

Dependability Requirements to Aid the Design of Virtual Companions for Later Life^{*}

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Abstract: Frail older people can normally not be given round-the-clock care-giving assistance. During the time there is no other person around they must be independent. Electronic assistive technology (EAT) can increase an older person's independence in everyday life, but to do so it must be dependable. This paper examines issues of dependability for a special class of EAT software, virtual companions for later life. A virtual companion is a personal system of interconnected functions aiming to assist an elderly user by imitating elder-caregiver interaction. In order to provide designers with an aid for defining, designing, and validating virtual companions, the first part of the paper identifies and discusses the special dependability requirements to be put on such software. The second part describes our own approach, and gives suggestions on how to design for dependability.

Keywords: electronic assistive technology, elderly, independence, dependability, trustworthiness, virtual companion, requirements, multiagent system, agent-oriented software design, user-centred software design, human-computer interaction

1 Introduction

It is a major concern of many frail older people to sustain independence in everyday life. This desire may be psychological [48], or practical in that one might need, but cannot be given round-the-clock care-giving assistance. Formal care services offer limited amounts of hours. In addition, a recipient may not be able to afford these. In Swedish municipalities, individually assigned home care usually varies between 1 and 119 hours/month (1–9 h: 37.2%, 10–25 h: 24.3%, 26–49 h: 17.9%, 50–119 h: 15.8%) [35, Table 3]. In the US, formal home care is 12.55 hours/week for the average recipient [27, Table 6]. Often, informal care must be added. This need is common and increasing in Sweden [47]. It is decreasing in the US (as in Japan [47]), but only within already high needs. In 1994, 64.3% of non-institutionalised disabled older people in the US were helped only by informal carers; 28% used both formal and informal home care [27, Table 2]. Obviously, informal care hours are also limited; these people need to handle their own lives, too.

Electronic assistive technology (EAT) can increase an older person's independence and improve quality of life [43]. In our work on advanced EAT, we adopted the frequent metaphor of a *virtual companion* for later life. It denotes a personal system of interconnected functions which aims at assisting an elderly user by imitating elder-caregiver interaction. This paradigm differs from smart homes in that a separate, 'man-like' presence is introduced, instead of making existing appliances smart. Imagine a software that 'accompanies' its user to the kitchen. It might interactively explain preparation of his or her favourite meals, and at the same time monitor him or her to anticipate accidents. Examples of virtual companions include personal service robots capable of e.g. escorting and reminding (Nursebot [4, 39], Robo-Care [7]), smart phones offering services like grocery shopping [29, 17, 44], and cognitive assistance integrated into smart homes (I.L.S.A. [19, 20], intelligent habitat [37, 38]).

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EAT can increase independence from human help only if the user can depend on the software instead. Hence, dependability is of crucial importance. How can it be achieved in a companion? In order to provide designers with an aid for defining, designing, and validating instances of this special class of EAT, Section 2 identifies and discusses requirements to be put on dependable companions. Section 3 describes our own approach, and formulates general design suggestions. Section 4 compares our approach to a toolkit for creating smart homes – a related class of EAT.

2 Requirements on Dependable Virtual Companions

A good companion is somebody you can depend on. But what does this mean? Laprie's original definition of dependability calls it 'the ability to deliver service that can justifiably be trusted' [2, page 2]. Vice versa, trust is often defined as a 'willingness to depend' [16, Table 1]. Hence, dependability and trustworthiness are basically equivalent [2, Appendix 2]. Dewsbury et al. [11] consider Laprie's model too technical for domestic EAT. In their own model, they add attributes, and make it holistic in that it demands the whole interplay between user, technology, and environment to be free of faults. Miller et al. [31] provide another list of design goals for trustworthy EAT, stressing safety as the primary objective.

This section collects requirements to help designers define, design, and validate dependable virtual companions. Originally, our work was guided by the non-functional requirements multifunctionality, adaptivity, and realistic specification [28]. These had been derived from literature and discussions with researchers in the area of ageing, as well as a survey of EAT research. Subsequent design work however revealed a need for more differentiated, complete, and verifiable requirements. In search of accepted and suitable requirement types, we studied literature on dependability, extracted relevant attributes, and specified their meaning for the case of virtual companions. Table 1 presents the findings with motivations and an illustrative case (Mrs N appears in [18]). It lists the requirements as general objectives applicable to any companion software. For a concrete system, they still need to be made testable (cf. [45]).

Table 1: Dependability requirements

Attribute	Specific requirements	Motivation	Example case
Adaptability Design for inter-individual variance; changeable configuration [31, 11]	A virtual companion must be personalised for its individual user and his or her living environment. It must be possible to easily add, update, and remove services and personal data. Updates should not lead to the inclusion of new errors.	Applications made for 'the elderly' may not work for a particular user [36]. For instance, most older people are not forgetful [14], and do not need reminders. They sometimes outperform younger people in everyday life prospective memory tasks [32, 30, 8]. A user may become forgetful later though, i.e. after the installation of the companion.	Our user Mrs N does not need a companion to remind her to take medicine, but to remind her to lock the wheelchair brakes. Later, she may have learnt to do this – or become more forgetful and need the medication reminder. She may further acquire a new wheelchair with a different breaking mechanism, or be prescribed new pills.
Availability Readiness for correct service [2]	A companion must not only hold its services ready, but also proactively offer them.	Active user requests may not be possible in situations when help is needed most [31]. Furthermore, patients trust human nurses to act in their interests without always spelling out what that means [10].	Mrs N will not issue a command, when she has fallen and is lying unconscious on the floor. But neither can interactive tasks like collaborative food preparation be expected to be called on.

<p>Relevance Support of the 'right' tasks [5]</p>	<p>A virtual companion must be multifunctional, i.e. offer more than only a few solutions to a few problems.</p>	<p>Assistive interaction in everyday life is complex. Most frail older people receive help with two or more ADLs[†] [15, Table 4] or IADLs[‡] [34, Table 2]. Also, there is social, emotional, and other dependency. People regulate dependency by different strategies: selection, optimisation, compensation [3].</p>	<p>Mrs N needs to learn food preparation from her wheelchair and be protected from accidents in the kitchen. A companion offering guidance in food preparation, but not guidance during fire emergencies may fail, as may a companion offering guidance during fire emergencies, but not training to prevent fires.</p>
<p>Acceptability Perceived as useful and easy to use [9]</p>	<p>Acceptability is threatened if a virtual companion cannot live up to its metaphor. First, interaction with it must be pragmatic, so that independence increases, and quality of life is enhanced (cf. [31]). Second, the effort saved by using the system must significantly exceed the effort of using it [11]. Interaction must be predictable and persistent, allowing the formation of mental models [33].</p>	<p>Acceptability is especially important due to a companion's expected pervasiveness in everyday life. It is conceived not as another tool, but an artificial 'companion'. Usefulness is important due to the ambitions of assistive technology; ease of use due to a probable lack of computer skills on the part of many users.</p>	<p>If Mrs N perceived her companion as merely an entertaining illusion, she could just as well play a video game, and do the kitchen work alone. In fact she could not, as she is not independent. She must not be confused by the many, interconnected functions. When warning that the cooker has been left on, which might cause a fire, the companion must use the same language as in training fire prevention or guiding food preparation.</p>
<p>Competence Working properly by routine performance, technical facility, and expert knowledge [33]</p>	<p>A companion must be intelligent and deliver not only correct, but also 'good' service. This requires smart algorithms that process personal, care-related, and technical knowledge or rules in relation to the environment context. Knowledge and rules must be obtained from the user, caregivers, and experts in relevant domains.</p>	<p>Software engineers may implement routine competence, but technical facility and expert knowledge must come from people who know. Having knowledge and rules constructed by trusted people should further increase initial trust in the system – like initial trust in nurses is based on trust in the health care system – and preserve basic moral judgement – a quality beyond technical competence expected from caregivers (cf. [10]).</p>	<p>Mrs N could not depend on an incompetent companion that demonstrates wheelchair transfers that are based on intuition and will not work in practice, or that has only a vague perception of her kitchen. Moral judgement would be preserved by coded knowledge of preparing not only a nutritious salad, but also one that tastes good.</p>

[†] Activities of daily living: Bathing, dressing, toileting, transferring, continence, eating [24].

[‡] Instrumental activities of daily living: Telephoning, shopping, food preparation, housekeeping, laundry, transportation, medication, finances [25].

<p>Reliability Continuity of correct service [2]</p>	<p>A companion must be fault-tolerant. Reliability is threatened, if it does not anticipate, notice, or take care of errors. Errors may be internal, on the user's part, or in the environment [42].</p>	<p>The user's quality of life may depend on correct service [11]. A human caregiver usually notices when he or she has done something wrong, and finds a way to compensate by doing the task differently. The technical equivalent would be concurrent error detection with rollforward [2].</p>	<p>If the companion's ability to close the kitchen window when it gets cold malfunctions, the system should notice the error, and find another solution, e.g. guide Mrs N to the window, and explain how to close it. In case of human error – she is too weak or sleeping – service might be continued by calling neighbours for help.</p>
<p>Adaptivity Fitness for purpose; tailored to individual needs during use [11]</p>	<p>Services must automatically adapt their kind and degree of automation to changing user goals and preferences, as well as interests and motivation.</p>	<p>Human caregivers provide needed assistance according to functioning in relation to ADL/IADL scales [24, 25] and occupational therapy assessment (cf. [26]). Too much help though can effect an old person to give up learning [23]. Functioning worsens or improves with time. Interests and motivation should be considered, as a trustworthy nurse does not only care <i>for</i> a patient, but also <i>about</i> him or her [10].</p>	<p>When Mrs N has learnt food preparation, this goal disappears, and the companion may deactivate training. This service should not be removed, as a time may come when she needs to revise. Preferences may include that she has trouble reaching, but is an excellent cook. Then, wheelchair positions should be explained, but not food recipes. Interests include favourite dishes; motivation why she wants to train.</p>
<p>Safety Not causing harm [31, 2]</p>	<p>Safety-threatening errors must be avoided. Risks include inaccurate situation assessment and inaccurate response generation. A companion must therefore understand the environment context and consequences of actions. When uncertain, it should involve human judgement.</p>	<p>Consequences of failure can be particularly severe for an already vulnerable user like a frail old person.</p>	<p>Mrs N's companion may open the window when it gets warm. This response will threaten her health though if there is rain, a smoker, or pollen she is allergic to outside [23]. Moreover, no water must flow into a full basin, and wheelchair brakes may be released only when Mrs N is about to move.</p>
<p>Security Keeping information and services confidential [2]</p>	<p>Access to a companion must be restricted to authorised persons, especially with respect to network-based services.</p>	<p>Unauthorised disclosure of information would have bad effects, as this EAT relies heavily on personal information. Unauthorised system state alterations would threaten particularly services for health and safety.</p>	<p>Mrs N will not want others to discuss her medical status, or observe intimate daily living routines. Criminals must not alter the configuration of her alarm equipment.</p>

3 Designing for Dependability

We are convinced that systems that meet the above requirements can be realised. To aid the designer of virtual companions in accomplishing this, this section presents our own approach, and then generalises ideas to give suggestions for the design of any companion software.

In compliance with the requirement of **adaptability**, our virtual companions will not be off-the-shelf products, but fit individual users. Let us return to the case of Mrs N. She is 73, lives with her family, but needs to be independent during morning and afternoon. This is difficult due to impairments in walking and different activities. Mrs N needs to learn food preparation from her wheelchair, and be protected from falls – she easily slips – and fire in the kitchen. She propels her wheelchair alone, but forgets to lock the brakes 30% of the time [18].

It would be inefficient, if software engineers had to create a companion for each such profile from scratch. We therefore plan to give users, caregivers, and experts a generic toolkit that enables them to build and maintain individual companions on their own. It will come in the form of a simple tool or programming language that allows the formulation of specifications, validates these, and compiles them into an initial companion, or later adds, updates, and removes parts. The toolkit will be based on a well-defined framework, which consists of a generic multiagent *architecture* plus a *specification process* for selecting, combining, and instantiating pre-implemented components.

A companion in terms of the architecture is a multiagent system: Figure 1. An agent is understood as a software module capable of autonomous behaviour, deliberation, i.e. reasoning on the basis of goals and knowledge, and/or reactivity, i.e. responding to outside stimuli, and for some agents learning. In a multiagent architecture, multiple agents are active concurrently. They communicate and work together in order to realise the global behaviour.

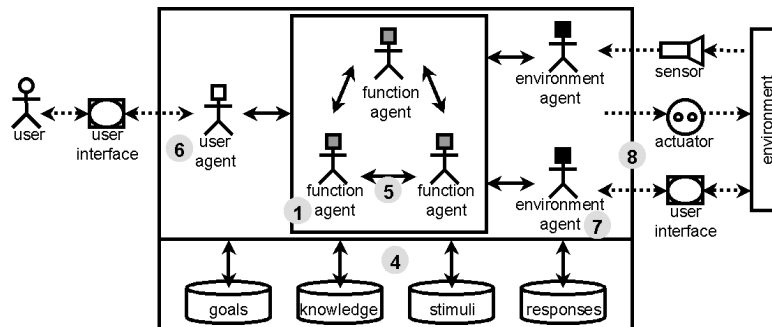


Figure 1: Generic framework architecture

The specification process involves filling the architecture by specifying each desired agent, one at a time. These are high-level decisions which have pre-defined low-level effects. For instance, creating an agent as an *environment agent* (item 7 below) automatically determines how it communicates. It will fit into the system like any environment agent, without bringing along new communication-related errors. In our scenario, this means that Mrs N's wheelchair can be easily replaced by a new model.

A description of the specification process and underlying architecture follows.

1. *Function agents*: Each companion is initially configured with a set of services. A service is added by specifying a function agent. After configuration, every new function agent is activated. It will autonomously check for short-term user goals, and proactively help if it can. This implements **availability**. For example, a *safety monitor* (cf. item 2) in Mrs N's companion would continuously monitor her and the environment, and act when a stimulus indicated a safety threat. A *food preparation guide* might offer its service when somebody enters the kitchen at noon.

2. *Combination*: Each function agent is specified as a pair of a *function* component ('the algorithms') determining autonomy, learning, and agent communication, and an *application area* component ('the data') determining goals, basic knowledge, and basic stimulus-response rules. By combining these two types of independent modules, many types of assistance in many possible situations can be defined, and **relevance** be achieved. Mrs N's companion might contain the function agents of Figure 2.

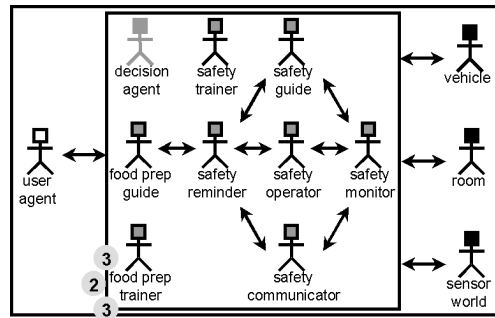


Figure 2: Agents in Mrs N's companion

3. *Components*: An example of a function component in Figure 2 would be a *trainer*. It stands for user-companion interaction in which a lesson is taught, and revised in an exercise. To attain usefulness, and thus **acceptability**, imitation of user-caregiver interaction must be pragmatic. Patterns of pragmatic elder-caregiver interaction can be derived from literature or, even better, through ethnographic studies (cf. [46]). Our ten basic functions (Figure 3) will implement ten patterns of assistive interaction derived from analysing literature on elder-caregiver communication ([6, 21, 40] and others). Application areas represent needs. We organised these in a hierarchy: Figure 4. In Mrs N's kitchen companion, *food preparation* and *safety* have been combined with functions. Further on, virtual companions seem to imply ease of use by providing uniform interfaces to different services. But this will only work with uniform behaviour underneath. To attain this, we employ ontologies. Agents will relate to the same concept when referring to a 'fire'. They further share databases. Thus, a *food preparation guide* and a *safety guide* will explain wheelchair movements in a similar way.

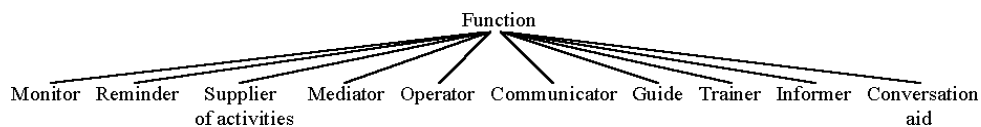


Figure 3: Functions

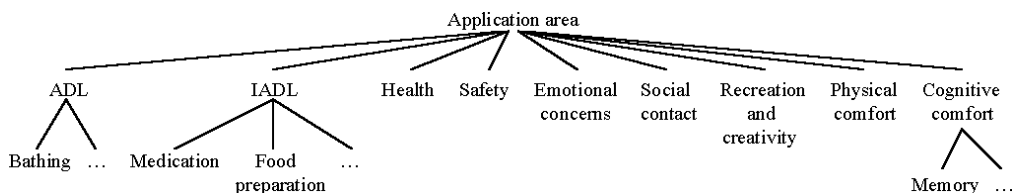


Figure 4: Application areas

4. *Databases*: Autonomous behaviour and basic rules or knowledge that it works on come with a function agent's function and application area. Advanced technical facility and expert knowledge however will not be pre-implemented, but obtained from user, caregivers, and experts through knowledge acquisition techniques (see e.g. [13]). The toolkit will facilitate specification, so that a plumber can model safety risks without drawing transition systems, and an occupational therapist can enter an ac-

tivity analysis [26] (Figure 5) without defining mathematical relations. This final function agent step lends **competence** to it.

Activity 'food preparation'			
Get in wheelchair	Open door	Reach	Cook until finished
Move wheelchair	Check supplies	Grasp	Serve
Position wheelchair	Choose recipe	Cut	
Lock brakes	Follow recipe	Stir	
Unlock brakes		Turn	

Figure 5: Knowledge about food preparation

5. *Multiple function agents*: Added function agents will communicate and work together. It is sensible to add redundant agents – different functions for the same application area – so that agents can choose which other agents to contact. Some agents will watch over others, notice errors, and learn their performance in certain situations. In Mrs N's companion (Figure 2), the *safety monitor* may notice that it gets cold and that the *safety operator* has mistakenly opened the window. It can then ask the *safety guide* to help Mrs N close the window, or the *safety communicator* to call a neighbour, depending on past experience. Another exploitation of redundancy is when two agents cause one other to do a task, to make sure that it is done. Redundancy and learning agents watching over each other should increase **reliability**.
6. *User agent*: One user agent is added as an internal representation of the user. As a variant of traditional user modelling (e.g. [1]), it does not only store goals and preferences – which here are specified by user, caregivers, and experts – but it also acts on the basis of this knowledge. It manages the user interface, and communicates with function agents, realising two types of **adaptivity**: By matching its goals against function agent goals, it activates and deactivates function agents. By matching preferences against function agent knowledge, it determines assistance that helps enough, but not too much. Interests and motivation are also considered. The user agent knowledge in Figure 6 could be used to make a *food preparation guide* help with wheelchair positioning, but not recipes. Recipes would still be available, and if Mrs N consistently requested them, this would be learnt as a new preference.

User 'Mrs N'			
Cannot position wheelchair	Limited reach	Visual learning style	Motivation: Independence
Does not lock brakes 30%	Limited grasp		Interest: Likes egg salad

Figure 6: Knowledge about Mrs N

7. *Environment agents*: Different environment agents are added as representations of people and things in the environment. For each agent, an *environment type* component – e.g. *sensor world* or *vehicle* – is selected. It determines goals, basic stimulus-response rules, and if needed basic knowledge. Rules representing technical facility or expert knowledge are chosen and added by user, caregivers, and experts. Autonomous behaviour and communication are the same for all environment agents: People and things are monitored through sensors, manipulated through actuators, and interacted with through user interfaces. Function agents simulate environment agents' responses to stimuli before sending them to the real world. This adds **competence** and **safety**. As an example, the *sensor world* in Figure 2 may model Mrs N's kitchen sink: Figure 7. By sending stimuli, the *safety operator* would simulate that turning on water is unsafe when the basin is FULL and the drain closed. Things would be more uncertain if the state were alternating between HALF-FULL and FULL, and sometimes water were on, sometimes off (Mrs N is doing the dishes). The companion would then give up autonomy and involve human judgement (adjustable autonomy [41]). Such interaction is handled by a special *decision agent* (Figure 2).

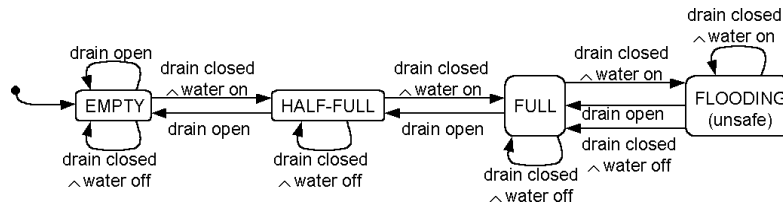


Figure 7: Rules for a kitchen sink

8. *Infrastructure*: User interfaces, sensor and actuator hardware, as well as a connected network are regarded as external to the framework and assumed as ‘given’. We are however aware that mechanisms for authentication and control of data transfer are needed to restrict access from the outside. We refer to Herzog and Shahmehri [22], who discuss possibilities and vulnerabilities of *residential gateways* as **secure** interfaces for remote access to connected homes.

In summary, we give the following general suggestions for the design of dependable companions: Make designs generic, so that individual configuration is possible. Increase availability by making services proactive. Design algorithms and data as independent modules to be combined for support of many situations. Implement patterns of pragmatic interaction, and adjust behaviour to ontologies. Design smart algorithms that exploit the competence of users, caregivers, and experts. Design redundant services that watch over each other and remember each other’s performance. During usage, have services be activated and deactivated according to user needs. Have services adapt to how much assistance is needed. Simulate consequences of actions. When this does not work, involve human judgement. Finally, restrict and control remote access.

4 Related Work

We know of one other specification toolkit for user-centred design of advanced EAT. CUSTODIAN [12] helps specify smart homes. In comparison to our approach, Dewsbury et al. deliberately allow less flexible design, in order to ensure reliability and safety. This makes sense, as smart homes centre on hardware appliances, whereas virtual companions centre on interaction with the individual user. Virtual companions need to emphasise adaptability and competence, which are connected to detailed specifications. Still, we think that these attributes are not naturally in conflict, and do not naturally demand trade-offs.

5 Conclusions

The paper introduced virtual companions as a special class of EAT. They aim at increasing frail older people’s independence in everyday life by imitating elder-caregiver interaction. Independence can only increase if the companions are dependable. To aid the design of dependable companions, we collected requirements specific to such software. Virtual companions must be adaptable, available, relevant, acceptable, competent, reliable, adaptive, safe, and secure. We showed how dependability is realised in our framework, and gave general design recommendations.

Our next step in this work is a step from requirements and design to implementation. We plan to create a concrete instance of a companion in the form of the virtual kitchen companion that served as an example throughout this paper. This will help us validate and finetune the design of architecture and specification process, and thus come closer towards the generic toolkit we envision.

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