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Master thesis report for the MSc Embedded Systems

TU Delft – Interactive Intelligence

Value Based Smart Reminders: Finding Appropriate Moments for Support in Socially Adaptive Electronic Partners

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# Abstract

This project will focus on finding what defines an appropriate moment in regards to providing support through a Socially Adaptive Electronic Partner (SAEP). Specifically, the goal is to find a way in which smart reminders systems can be extended through the use of user values to ultimately provide appropriately timed supportive feedback. A system is designed from scratch, combining existing concepts of activity prediction and value based design. A statistical Markov chain model is made from predictions based on several machine learning algorithms. A simplification is done to focus on the invoked nuisance of a notification and the effect of time on the effectivity of remembering. These values are quantified and optimized in the model to identify an appropriate moment for a notification. The model is implemented in a Node.js web application, following the principles of a RESTful web API. The model is shown to work in roughly 60% of the cases. Overall, a clear approach to value based smart reminders are shown in a statistical and dynamic approach to incorporate the concept of user values.

**Rewrite**

# Table of common terms

|  |  |
| --- | --- |
| **Term** | **Description** |
| ADL | Activities of daily living |
|  |  |
| SAEP | Socially Adaptive Electronic Partner |
| Middleware | Software layer that acts as acts a link between two layers by processing data before it is passed from one to the other. |
|  |  |
| Markov chain | Probabilistic model describing a sequence of events based solely on the state attained in the previous event. |
|  |  |
| Clustering | A method of grouping data points according to an algorithm |
|  |  |
| Route | And endpoint (or address) for an HTTP request |
|  |  |
| Hostname | Label or address used to identify a device. Usually this will be the domain linked to a certain IP address. For example: google.com |
|  |  |
| Endpoint/URL | Universal resource locator. The location, or address, of a certain resource. For example: http://www.google.com/search?query=blah |
|  |  |
| Path | The location identifying component of the URL. For http://www.google.com/, this would be ‘/’. For http://www.google.com/search?query=blah, this would be ‘/search’ |
|  |  |
| API | Application Programming Interface. A set of definitions used among applications to communicate between one another. |
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| RESTful | An API standard based on representational state technology (REST). A standardized, architectural approach web communication using HTTP methodologies: GET, POST, PUT, DELETE |
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# Reader context

This report was written for a diverse audience. It is equally meant for academics from various fields, experts from related companies, as well as the intelligent, common reader. As such, a choice was made to include explanations of several basic ‘text book’ principles of the various topics.

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# Introduction

It is natural for humans to increase their dependence on technology as technology improves [1]. Through applications in smart homes, wearables, virtual coaches and many others, people have increasingly adapted modern technologies into their daily lives. Their goals are to increase health, efficiency and many other values. Conversely, the abundance of apps and notifications have a negative effect on the users and cause them to grow immune to the constant stream of information that is presented to them in a daily basis [2]. Especially the elderly or people with a mental impairment could benefit from an effective support agent [3]–[8].



Figure 1.1: Overload of notifications

A proper implementation of such a support agent could improve the effectiveness of all notification-based applications. “Too many notifications cause the user to tune out” [9]. Rather than bombarding the user with notifications right when a related event occurs, the user is much more likely to act upon the notification if it is delivered at an appropriate time.

But what actually is an appropriate time? The appropriate time for notification is inherently linked to the nature of the user’s action. To illustrate this, consider the following example throughout this report.

An elderly gentleman, Peter, often forgets to close the garden doors before leaving the house or going to sleep.

In this example, timely notification is of the essence. The current situation? Usually a simple timer is set moments before the expected time of the deadline. Obviously, this is not very fool proof. The ideal solution? Getting a notification just before the deadline of sleeping or leaving the house. A smart reminder, so to say.

However, both solutions have an additional caveat. Say a person never checks their phone during cooking or does not want to be disturbed while working. Any notifications delivered then will be ineffective. So, the ideal solution is not only to find a moment just before the deadline, but to make sure that moment is an acceptable moment to notify.

Preliminary research has shown that there are many applications that attempt to use knowledge about their user’s activities. However, only few actually manage to create a predictive model that preempts the deadline. The following examples are of existing products and applications that combine user and device information in order to provide smarter notifications.

Olisto/IFTTT [10], [11] Can combine date, location and smart device information to, for example, send a notification when leaving home and a specific power consumption is still high (i.e. the TV is still on).

Maps/Waze [12], [13] Combines real-time traffic information and address in calendar events to provide timely departure reminders.

Timeful [14] Combines the user’s calendar and to-do items to estimate duration of to-do items, plan them in and generate reminders at off-peak times.

Similar to the implementations, papers frequently focus on finding novel ways of combining information from smart devices into producing reminders, following norms provided at design time. Examples include combinations of location and time [15]–[17], events based on smart devices [4], [18], [19], or a combination of numerous sources of information [20]–[22]. While all very promising, most concepts and implementations predominantly rely on design time logic. Exceptions to this, such as Timeful [14], usually create a predictive model and verify this with the user in order to strengthen the model. Nonetheless, not a single of these implementations take the user into account at the time of the notification.

In order to make an application aware of how the user may perceives the incoming notification, knowledge is required about a user’s values. Van Riemsdijk introduces the concept of a Socially Adaptive Electronic Partner (SAEP) [23]. A SAEP follows the ideology that technology should adapt to the user and not vice versa. This is achieved by providing methods in which applications can be made aware of a user’s values. Through this logic it is possible to gain an understanding about finding an appropriate moment for notifying the user, rather than just focusing on the timing.

## Problem description

The problem of finding an appropriate moment for notification boils down to a number of steps. For starters, in order to provide a reminder notification before a certain deadline, it is imperative that this deadline is known. Consecutively, the preceding activities have to be identified. For this, an existing smart reminder system or predictive model has to be chosen. This, in turn, can only be done once there is sufficient knowledge about the user’s activities of daily living (ADL).

Ultimately, the existing model can be extended using user values in order to provide more appropriately timed notifications.

### Research scope

Prior to being able to establish the research questions, the scope of the research should be limited since the problem itself is very broad. Most notable, since the area of activity recognition is a rapidly evolving one. However, the current state is that any form of activity recognition based on raw sensor data is still very limited or inaccurate in general solutions [38]. Accuracy can be improved by having location specific setups [24], or a severely limited number of recognized activities. Over the coming years, quality and accuracy of activity recognition is expected to increase thanks to, among others, the exponential rise in IoT devices in houses and public building [37] providing more and different data, as well as the improved sensors in and capabilities of smartphones. Even partly focusing on actual activity recognition would therefore be a substantial enlargement of the scope of research. As such, a choice was made to make use of existing datasets or data streams hat directly provide information about the user’s ADL. However, to not limit the applications of the designed concept and implementations, instead the focus was shifted from the aspect of activity recognition and placed onto a proper form of implementation.

## Research question

Following from the concepts discussed previously, the focus of this thesis will be combining the concepts of existing models and trying to extend them with the concept of user values. This leads to the main research question:

How can a smart reminder system be extended to incorporate user values to provide more appropriately timed notifications?

The expected outcome of this question is a model which provides timed feedback based on the user’s ADL and value input. Subsequently this leads to a number of sub-questions that need to be answered before this.

While it was discussed before the numerous existing smart reminder models exist, it was found that only a few actually use a predictive model to analyze future activities. This, among others, are requirements that need to be decided analyzed in pursuit of an appropriate model.

R1: What are the requirements for the smart reminder system model?

Subsequently, existing concepts and implementations should be tested and compared for these requirements.

R2: Which existing models and systems exist for smart reminder systems and how do they compare?

These two questions should provide a good overview on the abilities of the existing systems and the amount of work required to extend them to incorporate user values and to ultimately improve the timing of the notifications. Of course, for this knowledge about user values is required.

R3: How can user values be analyzed and quantified?

R4: How can a smart reminder model be extended to incorporate user values?

Ultimately, all knowledge can be combined into a model which can be used to approximate the most “appropriate time” for dispatching a notification. This model can subsequently be implemented in a piece of software in order for the model to dynamically adapt to new input of the user’s ADL or values. In order to make the solution more generic, it is important to analyze how the implementation should be structured.

R5: How should the smart reminder model be implemented in order to allow easy collaboration with third party software.

Eventually, the improvement through the inclusion of user values should be tested allowing an answer to the final sub-question:

R6: Does the use of the value-extended model provide more appropriately timed notifications?

## Approach

Below is a sneak-preview of how all aspects of this thesis were approached. After a literature review to analyze existing concepts and implementations, a concept was designed and implemented of which the basic structure is shown in Figure 1.2. Ultimately, the concept was evaluated according to various scenarios to show its added value.

#### Literature review

In order to answer the first four sub-questions, existing literature was discussed and compared. Ideally, an existing smart reminder system was sought that already takes into consideration the timing of the notification as well as many user and environment variables as possible, while being able to adapt to changes at runtime. In **<vul sectienummer in>** the reasoning behind these requirements were discussed. Subsequently, in **<vul sectienummer in>**, the existing papers and implementations were compared. This comparison resulted in the conclusion that no adequate systems exists and therefore concepts would have to be combined.

Leading from this and considering no actual analysis of sensor data is done, several methods of data acquisition were discussed. A choice was made to use a chosen dataset, but keep in mind a possible data stream from a third party. This was motivated in **<vul sectienummer in>**.

Simultaneously, an approach to incorporating user values was researched and discussed in **<vul sectienummer in>**. Rather than looking at different types of user values at different moments in the decision process, it was argued that if was sufficient to only look at the annoyance of the notification during a certain activity. Thereby, directly linking activities to values. The subsequent quantization could then be done through an easy questionnaire.

Activity prediction

Data acquisition

Model

Dataprocessing

Values

Suggested

notification

Deadline

Figure 1.2: High level overview of the concept

#### Concept design and implementation

A concept was designed, based on two main components. First, a one-step algorithm for activity prediction was created, based on a past paper which uses clustering and data mining algorithms. Second, successive predictions were combined with the quantified values in a statistical model based on Markov chains. Using this, predictions could be made regarding possible moments for notifications. These predictions regard two important properties of the moment. Firstly, the expected time between the moment and the deadline, which was desired to be minimized. Secondly, the probability of actually executing the chosen activity corresponding to the moment, and hence the (mathematical) expected value. The latter, which was desired to be maximized. All of the aforementioned considerations were discussed in **<vul sectienummer in>**.

An implementation was required to do proper testing. However, rather than creating a local test suite, a client-server-based implementation was set up. This allowed for easy data management, client-side input and connections to other data sources, all accessible through an API. The details and reasoning behind all choices were explained in **<vul sectienummer in>**.

#### Experimentation

In order to test the designed concept, several test scenarios were established and unleashed upon the dataset. All scenarios were tested in two aspects: success rate (the number of times a notification was successfully dispatched before reaching the deadline), and a score analyzing how well the timing and user values were upheld. The actual results and the details of the scenarios can be found in **<vul sectienummer in>**.

# Literature review

This chapter analyzes all aspects necessary to answer the first four research questions before designing the initial concept. First, numerous related concepts, papers and implementations are analyzed and discussed with respect to requirements for a good smart reminder system. In conjunction with this, the concept of user values and their inclusion in a smart reminder system has to be analyzed before any combined concept.

## Requirements of a smart reminder system

There have been various approaches as to how and when to provide feedback to the user. Generally, the preferred method of feedback is the concept of smart reminders [16], a reminder that takes into consideration aspects of the user or their environment. Newly developed products as well as scientific papers frequently focus on finding novel ways of combining information from smart devices into producing reminders. Examples include combinations of location and time [17]–[19], events based on smart devices [3], [20], [21], or a combination of numerous sources of information to provide insight about a user’s ADL [22]–[24].

There are various properties that characterize these and other concepts and determine what makes the reminders they provide truly smart.

### Notification producing or intercepting

The aforementioned, and many more, concepts may all be loosely categorized in two categories. Firstly, the notification *producing* concepts. Such concepts react to a number of events (as programmed at design-time) that have happened and subsequently dispatch a notification. Secondly, the notification *intercepting* concepts, which intercept such notifications and perform a run-time analysis about the current user context prior to actually dispatching the notification. For example, checking the notification for priority or checking the user’s current availability.

In principle, the notification interception analysis can be an extension of the original notification producer. However, these two concepts are generally approached separately. In order to arrive at an appropriate moment for notification, the interception analysis is of most importance as it can be built on top of any notification producing system. Hence, if no sufficing, existing system can be found, this aspect has to be built from scratch, but then the chosen notification producer should allow for incorporation of as many user and environment as possible.

### No specific setup

Quite frequently, studies in papers use specific setups to prove a relatively constrained problem. These setups usually comprise of pieces of hardware not usually found in users’ homes, even smart-homes, as opposed to more general, theoretic or software-based concepts. These concepts are quite apt and able for those scenarios, but quickly fall short when applied to other scenarios or when generalizing the solution. Considering a more general solution is desired, such concepts should be filtered out.

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# Appendices

## Unique activities in dataset

|  |
| --- |
| bathe |
| cleaning |
| dress |
| drink |
| eatingdrinking |
| entertainguests |
| groom |
| mealpreperation |
| medication |
| outdoors |
| personalhygiene |
| phone |
| read |
| relax |
| sleep |
| snack |
| toilet |
| watchtv |
| work |