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Exploring conflicts in rule-based sensor networks

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ABSTRACT

This paper addresses rule conflicts within wireless sensor networks. The work is situated within psychiatric ambulatory assessment settings where patients are monitored in and around their homes. Detecting behaviours within these settings favours sensor networks, while scalability and resource concerns favour processing data on smart nodes incorporating rule engines. Such monitoring involves personalisation, thereby becoming important to program node rules *on the fly*. Since rules may originate from distinct sources and change over time, methods are required to maintain rule consistency. Drawing on lessons from Feature Interaction, the paper contributes novel approaches for detecting and resolving rule-conflict across sensor networks.

1. Introduction

This paper addresses rule conflict within sensor networks. There is an increasing interest in changing the behaviour of sensor networks once they are *in situ*. This is of importance in healthcare applications such as Ambulatory Assessment where networks need to be tuned to individuals. One means of providing this capability is through the use of rules; where network nodes each use rule engines to process rules distributed across the network. The rules dictate the behaviour of each node in response to sensor data values, and so control the overall behaviour of the sensor network.

As the networks are in effect programmable, it is important (as with any means of programming) that the rules act coherently to provide the desired behaviour. However if care is not taken some rules may produce conflicting behaviour and so it is imperative to detect and resolve these conflicts. Rule conflict detection and resolution must be embedded within such systems as a particular network may have a unique configuration of rules. In addition the rules may originate from different sources as settings such as healthcare have a range of stakeholders. Also as some systems allow rules to be distributed on the fly on a real-time basis, detection and resolution techniques must be embedded to respond to changing circumstances. Such changes can occur in Ambulatory Assessment as the needs of patients vary and can alter over time. Such rule conflict is compounded by the simple complexity of potential run-time events.

To address rule conflict within a sensor network this paper draws upon an established body of *Feature Interaction* research. Specifically the paper extends FI techniques to deal with rule-based sensor networks where the implementation can be either embedded within the network, or operated on a stand-alone basis. The granularity and nature of such rules distinguishes this domain from the more traditional applications of FI techniques.

This work is motivated by the PAM project which constructed a rule-based sensor network. A rule-based sensor network was designed, developed, and deployed within homes in a set of small scale trials. The PAM project aims to provide support

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in the home for patients with Bipolar Disorder. As the support is away from a clinical setting and is in a natural setting it can be considered as an example of *Ambulatory Assessment* (AA).

In response to the trials the authors produced a networked rule model to investigate rule conflict and resolution in greater depth. As a result a novel approach to detecting and resolving rule conflicts was developed. The work is set within the context of home-based psychiatric Ambulatory Assessment. Rules have been developed to control the behaviours of devices in a sensor network being used for psychiatric AA applications. This produces examples of rule conflict that can be found within AA sensor networks and forms a basis of research to test the efficacy of the proposed detection and resolution approach.

1.1. Contributions

This paper describes a rule-based Wireless Sensor Network that can be programmed on the fly. This provides the high degree of personalisation required for AA. AA monitors patients in everyday settings away rather than in a clinical environment, and it is important to program each WSN to "fit" the patient. Using this, we make a number of contributions. Firstly, we provide a taxonomy of rules common to AA WSNs. We then demonstrate that the flexibility they offer can result in rule-conflict and we describe a number of ways that these rules can conflict. We then contribute a novel approach to detect and resolve such conflicts. The paper identifies a number of scenarios that have not been published before. While this novel approach builds on research for the Feature Interaction problem, it is distinctive as it can operate at a low level of granularity on small rule-sets rather than the larger software applications and services that appear within FI research. Furthermore, the approach addresses all 5 types of FI identified in the FI literature; while the literature offers approaches on four types, this approach also addresses the fifth type. It also extends the existing methods of detection for the four types to operate successfully in a rule-based system, and shows that the approach is scalable within the confines of likely AA-WSNs which are expected to have a modest size.

1.2. Article organisation

The next section (Section 2) describes an overview of AA, WSN and Feature Interaction literature. This is followed (Section 3) by a description of rule conflict in terms of an extended Feature Interaction taxonomy. The proposed detection technique is described in Section 4, along with an overview of the experimental test-bed that encompasses this approach. A resolution approach is described in Section 5, and Section 6 explains the test-bed environment in more detail in preparation for the presentation of the results in Section 7. Section 8 describes future work and concludes with Section 9.

2. Background and related work

Rule-based sensor networks are not in common use for AA systems and so a contribution of this paper is describing and justifying the distinctive nature of this domain for the subsequent Feature Interaction research. The section describes two sources that motivated the choice and development of AA-WSN features; firstly functionality cited in the AA literature, and secondly experiences from the PAM project. It also provides background material on rule oriented sensor networks and related work for conflict detection.

2.1. Ambulatory Assessment functionality

Ambulatory Assessment, as defined by [1],

> "comprises the use of field methods to assess the ongoing behavior, physiology, experience and environmental aspects of people in naturalistic or unconstrained settings. Ambulatory Assessment uses ecologically-valid tools to understand biopsychosocial processes as they unfold naturally in time and in context".

A major advantage of AA over the more traditional forms of assessment is reducing the reliance on retrospective recall [2]. AA based studies are also more general than the laboratory, as they have ecological relevance and can monitor dynamic situations through time. Other benefits include higher compliance rates than traditional paper-based surveys, improved survey structures, and rapid data access for researchers [3]. AA functionality supports micro-longitudinal studies by regularly sampling a range of parameters in a subject's life. This requires a core service that samples events over time and then stores the data. Sampling often employs momentary assessment where mobile devices such as PDAs are used to prompt subjects for answers to a set of questions. A number of additional features are also described in the AA literature; these include mechanisms to adjust prompting schedules, an ability to also collect physiological and environmental data, and a means of combining a range of triggers. Triggers may also reflect the state of a subject, or be the result of a change of context.

This paper draws on the literature [4] and Fischer [5] to provide insight into available AA functionality. It is worth noting that the paper does propose more extensive capabilities (based on wireless sensor networks) than is currently reported. For example consider three available systems: Experience Sampling Program (ESP) [6], Purdue Momentary Assessment Tool (PMAT) [7], and MyExperience [8]. These systems allow researchers to set up diary study protocols on Personal Digital