in large algorithm-directed workflows with little agency. The AI systems are often developed from a corporate's perspective with its best interest in mind, with little support for individual worker's personal preferences, motivation, and creativity.

I propose to explore a *bottom-up* approach that helps individual workers automate and augment their work with AI systems. Instead of replacing workers with AI, this approach can emancipate workers from mundane repetitive tasks, enabling them to focus on the creative and social aspects of work they love that AI systems cannot feasibly replace in near future. In our formative study with SUGILITE, many users stated they would love to automate their work tasks. The current SUGILITE is already able to learn work-related tasks that involve basic lookups, simple conditional rules, and well-defined actions through app GUIs. In the future, I plan to conduct contextual user research to investigate the automation needs of workers in different disciplines, study the societal impacts of end-user-programmable AI systems for the future-of-work, and develop more effective and more personalized interactive AI systems to assist individual users with their work-related tasks in their best interests.

A significant barrier to the bottom-up approach is the data ownership problem. An effective AI system usually requires a large amount of data to train, which is often only feasible for large organizations. I consider the recent advances in general-purpose language (e.g., BERT, GPT-3), reasoning (e.g., COMET, Atomic), and task completion (e.g., Almond) models an important step towards end-user programmable AI. These models are great fits for *few-shot learning* and *transfer learning*, allowing effective incorporation of general knowledge with small amounts of data and instructions from end users. For my future research, I plan to focus on designing the interaction between the user and the AI system in these scenarios, bridging the transparency and explainability of AI systems with the user's natural cognitive models for the task, and enabling the user to provide useful inputs that boost the generalizability, expressiveness, robustness of the AI system through effective human-AI collaboration.

Natural Interaction Modalities in Developer Tools

In my past work of designing different interactive developer tools, I have used several distinct input modalities and interaction methods for program specification, such as conventional source code, natural language spoken instructions and conversations, program synthesis with demonstrated examples, and direct manipulation in visual programming and GUIs. For the next step, **I plan to further explore the design space of interactive tools for diverse types of programming activities in the full end-to-end lifecycle of developing AI systems.** such as data labeling, data wrangling, exploratory analysis, model tuning, error analysis, bias mitigation, system deployment and monitoring, system extension, and performance optimization.

The advances in fields such as natural language processing, sensing for gesture and gaze tracking, interactive data visualization, program synthesis, and computational modeling of programming activities through software repository mining have laid the technical foundation for my next breakthrough in multi-modal interaction for software development. In my design process, I will specifically focus on the needs, capabilities, and routines of different types of developers, creating dynamic developer interfaces that are adaptive to these changing factors.

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