Helping a Clinician Understand Anomalous Patient Responses to Treatment.

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The Intensive Care Unit (ICU) in a hospital provides treatment for patients who are often critically ill and possibly rapidly deteriorating. Such patients provide complex challenges for the attending clinician. EIRA (Explaining, Inferencing, and Reasoning about Anomalies) [1] helps clinicians to detect anomalous patient responses to treatment in the ICU and provides decision support for clinicians by generating explanations for anomalies. Anomalies are of interest as they often point to the inadequacy of a currently held theory and require refinement of the related theory; consequently this can provide the impetus for the discovery of further domain knowledge. The explanations generated by EIRA can be considered as an anomaly-driven refinement of the clinician’s theory. One proposed function of EIRA is that it will be used by ICU clinicians as an ‘offline’ aid/tutoring tool.

EIRA comprises: a knowledge base consisting of several instantiated OWL ontologies (http://www.w3.org/2004/OWL/) and a Java program implementing strategies extracted from domain experts’ protocols. For each patient, EIRA also has access to data containing physiological parameters, and drug and fluid infusions. When attempting to detect anomalies, EIRA identifies the drugs given to the patient at a particular time point from the patient’s data and retrieves the anticipated effects of administering each drug from the ICU ontology. When the anticipated response(s) do not occur, the actual response observed in the data is noted. To generate context-dependent hypotheses for why the detected anomalies may have occurred, EIRA proceeds with each of the implemented strategies (algorithms) and, if appropriate, explanations are presented to the user. For example:

**Patient data contains**: Adrenaline is administered to a patient and this is followed by a decrease in the patient’s mean arterial pressure (MAP).

**EIRA’s knowledge base contains**: Adrenaline should increase MAP.

**EIRA suggests that**: A patient has responded anomalously to adrenaline.

**EIRA suggests the explanation that**: The patient may have severe sepsis and the adrenaline wasn’t high enough to observe the expected effect.

EIRA was based on complex algorithms that reflect the problem solving methods used by ICU clinicians in detecting and resolving anomalies. Whilst EIRA has proved to be very accurate [1, 2], it lacked a justification system that could make explicit the complex rationality behind the algorithms. This led to the development of arguEIRA (Figure 1) [3].

In arguEIRA, EIRA’s algorithms to detect an anomalous patient response have been replaced with a more flexible reasoning process based on logical argumentation (Stage 2, Figure 1). arguEIRA extends EIRA by providing a justification for EIRA’s detection of anomalies using the ASPIC argumentation framework [4]. ASPIC adopts Dung’s calculus of opposition [5] to identify and express argument exchanges.
Our mapping of EIRA’s algorithms into arguEIRA’s arguments required building an argumentation knowledge base differentiating between conclusive knowledge (clinical facts like the measurement of patient’s vital signs), and non-conclusive knowledge (e.g. clinical reasoning). To create an ASPIC knowledge base, schemes have been implemented in arguEIRA based on previous modelling of clinician argumentation [3]. Below is an example (abbreviated) dialogue:

Clinician 1: “The patient’s cardiac output has increased after giving noradrenaline. That is anomalous”.

Clinician 2: “I agree the dose is high but the scenario is not anomalous”

Clinician 1: “Maybe the noradrenaline just wasn’t working....”

Clinician 2: “Perhaps more sepsis and vasodilation is pushing the cardiac output up?”

Clinician 1: “Instead of the noradrenaline causing the problem, the dose has been increased as a result of the problem. Although the dose is very high you would normally see [cardiac output] coming back up again but you don’t see that”

Clinician 1: “What is anomalous is the fact the noradrenaline isn’t working. They have increased the dose and it isn’t working”

Clinician 2: “Yep, I agree”

Dialogues such as that shown above were expressed in ASPIC. For example, below is the first line of the above dialogue expressed in ASPIC.

Facts:
[a9] administered(p, noradrenaline, t1) 1.0
[a10] observed(p, cardiac_output, increase, t2) 1.0.

Rule:
[a1] anomaly < - expected(Patient, Attribute, Expected, t2), observed(Patient, Attribute, Observed, t2), different(Expected, Observed) 1.0.

The ASPIC facts and rules derived from these dialogues were then abstracted into argument schemes. The schemes are instantiated at run-time with information from the patient dataset and domain ontologies. Below are some example schemes:

- [scheme9] administered(p, [drug], t1) 1.0.
- [scheme10] observed(p, [observed parameter], [observed effect], t2) 1.0.
- [scheme12] expected_effect([drug],[expected effect parameter], [expected effect]) 0.7.
- [scheme1] anomaly < - expected(Patient, Physiological_Effect, Expected, t2), observed(Patient, Physiological_Effect, Observed, t2), different(Expected, Observed) 1.0.
- [scheme2] anomaly < - ~expected(Patient, Physiological_Effect, Expected, t2), observed(Patient, Physiological_Effect, Observed, t2), ~different(Expected, Observed) 1.0.
Once the knowledge base has been completed, the ASPIC argumentation engine determines the state of the arguments and whether an anomaly has occurred.

An argumentation graph and an equivalent textual representation are presented to the user to justify how arguEIRA detected the additional anomalies (Figure 2). The use of argumentation schemes allows the methods used to construct the argumentation framework to be separated from the form and content of arguments, as proposed in [6]. As in [7] the content of arguments is generated from queries of a domain ontology used as a reference source.
arguEIRA generated explanations for why an anomaly has been detected. In this example, a decrease in MAP has been observed after the patient was administered adrenaline.

To evaluate the potential clinical benefit of arguEIRA we held interviews with 3 specialty registrars (in Anaesthesia, Pain, and Critical Care). It became clear from these discussions that in some scenarios the extra information provided by the ASPIC-generated justification was not required as the clinician clearly understood why an anomaly had been identified; this was why, in general, two of the clinicians preferred EIRA’s original presentation of detected anomalies. However, the clinicians suggested that when they were faced with a complex anomaly, or one which they did not agree with, they liked having access to the additional information provided by the argumentation inferences. Subsequently, it is suggested that the ASPIC generated justifications should be considered as an additional feature available to the clinicians.

Currently, we are in the process of replacing EIRA’s strategies to generate explanations (Stage 3 in Figure 1). To do this we are creating ASPIC argument schemes that reflect possible explanations for why an anomaly has occurred. This will allow arguEIRA to provide justifications for all of its conclusions.
As part of our future work plans we propose a further extension to arguEIRA that uses argumentation-based dialogues to allow arguEIRA to challenge a clinician’s opinion, and discuss detected anomalous patient responses to treatment with the clinician. Such systems directly refer, according to [8], to persuasion dialogues. In previous work, argumentation has been used as a tool for changing health-related behaviours, tailoring explanations, advising patients on treatment regimes, and for designing agents working in cooperation with a healthcare team [9], [10], [11], [12]. Our planned use of argumentation-based dialogue will allow the clinicians to request detailed information on specific arguments of arguEIRA’s justification, disagree with non-conclusive clinical evidence upon which arguEIRA bases its explanations, and understand how those disagreements can influence the explanations provided by arguEIRA. This extension is important because even when a decision support system is consulted, the responsibility for the patient’s treatment still lies with the clinician. Consequently, we will have to develop arguments that exploit rich domain knowledge to provide a transparent and logical, clinical justification for the conclusion provided by arguEIRA.

In our dialogue-based extension of arguEIRA we will reuse the already adopted ASPIC argumentation system for reasoning during the dialogue-based interaction between the tool and the clinician. arguEIRA will decide what she knows by determining which propositions she has acceptable arguments for. arguEIRA will state propositions for which she has acceptable arguments, and accept propositions put forward by the clinician if she finds that the clinician’s arguments are acceptable. While arguEIRA has its own knowledge base, containing her beliefs, she will also be able to construct a set of commitments made in the dialogue. The speaker’s assertion and acceptance attitude, the locutions interpretation, and the dialogue protocol will be based on work by Parsons et al [13]. It is anticipated that by providing this additional information and allowing a clinician to interact with a decision support system it will act as an efficient training tool. Additionally, it is suggested that this approach could more generally lead to greater acceptance of decision support systems in the medical domain and provide a methodology for the maintenance of knowledge in the system.

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