

CARECOMPANION: A VIRTUAL ASSISTANT FOR ENHANCING QUALITY OF LIFE IN  
ALZHEIMER'S DISEASE AND RELATED DEMENTIA PATIENTS

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**Title**

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## **ABSTRACT**

Patients with Alzheimer's Disease and Associated Dementias (ADRD), as well as older adults, grapple with issues such as memory loss, trouble navigating, and feelings of loneliness. These challenges influence their daily routines, scheduled appointments, and interpersonal relationships. This research delves into the conceptualization, creation, and initial appraisal of "CareCompanion" – a specialized virtual aide crafted for these individuals. Utilizing state-of-the-art AI techniques like natural language processing, machine learning, and knowledge graphs, CareCompanion offers personalized reminders, guidance for navigation, and features to enhance social ties. Early assessments highlight CareCompanion's promise in elevating life quality, autonomy, and social interactions among ADRD patients and the elderly. Continued exploration and advancement promise to refine its proficiency, user-friendliness, and adaptability, meeting this group's distinct requirements and alleviating the adversities of memory gaps, navigational hurdles, and feelings of isolation.

## ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my advisor Dr. Jen Li, for her unwavering support, guidance, and valuable insights throughout this research. I am grateful for her encouragement and for always push me to the boundaries of my research.

I would also like to thank my committee members Dr. Jun Kong and Dr. Shuvashish Dey for their invaluable time and to show interest in my work.

A special mention goes to my lab mate Xin Wang, whose significant contribution in implementing the Personalized Knowledge Graph and exposing the API for seamless integration with our backend services has been pivotal. Kimia Tuz Zaman, another vital member of our team, meticulously worked on the Social Connection API, integrating it with tools like Zapier and various RSS feeds, thereby enhancing our system's connectivity and reach. Mohammad Shalan deserves immense appreciation for his expertise in building and integrating the Google Calendar API, enabling our system to efficiently set and retrieve reminders. Their collective hard work, dedication, and technical contributions have been invaluable. This project would not have reached its culmination without their instrumental support and innovative solutions.

Last but not least, I want to thank my wife, parents and in-laws who have been a constant source of love, support, and motivation throughout my academic journey. Their support, encouragement, and belief in me have kept me going through the ups and downs of my research work.

I am truly grateful for everyone who has played a role in my research work, and I couldn't have done it without their help and support.

## MY CONTRIBUTION

Throughout the development and realization of our intricate system, I played an integral and multifaceted role. In collaboration with my lab members, I was pivotal in weaving our collective vision into a functional whole. My primary responsibility was the design of an intuitive user interface and the coding of the mobile application using Flutter, ensuring the users enjoyed a seamless experience. My expertise also shone through in the construction of our backend service with the Spring Boot framework, which became the backbone of our application by linking the frontend with various critical APIs.

For the Personalized Knowledge Graph built by Xin Wang, I delved deep into designing diverse, scenario-specific queries, optimizing data retrieval and overall system usability. I was instrumental in the flawless integration and functioning of both the Calendar and Reminder APIs which was built by Mohammad Shalan, ensuring our users received timely push and pull reminders. The curation of local news and events was another area I focused on, leveraging the Social Connections API built by Kimia Tuz Zaman, to deliver relevant content directly to our users.

One of the standouts features I developed was the voice assistant using Google's Dialogflow. Through meticulous design of its Intents, Entities, and Fulfillments, I ensured users could interact naturally and efficiently. To keep our users updated, I implemented a Cron Job processor, pushing timely notifications about various occasions. Safety and navigation also received my detailed attention; I incorporated a specialized safety feature in Google Maps using the Geofencing API and crafted a user-friendly navigation experience tailored for older adults.

Lastly, I took the lead in formulating an evaluation strategy for our system, a critical component for gauging its efficacy and identifying potential areas of improvement. My

contributions, thus, spanned the project's entire spectrum, ensuring we delivered a harmonious and user-centric system.

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## LIST OF ABBREVIATIONS

ADRD .....	Alzheimer's Disease and Related Dementias
AI .....	Artificial Intelligence
GPS .....	Global Positioning System
DST .....	Digital Storytelling
NLU .....	Natural Language Understanding
NLP.....	Natural Language Processing
DST .....	Digital Storytelling
RSS .....	Really Simple Syndication
API.....	Application Programming Interface

## 1. INTRODUCTION

Aging is a global phenomenon that presents a multitude of challenges for individuals and societies worldwide [1]. With the continuous increase in life expectancy, the prevalence of age-related health issues has surged in recent years [2], [3]. Among these health issues, Alzheimer's Disease and Related Dementias (ADRD) have come into sharp focus. ADRD encompasses a group of neurodegenerative disorders characterized by cognitive decline and memory impairment [4]. Globally, it is estimated that approximately 50 million individuals currently live with dementia, with Alzheimer's disease accounting for the majority of cases [5]. As the world's population ages, these numbers are poised to rise significantly, placing an ever-growing burden on healthcare systems and caregivers.

Memory loss emerges as a pervasive and prominent symptom of ADRD [6], [7]. It manifests in various forms, significantly affecting an individual's ability to recall and retain information. Those with ADRD often struggle to remember recent events, important appointments, or even recognize familiar faces and names. Short-term memory becomes particularly elusive, leading to repeated questions or conversations in a short span of time. This memory impairment can result in frustration, confusion, and a profound erosion of self-identity for those affected.

Furthermore, individuals grappling with ADRD may face challenges in remembering even the most routine tasks, such as medication schedules or personal hygiene maintenance. They may forget to eat meals or inadvertently leave appliances turned on, posing risks to their well-being and safety [8], [9]. These memory-related issues not only impact individuals directly but also exert significant strain on caregivers and family members, who shoulder the responsibility of providing support and supervision [10].

In addition to memory loss, spatial and navigational difficulties often accompany ADRD [11]. Patients may struggle to recognize familiar places or find their way home, even within well-known surroundings. Disorientation and the risk of getting lost easily heighten their dependence on others for assistance.

Moreover, individuals with ADRD frequently find it challenging to maintain connections with their local communities and engage in social interactions. Participating in conversations, remembering names and faces, and actively joining community activities can become daunting endeavors. This social isolation exacerbates feelings of loneliness and contributes to an overall decline in well-being. As cognitive abilities diminish, they may become less attuned to local news, events, and activities, deepening their sense of detachment, isolation, and a waning sense of belonging.

In response to these formidable challenges, we introduce an innovative virtual assistant named "CareCompanion." This virtual assistant is meticulously designed to provide holistic support for individuals navigating ADRD and older adults, effectively addressing their memory loss, navigation difficulties, and social isolation. CareCompanion leverages cutting-edge AI technologies, including natural language processing, machine learning, and knowledge graphs, to offer a comprehensive suite of features aimed at mitigating the multifaceted challenges faced by this demographic.

Preliminary assessments underscore the potential of CareCompanion in enhancing the quality of life and fostering independence among individuals grappling with ADRD and older adults. Nonetheless, further research and development efforts are imperative to fine-tune its effectiveness, usability, and customization, ensuring it caters to the unique needs and preferences of this distinct population.

## 2. LITERATURE REVIEW

In an aging global population, the challenges faced by individuals with Alzheimer's Disease and Related Dementias (ADRD) and older adults are becoming increasingly prevalent. Cognitive impairments, such as memory loss, and the complexities of navigation, coupled with social isolation, present formidable challenges that impact the quality of life, independence, and well-being of these individuals. In an era where technology permeates every facet of life, it becomes essential to leverage advancements in artificial intelligence (AI) to cater to the specific needs of this demographic.

The emergence of virtual assistants in the realm of healthcare provides a beacon of hope. These systems, when thoughtfully designed and implemented, have the potential to revolutionize how older adults and individuals with ADRD manage their daily tasks, stay socially connected, and navigate their environments. However, the success of these virtual assistants hinges on their ability to truly understand and cater to the unique challenges and needs of their users.

CareCompanion represents an innovative stride in this direction. Tailored specifically for individuals with ADRD and older adults, this virtual assistant utilizes cutting-edge AI technologies, including natural language processing, machine learning, and knowledge graphs. Its design focuses on addressing the multifaceted challenges faced by its target users, aiming to enhance their quality of life, independence, and social engagement.

This paper delves into the design, development, and preliminary evaluation of CareCompanion. Through the subsequent sections, we will explore the intricacies of its functionalities, its underlying technologies, and its potential impact on its users. The literature review that follows provides a comprehensive overview of the current state of research in this

domain, setting the stage for a deeper understanding of the significance and potential of CareCompanion.

## **2.1. Memory support technologies**

In recent years, there has been a noticeable surge in the exploration and development of technologies aimed at assisting those grappling with memory impairment. These technologies, ranging from electronic devices to smartphone applications, hold significant potential for transforming the lives of individuals with Alzheimer's Disease and related dementias (ADRD).

One of the more traditional, yet effective, interventions has been the deployment of electronic reminder devices. For instance, medication dispensers equipped with alarms [12] have emerged as a reliable tool, demonstrating significant efficacy in reinforcing medication adherence and assisting patients in managing their daily routines. But as technology has advanced, so have the tools at our disposal. We now witness a plethora of digital platforms, including calendars and dedicated smartphone applications, engineered explicitly for the task of providing timely reminders. Whether it's about medical appointments, personal tasks, or special events, these digital platforms ensure that individuals with ADRD stay on top of their schedules [13].

Delving deeper into the realm of smartphone-based interventions, a pivotal study led by Scullin et al. [14] presents noteworthy insights. The study embarked on a mission to decipher the feasibility and effectiveness of smartphone-driven strategies tailored for enhancing prospective memory in older adults manifesting cognitive impairments. Participants were meticulously trained to harness the power of either a digital voice recorder app or a dedicated reminder application, all in a bid to aid their prospective memory tasks. Encouragingly, the outcomes pointed towards not only the feasibility of such an approach but also its acceptance among the

participants. Most notably, a majority of participants reported a discernible enhancement in their day-to-day prospective memory functions.

Another intriguing exploration comes from the work of Ferguson et al. [15]. The study was steered with the goal of unveiling the potential merits of task reminder prompts channeled through smartphone calendars. The empirical evidence gathered painted a promising picture – the incorporation of smartphone reminders led to a marked elevation in the rates of task completion. Delving further into the data, a thematic analysis unraveled some additional benefits. It was observed that such reminders played a pivotal role in bolstering personal independence, infusing a renewed confidence in individuals to combat memory challenges, and fostering an overall positive mood.

In a distinct yet related study spearheaded by McCallum et al. [16], the spotlight was cast upon the renowned Google Calendar. The objective was to probe its capabilities in addressing prospective memory challenges in a patient diagnosed with Alzheimer's disease. The study required the participant to recollect fundamental daily activities and select events, such as a recurring weekly bridge game. Impressively, with cues provided by Google Calendar, the results indicated that the patient's rate of forgetting targeted events during the intervention phase plummeted compared to the baseline. This observation emphatically underscores the potential of tools like Google Calendar in mitigating prospective memory challenges, particularly in individuals with the early stages of Alzheimer's disease.

Collectively, these advancements in memory support technologies offer a glimmer of hope. They hint at a future where the challenges of memory impairment can be alleviated, if not entirely overcome, by leveraging the power of modern technology.



## 2.2. Exploring navigation assistance

In the face of rising complexities associated with Alzheimer's Disease and related dementias (ADRD), the arena of technological interventions has responded with innovation, particularly in the domain of navigation assistance. These innovations cater to the pronounced spatial and navigational challenges often experienced by ADRD-afflicted individuals.

One of the pioneering solutions to address these navigational woes has been the integration of Global Positioning System (GPS) trackers. These trackers, often embedded within wearable devices, come equipped with state-of-the-art location tracking mechanisms. Their primary function is to assist caregivers or relatives in swiftly locating individuals prone to wandering or inadvertently getting lost, a common manifestation among those with advanced ADRD.

Venturing into the more advanced technological domain, the application of virtual reality (VR) in navigation training programs deserves special mention. Initial investigations into VR-based navigation systems have returned optimistic results, indicating a tangible improvement in participants' spatial orientation capabilities and wayfinding proficiencies [17]. These VR programs, often immersive in nature, provide a controlled environment where ADRD patients can practice navigation without the risks associated with real-world wandering.

However, despite the promise shown by these technological marvels, it's crucial to comprehend the depth of the challenges they aim to address. Renowned researchers Manderson and Sohlberg [18], [19] have shed light on the multifaceted challenges encountered by individuals with cognitive impairments during navigation. They emphasize the intricacies of these challenges, highlighting how seemingly straightforward tasks can become daunting obstacles for those with ADRD. Their research accentuates the dire need for robust strategies,

not just to address the symptoms but to root out the underlying difficulties faced by these individuals.

Lending further clarity to this discussion, Pillette's exhaustive literature review [20] delves into various navigation assistance systems crafted specifically for dementia patients. This comprehensive analysis surfaces the recurrent challenges posed by navigation for this demographic and subsequently discusses potential avenues for future technological enhancements. Through the lens of Pillette's insights, it becomes evident that while numerous interventions exist, there's a continual need for evolution, driven by the ever-changing nature of ADRD.

Taking a nuanced perspective, Cogné [21] offers a fascinating exploration of virtual reality's utility in quantifying spatial navigation disorders. Beyond mere quantification, the study also evaluates the potential influence and efficacy of different navigational aids, imparting invaluable knowledge for prospective technological advancements in this domain.

In synthesizing the wealth of information presented in these studies, a singular notion emerges: while several strides have been made in developing navigation technologies for ADRD patients, the design and functionality of these tools must be laser-focused on the idiosyncratic demands of this unique population. It's imperative to remember that mere crisis aversion, such as locating a lost individual, is only one piece of the puzzle. For a truly holistic solution, continuous support during routine, daily navigation tasks is just as critical.

### **2.3. Connecting to communities**

Amid the growing concerns surrounding the isolation and alienation experienced by individuals with Alzheimer's Disease and related dementias (ADRD) and the broader older adult population, numerous initiatives have been spearheaded to foster social integration and

community connectivity. These efforts aim not only to enhance their social well-being but also to address the mental and emotional challenges they often face.

At the forefront of these social interventions is the advent of social robots. These robots, characterized by their human-like interactions, have been meticulously designed to foster meaningful social connections [22]. Unlike standard devices, these robots employ a blend of artificial intelligence and emotional recognition software to engage individuals in more profound, meaningful activities. Their programmed nature allows them to interact without judgment, providing a steady source of companionship and engagement, especially for those who might find human interactions increasingly challenging.

Parallel to this, the digital age has ushered in the rise of online platforms tailored for older adults and those with ADRD. Virtual communities have sprouted across the web, each designed to foster a sense of belonging and provide a platform for peer support [23]. These communities serve as digital sanctuaries, where individuals can share their experiences, exchange stories, and draw strength from communal bonds.

An especially innovative approach to bridging generational gaps and alleviating feelings of isolation is the telephone-based reminiscence program, which seamlessly integrates digital storytelling (DST). This program encourages intergenerational conversations, allowing older adults with ADRD to connect with younger generations over shared stories and memories [24]. The beauty of this initiative lies in its simplicity; by using a tool as ubiquitous as a telephone and pairing it with the power of storytelling, deep-seated memories are rejuvenated, fostering connections that transcend age.

A synthesizing glance over existing literature and research underscores the potential and efficacy of peer support networks and intergenerational connections. These interventions, as

highlighted by various studies [25], offer promising avenues for bolstering social connectivity and overall mental well-being among ADRD patients and older adults.

However, a critical caveat persists. While these initiatives are undoubtedly beneficial, they sometimes miss the mark in delivering the warmth and familiarity intrinsic to personal interactions and connections with one's local community [26]. Digital platforms and virtual engagements, no matter how advanced, may still lack the nuanced touch, shared history, and communal bonds that come with face-to-face interactions in one's immediate surroundings.

#### **2.4. The strengths and weaknesses of existing technology**

Over the past few years, the technological realm has seen an influx of solutions aimed at assisting those with Alzheimer's Disease and related dementias (ADRD) and the broader older adult community. These innovations, grounded in the nexus of engineering, cognitive science, and gerontology, have strived to provide a semblance of normalcy and aid in the lives of those grappling with the challenges of cognitive impairments and aging.

However, a closer examination of these technologies reveals a mosaic of strengths and inherent limitations. A predominant concern lies in the fragmented nature of many of these tools. Rather than offering a holistic, all-encompassing solution, there's a tendency to create niche products that address singular concerns or needs. While each of these solutions serves a crucial purpose, the result is often a scattered user experience, requiring individuals to juggle multiple tools, each catering to different facets of their daily lives. This can be particularly daunting for the elderly or those with cognitive challenges, who may find the task of navigating between various platforms overwhelming.

Moreover, the personal touch, so essential in care and therapeutic interventions, seems to be amiss in several existing technologies. There's a prevailing trend towards generic solutions,

designed with a one-size-fits-all mindset. These often overlook the idiosyncrasies, preferences, and unique challenges faced by each individual. For instance, a reminder application might not account for a user's specific daily rituals or familial relationships, offering standardized prompts instead of tailored cues aligned with an individual's lifestyle.

Perhaps the most significant oversight in the current technological landscape for ADRD and older adults is the insufficient emphasis on the emotional and psychological dimensions of their experiences. Cognitive challenges, especially those related to memory loss and aging, are not just clinical issues; they carry profound emotional and psychological implications. Feelings of isolation, frustration, and a dwindling sense of self often accompany these conditions. However, many tools, in their bid to offer functional solutions, miss delving into these deeper emotional terrains, thus failing to provide a holistic support system.

In essence, while the current wave of innovations for ADRD patients and older adults marks a commendable stride in addressing their challenges, there's a palpable need for more integrative, personalized, and emotionally attuned solutions.

In light of the fragmented landscape of current technological solutions for ADRD and older adults, we've envisioned a revolutionary approach that converges comprehensive functionalities into a seamless, integrated interface. Our innovative system is fortified with state-of-the-art AI methodologies, harnessing the capabilities of natural language processing and machine learning to transcend traditional barriers.

At the heart of our platform is the commitment to deep personalization. Recognizing that every individual is a tapestry of unique needs, histories, and aspirations, our system dynamically tailors its functionalities to resonate with each user. From crafting reminders that are weaved into

the user's daily rhythms to providing intelligent navigation support that understands their habitual routes, our solution anticipates and adapts.

Beyond the pragmatic, we've also delved into the profound emotional landscape of our users. Our platform isn't just a tool; it's a companion. By anchoring features that evoke a sense of familiarity and warmth, such as greeting users by their preferred name or recalling the nuances of their familial and social ties, we ensure that our technology serves as a beacon of comfort. This level of personal touch not only fosters a deeper engagement but also cultivates a bond of trust, making users feel seen, heard, and valued.

Additionally, the system is designed to be attuned to the diverse interests and preferences of its users. Whether it's curating information on a hobby they cherish or connecting them with events in their community, the virtual assistant endeavors to enrich their lives in myriad ways.

In sum, our solution heralds a new paradigm in ADRD and elderly care technologies. By marrying cutting-edge AI with a compassionate, user-centric design, we aim to provide not just a product but an experience - one that champions convenience, emotional well-being, and a genuine sense of companionship.

## **2.5. Novelty of this work**

The landscape of memory support technologies, navigation assistance, and community connection platforms has seen significant advancements in the past decade. While there has been remarkable progress in these fields, the integration of these technologies into a single, coherent system has remained largely unexplored. This work presents a groundbreaking approach to addressing the intertwined challenges of memory, navigation, and social connections.

Several key innovative aspects distinguish this study:

### **2.5.1. Integrated system design**

While many studies have focused on singular aspects such as memory support or navigation assistance, our work introduces an integrated system design. This cohesive approach ensures that users benefit from a seamless experience without the need to juggle multiple platforms or tools.

### **2.5.2. Personalized knowledge graph**

The implementation of a personalized knowledge graph is a pioneering step towards understanding individual user needs and preferences. This not only ensures more tailored recommendations but also adapts to the evolving requirements of the user over time.

### **2.5.3. Voice assistant enhancement**

Building upon the traditional voice assistant framework, our system offers nuanced features tailored for the specific challenges related to memory and navigation. This makes our voice assistant not just a tool but a personalized companion for users.

In conclusion, the novelty of this work lies in its integrated approach, personalized features, and a deep understanding of user needs, setting it apart from existing technologies and studies in the domain.

### 3. SYSTEM DESIGN

In our modern tech-savvy world, it's essential to have tools that help specific groups of people. Enter the CareCompanion app, designed especially for older folks and those with Alzheimer's Disease and Related Dementias (ADRD). This app isn't just smart; it's also user-friendly. By combining voice commands with simple touch features, CareCompanion offers solutions that make daily life easier. It helps users remember tasks, find their way around, and stay connected with friends and family. In this section, we'll take a closer look at how this helpful app is put together.

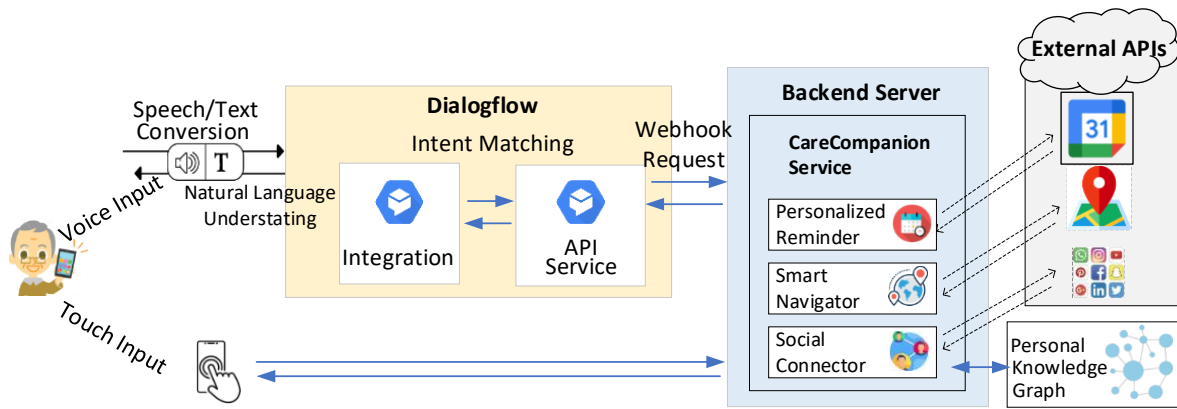


Figure 1. System architecture

As illustrated in Figure 1, the CareCompanion mobile application introduces a versatile interface that seamlessly integrates voice and touch-based functionalities. This dual-modality permits users to engage with the application either by employing voice commands, facilitated by Google's Dialogflow [27] for efficient speech interpretation, or by direct touch-based inputs, thus granting users a choice in their interaction mode with the virtual assistant.

At the heart of this system lies a central server where CareCompanion's core services reside. These crucial services encompass a trio of features: the Personalized Reminder Service, the Smart Navigator, and the Social Connector, each of which is paramount to the application's



functionality. To amplify their effectiveness, these services incorporate several external Application Programming Interfaces (APIs).

Delving deeper into the services, the Personalized Reminder Service adeptly integrates the Google Calendar API. This fusion ensures the provision of timely reminders, tailored to the user's context - be it for doctor's appointments, medicinal doses, or notable occasions. The advantage of meshing with Google Calendar is the guarantee of precision and real-time synchronization of reminders, ensuring users never miss a beat.

Next, the Smart Navigator, a cornerstone feature of CareCompanion, marries the Geofence API with the Google Maps API. This union is designed to aid Alzheimer's Disease and Related Dementias (ADRD) afflicted individuals in effortlessly navigating their immediate environment. The navigator furnishes users with precise directions, invaluable guidance, and relevant location-centric data, ensuring that they always find their path and arrive at their intended destinations without hitches.

Lastly, the Social Connector bridges the application to multiple social network APIs and RSS channels. This feature is adept at curating and presenting local news, offering the latest updates about community happenings, and streamlining communication with loved ones. Such integration is pivotal in ensuring users remain in the loop with their social environments, thereby alleviating potential feelings of loneliness and significantly improving their holistic well-being.

Furthermore, CareCompanion uses a personal knowledge graph to make its services even more user-centric. This knowledge graph keeps track of the user's basic details, their family ties, friendships, likes, and other key information. With this data, CareCompanion can fine-tune its services to match each user's specific needs and likes. By taking such a personalized route, the

app makes the user's experience better, helps them maintain their independence, and provides effective daily life management for those with ADRD.

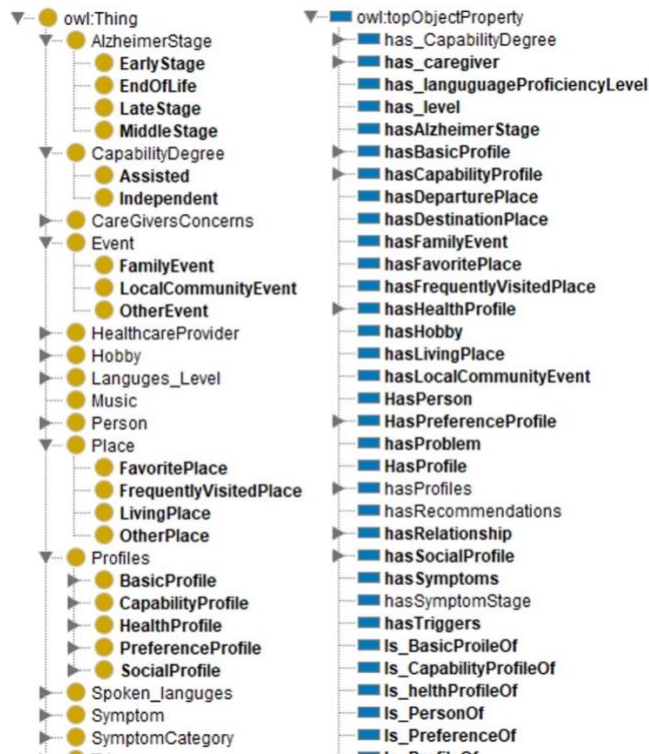


Figure 2. User profile ontology

### 3.1. Personalized knowledge graph

At the core of CareCompanion is its unparalleled commitment to providing a tailored experience. This is evident in features such as the Personalized Reminder, Smart Navigator, and Social Connector. These functionalities demand an in-depth knowledge of each user's specifics, often subject to updates and regular access. To manage this dynamic data efficiently, a personal knowledge graph is employed.

What sets Knowledge Graphs apart from conventional databases is their unique organizational structure. Instead of merely storing data, they identify entities (or nodes) and establish connections (or edges) between them. This emphasis on relationships is particularly

crucial for platforms like CareCompanion, where understanding the intricate web of user relationships can make a world of difference.

The graph's foundation, illustrated in Fig.2, is based on an all-encompassing user profile ontology. It outlines the crucial connections and user data points. This ontology has its roots in our previous research endeavors [28], where we crafted a model tailored for ADRD patient care.

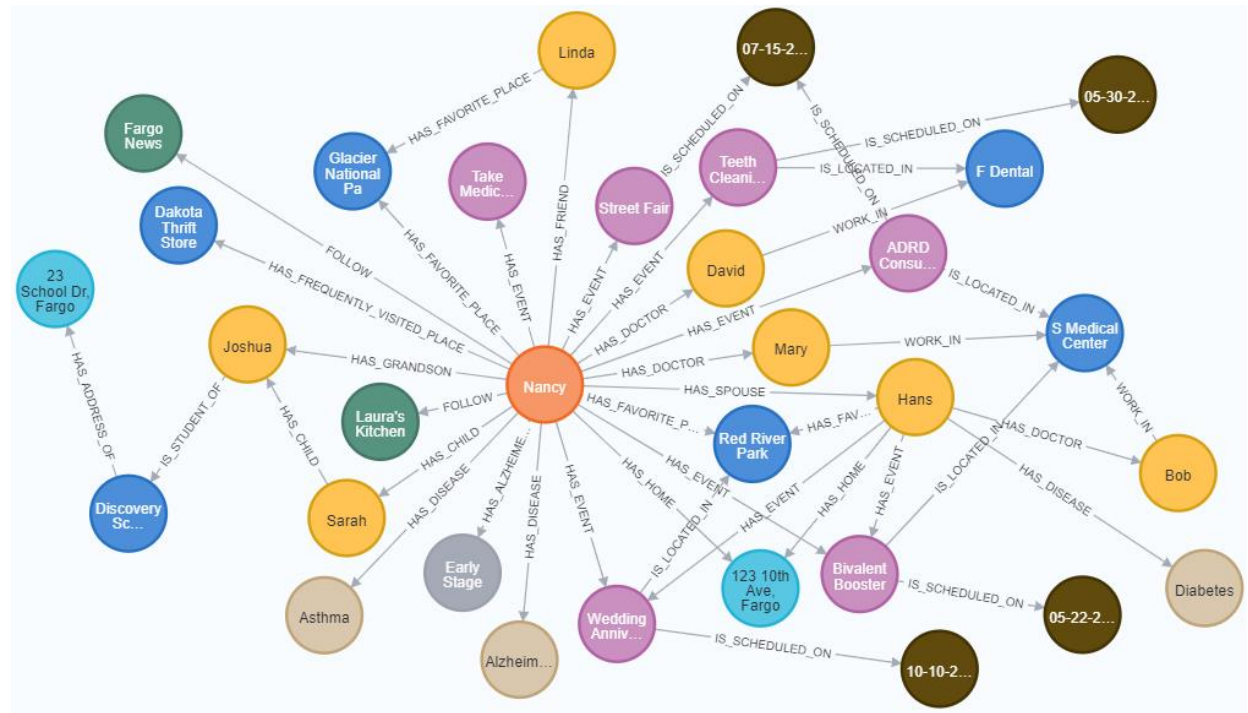


Figure 3. User Nancy's personal knowledge graph

But what truly makes these graph databases shine is their prowess in rapid data access. This is especially pertinent when handling data rich in relationships, a strength highlighted in Fig.3, which depicts a user, Nancy's, personal knowledge graph. Imagine Nancy requesting, "Navigate to my grandson's school." While standard systems might stumble, unsure of who Nancy's grandson is or his school's location, CareCompanion's knowledge graph navigates these waters with ease. It discerns the connection: Nancy—has grandson—Joshua; Joshua—studies at—Discovery High School; Discovery High School—located at—23 School Dr. This ensures

that even if specific details elude Nancy, she's still seamlessly directed to her destination. Such capabilities underscore CareCompanion's mission: to offer timely, intuitive, and efficient support, enriching the lives of individuals with ADRD.

### **3.2. Voice assistant**

The foundation of CareCompanion lies in its utilization of sophisticated Natural Language Understanding (NLU) and Natural Language Processing (NLP) technologies. A core component of its interface is the integration with Google's Dialogflow, a leading platform for NLU. In Dialogflow, a virtual agent acts as the conversational conduit, processing and understanding user inputs to facilitate interactive and intuitive responses. Let's delve deeper into the main components of this system:

**Intent:** This is the crux of user-agent interaction. Essentially, an intent captures the specific objective or action that a user aims to achieve during a conversation. When users engage with the virtual agent, they usually have a specific task or query in mind. For instance, they might say, "Set a reminder for my doctor's appointment" or inquire, "When is my next medication due?" These statements signify specific intents, directing the agent on the best way to assist or respond.

**Entity:** Entities are integral to understanding context in conversations. They act as anchors, pinpointing specific types of data or objects that are crucial for the agent's comprehension. An entity is often structured as a key-value pairing. The 'key' denotes a particular object or item of interest, while the 'values' are various terms or synonyms that might represent the same object. To illustrate, in the statement "my doctor's appointment", the phrase itself could be designated as a key. Alternative phrases, such as "medical visit", "doctor's visit", or "check-up", might then be cataloged as potential values for that key.

**Fulfillment:** This component acts as the bridge between the virtual agent and backend systems. It's responsible for translating user intents into actionable tasks or responses. Whether it's triggering specific code snippets, initiating API calls, or producing dynamic feedback based on the user's query, fulfillment ensures that the agent's response is both accurate and tailored to the user's needs.

By Utilizing these components, CareCompanion ensures a seamless and responsive user experience, catering to the diverse and evolving needs of its user base.

### **3.3. Personal reminder**

CareCompanion stands as a support for individuals with Alzheimer's Disease and Related Dementias (ADRD), primarily due to its innovative approach in offering tailored reminder features. These features are ingeniously designed to aid these individuals in seamlessly navigating their daily tasks, ensuring they uphold essential routines. The methods employed in delivering these reminders are delivered into push-based and pull-based modalities, each contributing to proactive support and enhanced medication compliance.

The push-based methodology in CareCompanion is an essential tool that forges a bridge between established calendar utilities, like Google Calendar, and its end-users. When an event, such as a doctor's visit, is scheduled, the calendar tool dispatches a basic reminder. However, CareCompanion adds a layer of customization to these reminders, ensuring they're adapted to the user's unique requirements. It's not just about reminding the user of an impending appointment. It's about doing so at optimal times — perhaps a week in advance, then a day prior, and a short reminder, say, 30 minutes before the event. Such systematic alerts ensure users are not only reminded but are also prepped and punctual for their commitments.

Complementing the push strategy is the pull-based interaction mechanism. This feature empowers users by allowing them to engage actively with the virtual assistant. Beyond just receiving reminders, users can now pose questions related to their schedules or medications. Whether it's a query about an upcoming medical check-up, their grandchild's birthday celebrations, or the specifics of their medication intake, CareCompanion stands ready to furnish pertinent details, be it the type of medicine, the recommended dosage, or the ideal time for consumption. This dialogic engagement is instrumental, not only in keeping users informed but also in encouraging a proactive role in their healthcare trajectory.

By harmoniously blending proactive alerts with responsive querying, CareCompanion carves out a niche in offering unmatched, personalized support for ADRD-afflicted individuals. The system functions not just as a mere virtual assistant, but as a dependable ally — consistently guiding users, addressing their concerns, bolstering medication fidelity, and enabling them to effortlessly manage their commitments.

### **3.4. Navigation assistance**

The innovative CareCompanion system is dedicated to empowering individuals with Alzheimer's Disease and Related Dementias (ADRD) by offering sophisticated navigation support. Recognizing the unique spatial and navigational challenges these individuals often face, CareCompanion acts as a guiding hand, helping them journey through unfamiliar environments and ensuring they can return safely to known destinations. Beyond mere navigation, it actively works to bolster safety mechanisms, particularly by addressing the prevalent wandering behaviors seen among ADRD patients.

Integral to CareCompanion is its dedicated Navigation Assistance module. Crafted with meticulous care, this feature-rich module operates through a user-friendly mobile application that

comes with an intuitive voice interface. With its primary focus on safety and convenience, this app serves as a constant companion for those on the move.

A pivotal aspect of the Navigation Assistance is its adept use of geofencing technology. By establishing what can be termed as a 'safety perimeter', geofencing keeps a vigilant watch over the user's movements. If the individual happens to step beyond this predefined zone, it immediately triggers an alert. Caregivers or family members receive instant notifications coupled with a real-time location tracking feature. This dual-action mechanism not only appries them of the situation but also enables swift intervention, ensuring the safety of their loved ones.

Delving deeper into its offerings, CareCompanion boasts a personalized knowledge repository tailored for each user. Encompassed within this database are details about the user's commonly frequented places — be it their residence, workplace, regular grocery store, doctor's clinic, favored parks, or any other location deemed safe and significant. This personal touch ensures that users receive navigation assistance that's aligned with their regular routines and habits.

Designed with user-centricity at its core, the application interface is a blend of simplicity and functionality. Users have the flexibility to voice out their destination preferences or, if they prefer, to tap through a streamlined menu that presents a curated list of locations. Integration with Google Maps, once a destination is chosen, the app proffers voice-assisted navigation, leading the way. This list, curated with the user's habits in mind, simplifies the navigation experience, eliminating the often overwhelming features of traditional navigation apps. Nevertheless, for the more adventurous souls who wish to venture beyond the curated list, manual search capabilities remain at their fingertips. But even here, safety isn't compromised, as

the app ensures searches are restricted to specific city boundaries, striking a balance between independent exploration and safety.

### **3.5. Social connections**

In our quest to foster deeper social connections for our users, we've designed to immerse individuals in the heart of their community's activities and happenings. By intertwining personalized community insights and updates, we aim to spark a feeling of togetherness and keep our users always in the loop. Let's delve into the intricacies of this endeavor.

Central to this system is our intricate knowledge graph, acting as a reservoir of data about each user's community interactions and social relationships. This vast pool of information enables us to tailor content specifically for each user, ensuring they receive updates that resonate with their interests and affiliations. Be it local news, family milestones, or community events, our approach guarantees a curated experience, tailored to individual preferences.

Tapping into the pulse of the community, our backend is in constant synchronization with local news channels through RSS feeds. These feeds offer a continuous stream of current events, stories, and updates, ensuring that our users are always informed about the latest happenings in their vicinity. Furthermore, we've expanded our horizons by integrating platforms such as Facebook and other community portals. This way, our users don't just hear about global news but are also informed about local events, gatherings, and celebrations.

Moreover, with the assistance of automation tools like Zapier, we transform various data sources into a cohesive RSS feed. This ensures a seamless flow of comprehensive community updates directly to our users.

The overarching goal of this initiative within CareCompanion is simple yet profound: to bridge the gap between individuals and their communities. In doing so, we not only enhance the



user's sense of belonging but also elevate their overall social well-being, ensuring they feel connected, valued, and engaged at all times.

## 4. EVALUATION

For the CareCompanion app, specifically designed for individuals grappling with Alzheimer's Disease and Related Dementias (ADRD), a rigorous and detailed assessment is paramount before its actual deployment to the intended user base. Since the app is primarily tailored for ADRD patients, it's of utmost importance that every facet of the application—from its functionalities to its usability—is meticulously evaluated to ensure it aligns perfectly with their unique needs.

Our evaluation strategy is twofold. First, we delve into use case testing. This involves simulating real-world scenarios where the app would be utilized by an ADRD patient. By walking through these scenarios, we're able to gauge the app's responsiveness, intuitiveness, and reliability. Does the app respond as expected? Is the interface intuitive enough for someone with ADRD? These are the critical questions we seek to answer through this phase of testing.

Subsequently, we transition into role-playing based testing. Here, evaluators immerse themselves in the role of an ADRD patient, attempting to use the app as such a patient would in their day-to-day life. This method offers a unique vantage point, enabling us to empathize with the challenges these individuals might face and assess how the app addresses these challenges. It provides a holistic view of the user experience, highlighting potential areas of friction and opportunities for enhancement.

By integrating these comprehensive testing approaches, we aspire to obtain a profound understanding of the app's performance in real-world scenarios. The insights derived from this rigorous evaluation will be instrumental in fine-tuning the app's design, ensuring that CareCompanion not only meets but exceeds the expectations of its users, offering them an invaluable tool in their journey with ADRD.

## 4.1. Prototype implementation

The CareCompanion virtual assistant is a tool tailored for ADRD patients and the elderly. At its core, this assistant is fueled by the prowess of Google's Dialogflow platform. This platform's primary role is intent recognition, which means understanding user requests and translating them into actionable tasks.

In complementing Dialogflow, we have a serverless Webhook application to take care of intent fulfillment. To elaborate, once Dialogflow understands a user's request, the Webhook application steps in to ensure that this request is addressed effectively. It communicates with our dedicated backend server, constructed with the robust Spring Boot Java framework. This server, in turn, liaises with a variety of APIs to provide an array of services.

For instance, to craft timely reminders that are integral for ADRD patients, we've integrated the Google Calendar API. This ensures users get notified of important dates, be it medication timings or doctor's appointments. On the navigation front, a blend of Google's geofencing API, geolocation API, and the Google Maps API ensures that users are always on the right path, whether they're heading to a familiar destination or exploring new terrains.

Our app also understands the significance of social connection. Thus, by harnessing the capabilities of the Zapier API, CareCompanion fetches and presents pertinent social news and community events. It connects to community pages, curates RSS feeds, and ensures users are always in the loop about local happenings.

Underpinning our system's intelligence is the personal knowledge graph, meticulously stored in the Neo4j graph database. This graph houses vital information about each user, fostering personalization at every touchpoint.

Lastly, for a seamless user experience across mobile devices, we've chosen Flutter as our developmental framework. It's flexible, efficient, and ensures that through simple voice commands, users can unlock the full potential of CareCompanion, from navigation aids and social connectors to tailored reminders.

#### **4.2. Use case study**

In our research, we delved deep into the lived experiences of our users, aiming to understand and capture the nuanced challenges faced by those with ADRD in their daily lives. Through extensive evaluations, we sought to measure the real-world impact of CareCompanion and its efficiency in addressing the unique hurdles that individuals with ADRD often grapple with.

Let's take a closer look through the lens of a specific scenario. Meet Nancy, a spirited 76-year-old lady who, despite her recent diagnosis of early-stage AD, is keen on leading a fulfilling life. She shares her life with her husband of the same age, and they cherish the regular visits from their daughter. However, the early onset of memory lapses is starting to cast a shadow on Nancy's everyday activities. She often finds herself grappling with forgotten appointments, mismanaged medication schedules, and at times, a sense of disorientation in once-familiar settings.



Figure 4. Reminder and social connection cases

Our virtual assistant – meticulously crafted to be a supportive beacon for individuals like Nancy. Here's a snapshot of how CareCompanion weaves itself into Nancy's routine, bringing solace not just to her, but also to her concerned family.

#### 4.2.1. Reminder cases

Nancy often finds solace in the assistance provided by CareCompanion's reminder functionalities. This sophisticated system plays a pivotal role in ensuring that Nancy stays on track with her various commitments, be it doctor's visits, medication intakes, or social engagements.

When it comes to appointment management, Nancy effortlessly uses the voice commands of CareCompanion. The system intuitively helps her log any upcoming events or visits. Moreover, it doesn't just stop at recording. CareCompanion believes in proactive support. Hence, it sends Nancy gentle nudges well in advance — a week ahead, followed by reminders a day prior, and then the final alert 30 minutes before the event. This layered approach not only fosters Nancy's sense of independence but also minimizes the chances of any missed commitments, ensuring her peace of mind.

But what amplifies the efficiency of CareCompanion is its ability to involve caregivers in the process. They can seamlessly feed in appointments or schedules, thereby enhancing the collaborative care ecosystem around Nancy.

Diving deeper into medication management, CareCompanion acts as a diligent aide. It schedules and keeps track of Nancy's medication timings, ensuring she gets the necessary dosage at the right intervals. Following each intake, post-medication alerts are sent out, ensuring Nancy's well-being and keeping her caregivers informed.

In essence, CareCompanion, through its myriad features, crafts a structured and reassuring environment for Nancy. It ensures she remains actively involved in her social circles, manages her health efficiently, and navigates the intricacies of daily routines with confidence and grace.

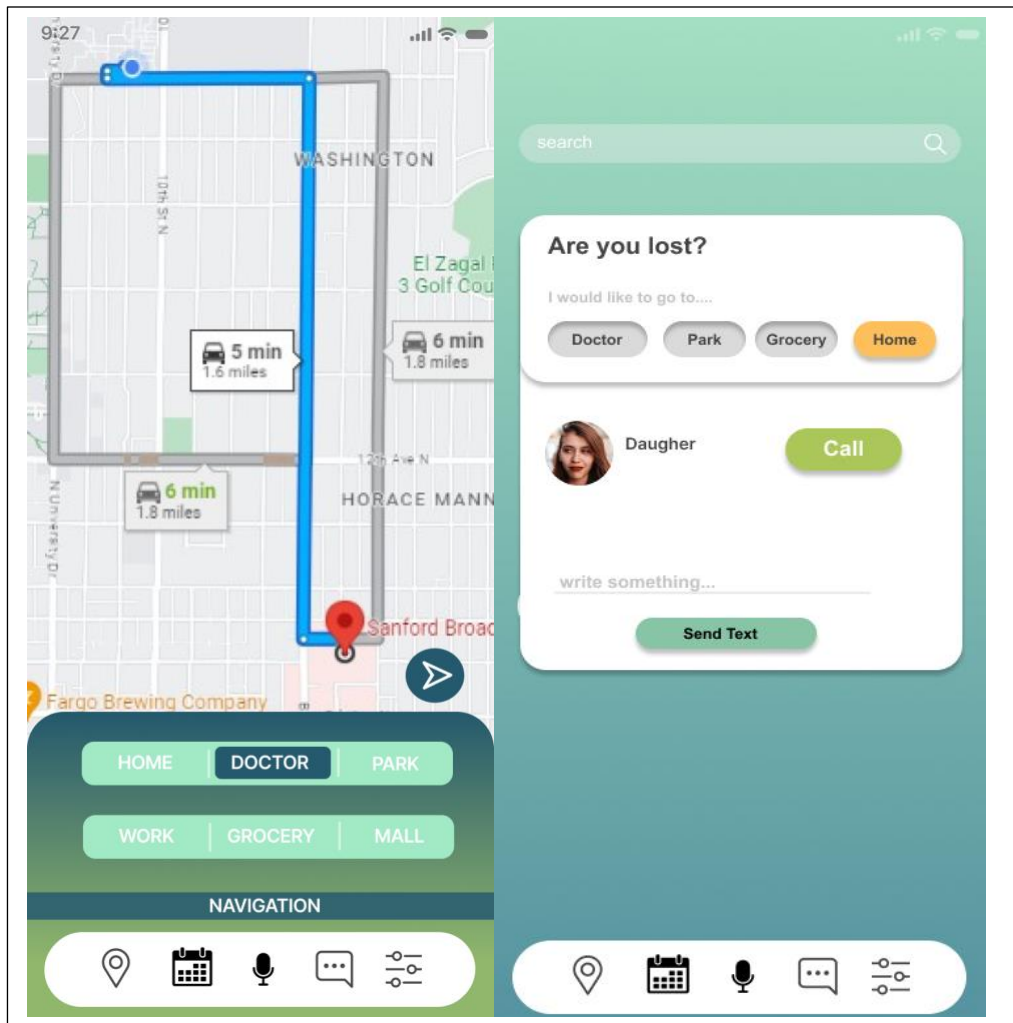


Figure 5. Navigation and wondering warning cases

#### 4.2.2. Navigation cases

Navigating the world with Alzheimer's Disease and Related Dementias (ADRD) brings its unique set of challenges. While the physical landscape remains the same, the cognitive map that individuals like Nancy rely on becomes increasingly foggy, making once-familiar terrains seem unfamiliar and daunting. In such instances, the role of technology becomes paramount, bridging the gap between disorientation and clarity. CareCompanion, with its suite of features, offers a guiding hand to individuals like Nancy, helping them find their way in a world that sometimes feels labyrinthine. Here are some illustrative scenarios that showcase the profound impact of CareCompanion on Nancy's daily life and navigation experiences.

#### ***4.2.2.1. Finding way home***

One morning, Nancy took a leisurely stroll in her neighborhood. However, as she delved deeper into her thoughts, the familiarity of her surroundings began to fade. Lost in a maze of winding streets, a cloud of panic began to overshadow her. In this moment of uncertainty, she turned to CareCompanion. By merely voicing her desire to return home, the virtual assistant sprang into action, providing her with concise and coherent directions. The once overwhelming environment became a navigable path, leading her safely back to her doorstep. This incident underscored CareCompanion's role as not just a navigational tool, but as a beacon of comfort in Nancy's moments of distress.

#### ***4.2.2.2. Navigating a familiar location***

One afternoon, as Nancy prepared for her doctor's appointment, she grappled with recollecting the clinic's location. Instead of succumbing to frustration, she sought the guidance of CareCompanion. Recognizing her intent and drawing from its extensive database of Nancy's frequented places, the assistant promptly provided her with the needed directions. Moreover, it complemented the visual directions with voice-guided prompts, ensuring that Nancy reached her doctor without any hitches. This episode highlighted the system's adeptness in making familiar journeys stress-free.

#### ***4.2.2.3. Ensuring safety during wandering behavior***

Nancy, like many with ADRD, occasionally wandered, veering off her usual paths. These unplanned escapades posed potential risks and worried her family. However, with CareCompanion's vigilant geofencing technology, her family had an added layer of security. On instances where Nancy would wander past the predefined safe zones, the system would swiftly detect this deviation. Without delay, alerts, complete with Nancy's real-time location, would be



sent to her immediate caregivers. This immediate relay of information not only provided Nancy's family with peace of mind but also equipped them to intervene swiftly, ensuring her safety at all times.

In these scenarios, CareCompanion emerged as more than a mere navigation tool; it became Nancy's trusted ally, guiding her through challenges and ensuring her safety and well-being.

### **4.2.3. Social connection cases**

For individuals like Nancy, diagnosed with Alzheimer's Disease, the world may often seem disjointed and distant, with social connections appearing elusive. This is where the innovative features of CareCompanion step in, illuminating the path to an enriched and connected life. The following scenarios delve deep into the layers of social interactions facilitated by CareCompanion for Nancy, underscoring the significance of staying integrated into one's community and social circles.

#### ***4.2.3.1. Engaging with local news updates***

Every day, as the sun rises, Nancy starts her morning ritual by conversing with CareCompanion. The virtual assistant promptly offers her a digest of the latest community updates, from notable neighborhood events to intriguing news stories tailored to her preferences. This daily dose of curated information keeps her grounded, reinforcing her bond with the local community and ensuring she never misses out on relevant happenings.

#### ***4.2.3.2. Discovering community events***

CareCompanion isn't just an information relay; it's an active participant in Nancy's social planning. The system alerts her to intriguing local events like craft workshops, community theater shows, or senior-friendly yoga sessions. With ample notice, Nancy can organize her

schedule, ensuring she remains socially active and embedded within her community. This proactive approach by CareCompanion means that Nancy has regular opportunities to mingle, make new acquaintances, and maintain her existing friendships.

#### ***4.2.3.3. Facilitating communication with family and friends***

In the digital age, physical distance shouldn't translate to emotional distance. CareCompanion aids Nancy in this, acting as a conduit between her and her close ones. With its easy-to-use interface, Nancy can send messages, make calls, or even share cherished moments with her family and friends, ensuring that even if miles apart, her heart stays close to those she loves.

In essence, Nancy's journey with CareCompanion paints a picture of a life with Alzheimer's that, despite its challenges, can still be filled with meaningful connections, enriching experiences, and unwavering support. The assistant's innovative design and adaptive features empower Nancy, ensuring that her diagnosis doesn't overshadow her zest for life and her need for human connection.

### **4.3. Role based testing**

Before CareCompanion can make a meaningful impact on the lives of older adults and individuals diagnosed with ADRD, it must first withstand the rigors of a comprehensive evaluation. To achieve a nuanced understanding of its capabilities, we embarked on an innovative role-based testing strategy. Over a span of two weeks, our dedicated team of lab researchers immersed themselves in this simulated environment, mimicking the experiences and challenges of both ADRD patients and their caregivers. Here's a deep dive into the intricate process:

- Scenario Design:

Central to this evaluation was the creation of diverse scenarios, each mirroring the daily realities faced by the ADRD community and their caregivers. From managing reminders and seeking navigation aids to nurturing social connections, these scenarios were tailored to test every facet of CareCompanion, ensuring no feature went unscrutinized.

- Role Assignment:

With the scenarios set, our lab researchers stepped into the shoes of their assigned roles. Some took on the persona of ADRD patients, channeling the characteristic cognitive challenges, while others embodied concerned caregivers. This role immersion ensured a genuine interaction experience with CareCompanion.

- Interaction and Performance Evaluation:

Donning their assigned hats, researchers initiated a series of dialogues and tasks with CareCompanion. Whether it was seeking event reminders or asking about local news, every interaction was meticulously documented. Key performance indicators like accuracy, system responsiveness, and user satisfaction were noted during these sessions.

- Data Analysis:

Post-interaction, the accumulated data underwent a meticulous analysis. By assessing metrics like success rate and the relevancy of responses, the team gauged CareCompanion's efficacy. Beyond the numbers, subjective experiences about system fluidity and user-friendliness were also taken into account to paint a comprehensive picture of the virtual assistant's potential.

Table 1 offers a comprehensive breakdown of findings from our role-based testing strategy. This table is thoughtfully segmented into distinct scenarios, each spotlighting a pivotal

feature of CareCompanion, namely: Reminder Management, Navigation Support, and Social Connections.

In every scenario, two core perspectives are considered - that of the ADRD patient and their family member or caregiver. This dual approach ensures a holistic evaluation. The table then delves deeper, detailing the specific tasks undertaken by each role in the context of the said scenario. For every task, there's a clear benchmark - the expected outcome. This serves as the standard against which the system's real-time performance is gauged.

Not stopping at mere task execution, the table also quantifies CareCompanion's efficacy in two key metrics: the rate at which tasks were successfully executed and the accuracy of the information CareCompanion furnished in response to user queries. These metrics are instrumental in understanding the technical prowess of the system.

Lastly, a pivotal component of the evaluation is the user experience score. Ranging from 1, which signifies a less than satisfactory experience, to 5, denoting an exemplary user interaction, this score encapsulates the intuitive nature, ease of use, and overall satisfaction derived from interacting with CareCompanion.

Table 1. Performance test evaluation table for role-based testing

Scenario	Role	Tasks	Expected Outcome	Success Rate (%)	Information Accuracy (%)	User Experience* 1(worst) – 5 (best)
Reminder Management	ADRD Patient	Receive reminders	Timely and accurate reminders	100	100	5
		Ask for schedules	Accurate Schedules	100	100	5
	Family Member	Set reminders	Reminders set successfully	98	100	4
Navigation Support	ADRD Patient	Request direction to familiar place	Accurate directions provided	100	100	5
		Request direction to a specific address	Accurate directions provided	100	100	5
	Family Member	Set favorite locations	Locations set successfully	96	100	4
		Get warning for wandering behaviors	Get wondering notification successfully	100	100	5
Social Connections	ADRD Patient	Get local news	Relevant local news provided	100	100	4.5
		Get Community events	Community events notification provided	100	100	4.5
		Communicate with family members	Call and SMS sending were successfully	100	100	5
	Family Member	Subscribe news and events	Successful subscription to news and events	100	100	5
		Communicate with patients	Call and SMS sending were received and sent successfully	100	100	5

\*User experience includes system's responsiveness, ease of use, and the extent to which it met the needs and expectations

Here's an elaborated overview of each column:

- **Scenario:** This column highlights the specific function of CareCompanion under examination. It encompasses areas such as Reminder Management, assisting with Navigation, and facilitating Social Connections.
- **Role:** This designates the participant's identity during testing — either an individual diagnosed with ADRD or a family member assisting them.

- **Tasks:** This delves into the exact actions or queries made by the participant, be it setting a reminder or seeking directions to a location.
- **Expected Outcome:** It delineates the ideal response or result the CareCompanion system should exhibit for each task executed.
- **Success Rate (%):** A crucial metric, this depicts the efficiency of the system, showcasing the frequency with which CareCompanion met or surpassed the expected outcome.
- **Information Accuracy (%):** Going beyond mere task execution, this metric gauges the validity of CareCompanion's responses, reflecting the instances where the system's information aligned perfectly with the query.
- **User Experience (1-5):** This offers a subjective assessment from the participants. Scored between 1 (indicating a lackluster experience) to 5 (representing a seamless, highly satisfactory interaction), it measures the overall user satisfaction and system intuitiveness during each task.

In the displayed table, CareCompanion's efficacy across various functionalities is evident, boasting commendable success rates and a high degree of accuracy in the data it provides. Users predominantly experienced a smooth interaction with the system, as reflected in the favorable user experience scores. However, certain nuances were observed when family members interacted with the system. Specifically, while setting reminders or saving favorite destinations, voice command interpretation seemed to be a challenge. These minor hitches led to occasional command repetitions and marginally affected the overall interactive experience.

Elaborating on the user experience score derivation, a systematic procedure was set in place. Lab members meticulously gauged each encounter with CareCompanion on a

predetermined scale, spanning from 1 (indicative of an unsatisfactory experience) to 5 (showcasing a flawless interaction). Different lab members were tasked with evaluating distinct elements of the system. These elements spanned from how promptly CareCompanion responded to queries, its user-friendliness, and its alignment with user expectations. These criteria, thoughtfully chosen, encapsulated the vital dimensions of a user's experience. This rigorous assessment ensured that the feedback acquired was holistic and had substantial depth.

Upon the completion of all interactions under various scenarios and assigned roles, individual scores from lab members were consolidated. An average score was then deduced by aggregating these scores and dividing them by the total interactions. This process provided a median user experience score, representative of the system's overall performance.

By employing a role-based testing paradigm, the assessment of CareCompanion transcended mere technical evaluation to simulate authentic user challenges. This not only enabled a granular analysis of its functional prowess but also illuminated its strengths and potential improvement areas.

Such findings from these role-centric assessments endowed the research team with rich insights into CareCompanion's operational dynamics. They could pinpoint specific areas needing tweaks, streamline operations, and rectify any anomalies. Yet, it's imperative to recognize the role-based tests, conducted within a lab setup, as preliminary evaluations. While they provide an insightful foundation, real-world validation with genuine ADRD users is quintessential. These preliminary tests lay the groundwork, ensuring that CareCompanion transitions seamlessly into the subsequent testing phases and is adeptly primed for deployment to its intended user base.

## 5. CONCLUSION

In this article, we introduce "CareCompanion," a cutting-edge virtual assistant meticulously crafted for the elderly, especially those grappling with ADRD. Embedded with sophisticated AI frameworks such as natural language processing, machine learning, and expansive knowledge graphs, CareCompanion stands as a beacon of hope for challenges arising from memory lapses, navigational hurdles, and feelings of detachment from the social fabric. Initial evaluations reflect CareCompanion's vast potential in uplifting the life quality, autonomy, and social interactions of older adults and those with ADRD.

However, while these preliminary findings shine positively on CareCompanion, certain study constraints warrant mention. Notably, the evaluations were based on lab-created simulations instead of real-time interactions with the target demographic. While these simulations offer valuable insights, the authenticity of feedback from actual users in their everyday settings would undoubtedly elevate the validation.

Our forward trajectory is set on the integration of genuine user interactions. The upcoming phases aim to dive deep into the experiential feedback of the elderly and those with ADRD, offering a layered analysis of CareCompanion's diverse offerings, user-friendly nature, and adaptability quotient. Garnered insights from these users will play a pivotal role, enabling iterative refinements to ensure CareCompanion resonates with its intended audience seamlessly.

In essence, CareCompanion is poised as a promising beacon, ready to combat the multi-dimensional obstacles faced by older adults and those with ADRD. As we venture into successive phases of research and enhancement, grounded in real-world user experiences, our objective remains clear: to continually refine CareCompanion. Our mission is to empower individuals, enabling them to effortlessly manage their daily commitments and nurture their



social bonds, all while minimizing the strain of memory challenges, navigational barriers, and the looming shadow of societal disconnection.

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