Alert rules for remote monitoring of cardiovascular patients

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Abstract: Cardiovascular disease is the leading cause of death in most European countries and its prevention requires major life-style changes using limited health-care resources. Remote cardiovascular decision support seems to allow cardiovascular patients to lead a productive life and to minimize the costs of treatment. In this paper, the current development stage of remote monitoring in our developing decision support system is described. It uses alert rules that can notify clinicians or other parts of the system if a patient is at risk, which is useful for prevention of malignant events. A mathematical definition of alert rules and their combination into one output, their software implementation and example data are given.

Key words: alert rules, real-time monitoring, decision support, cardiology

1. Introduction

According to (2), cardiovascular diseases have been reported as the principal cause of death in most European countries. They account for 43% of mortality among men and for 56% among women. A major challenge facing healthcare organizations is the provision of quality services at affordable costs. Quality service implies diagnosing patients correctly and administering treatments that are cost-effective. Monitoring risk factors is important for the prevention of malignant events. Three areas of prevention can be distinguished: a) prevention in the total population; b) prevention in high risk groups; and c) prevention after cardiovascular events. Prevention in high risk groups and prevention after cardiovascular events require major life style changes and medication using limited health-care resources.

As active participants of the BraveHealth project, we are interested in continuous and remote monitoring and real time prevention of malignant events for people already diagnosed as subjects at risk of further cardiological or cardiovascular events. In the project, our patients

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are required to use a wearable unit with sensors and other devices such as scales and blood pressure cuffs so that we can obtain regular data about them. The data is analyzed in real time by several techniques. These techniques independently decide if a patient is high risk and their results are combined into a final decision about the patient. If the patient is considered high risk, all necessary steps are carried out so that malignant events can be prevented. Techniques used for real-time analysis in the BraveHealth system include: a) data mining techniques (1)(3)(5); b) monitoring if some important measures, such as systolic blood pressure, diastolic blood pressure, heart rate, etc., are within limits set by clinicians.

The work reported in this paper is focused on alert notifications through alert rules executed on monitored measures. Alert notifications are defined by clinicians as follows: a) red notification: a serious modification of clinical parameters which require immediate attention has appeared; b) yellow notification: a non-critical but potentially dangerous modification of clinical parameters has appeared; c) green notification: the patient's condition is reverted to the normal status. The BraveHealth system enhances the support provided to both the patients and the clinicians and indicates changes to the clinicians to patient risk level based on alert notifications. Green notifications are only sent when the prior alert was yellow notification or red notification. The following measures are currently considered: systolic blood pressure (mmHg), diastolic blood pressure (mmHg), heart rate (bpm), respiratory rate (rr/min), SPO_2 (%), OptiVol fluid index (Ohm), change of weight (%) and temperature (°C).

This paper is organized as follows. Alert rules for remote monitoring of cardiovascular patients are defined in Section 2. Software implementation of the rules is described in Section 3. Section 4 contains fictional data that mimic the expected use of developed alert rules in the BraveHealth system. Finally, we conclude this paper with discussion in Section 5.

2. Alert rules

A group of alert rules is defined for each monitored measure. The particular alert rules are classification rules in the form "IF *Condition* THEN C is c_j". C = *AlertStatus* has possible values *red* (c_1), *yellow* (c_2), *green* c_3, which is symbolized by $C = \{c_1; c_2; c_3\}$. Values *red*, *yellow* and *green* mean red notification, yellow notification and green notification, respectively. Condition contains several assignments connected with operator "AND". When an instance $\boldsymbol{e}$ of data about a particular patient is received, the group of alert rules for a monitored measure is used for production of one alert notification $c^{\boldsymbol{e}}_{\text{notification}} \in C$. The formula in [1] is used for this production. Symbol R_{c_j} represents all alert rules with $c_j \in C$ in

the group of alert rules. Symbol w_{r_q} is the weight of alert rule $r_q \in R_{c_j}$. Symbol $\text{apply}(r_q; \boldsymbol{e})$, r_q is an alert rule in the group of alert rules, $\boldsymbol{e}$ is an instance of data about a particular patient, stands for 1 if conditions in alert rule r_q apply for instance $\boldsymbol{e}$ and 0 if not. Symbol $\text{argmax}_{c_j \in C}\{\text{f}(c_j)\}$, where c_j is an alert notification and C is *AlertStatus*, stands for a set of all $c_j \in C$ where $\text{f}(c_j)$ is the maximal value. Symbol $\text{mostSerious}\{X\}$, where X is a subset of or equal to C, stands for the most serious $c_j \in C$. Note that *red* is more serious than *yellow* or *green* and that *yellow* is more serious than *green*.

$$c^{\boldsymbol{e}}_{\text{notification}} = \text{mostSerious}\left\{\text{argmax}_{c_j \in C}\left\{\sum_{r_q \in R_{c_j}} w_{r_q} \cdot \text{apply}(r_q; \boldsymbol{e})\right\}\right\} \qquad [1]$$

An example of a group of alert rules for systolic blood pressure (SBP):

r_1: IF *Risk* is *low* AND *SBP* is in [60;80] Or [180;250] THEN *AlertStatus* is *red* (weight: 1);

r_2: IF *Risk* is *low* AND *SBP* is in (80;90] Or [150;180) THEN *AlertStatus* is *yellow* (weight: 1);

r_3: IF *Risk* is *low* AND *SBP* is in (90;150) THEN *AlertStatus* is *green* (weight: 1);

r_4: IF *Risk* is *medium* AND *SBP* is in [60;80] Or [180;250] THEN *AlertStatus* is *red* (weight: 1);

r_5: IF *Risk* is *medium* AND *SBP* is in (80;95) Or [160;180) THEN *AlertStatus* is *yellow* (weight: 1);

r_6: IF *Risk* is *medium* AND *SBP* is in [95;160) THEN *AlertStatus* is *green* (weight: 1);

r_7: IF *Risk* is *high* AND *SBP* is in [60;80] Or [170;250] THEN *AlertStatus* is *red* (weight: 1);

r_8: IF *Risk* is *high* AND *SBP* is in (80;170) THEN *AlertStatus* is *yellow* (weight: 1);

3. Software implementation

Our software implementation of alert rules in BraveHealth is a part of its developing decision support system written in Java. Our class diagram for the support of attributes described with UML (4) is in Figure 1. Classes CategoricalAttribute, NumericalAttribute, FuzzyAttribute, AttributesForClassifiation are used for a representation of categorical attributes, numerical attributes, fuzzy attributes and groups of attributes with specified class attributes *AlertStatus*, respectively. Classes Assignment and Assignments in Figure 2 are used for assigning values to attributes and connecting these assignments using operator "AND". Particular alert rules and a group of these rules can be created with classes AlertRule and AlertRules in Figure 3, respectively. When an alert rule is being created with class AlertRule, its identification, its weight, its condition consisted of assignments connected with operator "AND" and its

conclusion consisted of an assignment of *AlertStatus* to an alert notification are given. Once an object of a group of alert rules is created with class AlertRules, method execute can be called for an instance paInstance of data about a patient and it returns the corresponding alert notification which is then used by the decision support system of BraveHealth.

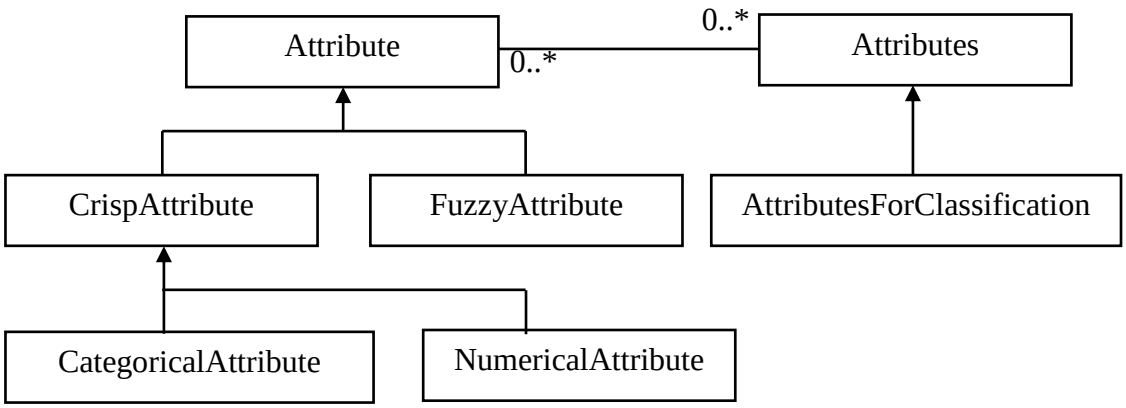

Figure 1: Class diagram for attributes.

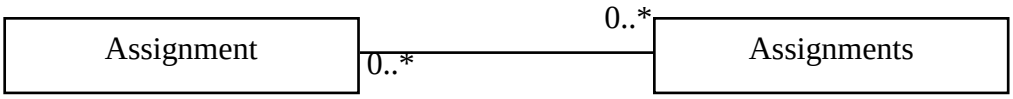

Figure 2: Class diagram for assignments.

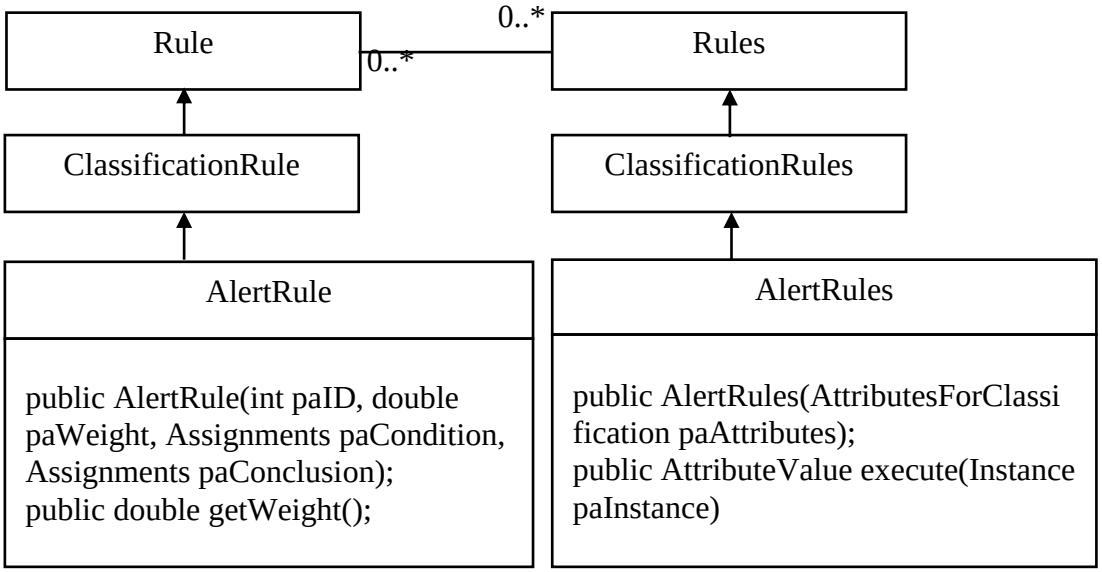

Figure 3: Class diagram for alert rules.

```
String attributesDataFile = "..\\Data\\Alert Data\\Attributes.txt";
String classAttribute = "AlertStatus";
AttributesForClassification attributes = new
AttributesForClassification(attributesDataFile);
attributes.setClassAttribute(attributes.getAttribute(classAttribute));
Assignments conclusionRed = new Assignments(attributes);
conclusionRed.add(new Assignment(attributes.getClassAttribute(), new
IsAttributeOperator(), new NullModifier(), new LinguisticAttributeValue("red")));
Assignment Risk_is_low = new Assignment(attributes.getAttribute("Risk"), new
IsAttributeOperator(), new NullModifier(), new LinguisticAttributeValue("low"));
AlertRules SystolicBloodPressureAlertRules = new AlertRules(attributes);
Attribute SystolicBloodPressureAttribute =
attributes.getAttribute("SystolicBloodPressure");
Assignments SBP_condition1 = new Assignments(attributes);
SBP_condition1.add(Risk_is_low);
Assignment SBP_condition1_tmp1_1 = new
Assignment(SystolicBloodPressureAttribute, new IsInAttributeOperator(), new
NullModifier(), new
ClosedIntervalAttributeValue(((NumericalAttribute)SystolicBloodPressureAttribute)
getSetMinimalValue().value(), 80));
SBP_condition1_tmp1_1.add(new NullModifier(), new
ClosedIntervalAttributeValue(180,
((NumericalAttribute)SystolicBloodPressureAttribute).getSetMaximalValue().value();
SBP_condition1.add(SBP_condition1_tmp1_1);
SystolicBloodPressureAlertRules.addRule(new
AlertRule(1,1,SBP_condition1,conclusionRed));
```

Figure 4: Code fragment for creating systolic blood pressure alert rules.

A code fragment usable for creation of systolic blood pressure alert rules is in Figure 4. It shows how to create rule r_1: IF *Risk* is *low* AND *SBP* is in [60;80] Or [180;250] THEN *AlertStatus* is *red* (weight: 1) and how to add it to systolic blood pressure alert rules.

4. Example data

Fictional data that mimic the expected use of developed alert rules in the BraveHealth system is provided here. Table. 1 contains (some of) the data that would be entered for patients when they are first recorded into the BraveHealth system.

Table. 1: Patient details.

Patient ID	Name	Gender	Date of Birth	Height (m)	Weight Min (kg)	Weight Max (kg)	Initial Weight (kg)
bh123	Toni	male	03/03/1950	1.77	58.00	85.00	77.1
bh125	Antonio	female	06/11/1960	1.67	52.00	81.00	78.2
bh129	Bertie	male	30/06/1952	1.70	55.00	82.50	75

An example of patient status history is given in Table. 2 and Table. 3. Table. 2 shows patient ID (referencing Table. 1), time and date stamp, with pathology, risk level and previous overall status. Table. 3 shows a status field for each physiological measure that has a group of alert rules. Table. 4 contains the history of the patient data points. SBP, DBP, HR, RR, OFI, CW, and T in Table. 3 and in Table. 4 mean systolic blood pressure, diastolic blood pressure, heart rate, respiratory rate, OptiVol fluid index, change of weight, and temperature, respectively.

Table. 2: Part one of the patient status history.

Patient ID	Date	Time	Pathology	Risk Level	Previous Overall Status
bh123	11/02/2011	20:01	hypertension	medium	green
bh125	11/02/2011	20:01	hypertension	low	yellow
bh129	11/02/2011	20:01	heart failure	medium	yellow
bh123	12/02/2011	20:01		medium	
bh125	12/02/2011	20:01		low	
bh129	12/02/2011	20:01		medium	

Table 3: Part two of the patient status history.

Patient ID	Status-SBP	Status-DBP	Status-HR	Status-RR	Status-SPO_2	Status-OFI	Status-CW	Status-T
bh123	green	green	green	green	green	green	green	green
bh125	green	green	yellow	green	green	yellow	green	green
bh129	green	green	green	green	green	green	green	red
bh123	green	green	green	green	green	green	green	green
bh125	green	green	green	green	green	yellow	green	green
bh129	green	green	green	green	green	green	green	green

Table 4: Patient data history.

Patient ID	Date	Time	SBP	DBP	HR	RR	SPO_2	OFI	CW	T
bh123	11/02/2011	20:00	107	70	65	17	96	2	77.1	36.3
bh125	11/02/2011	20:00	110	71	60	11	95	77	78.2	37.1
bh129	11/02/2011	20:00	110	80	70	12	96	15	75	35.1
bh123	12/02/2011	20:00	110	72	66	14	95	20	77.1	36.2
bh125	12/02/2011	20:00	110	71	62	14	97	75	78	36.5
bh129	12/02/2011	20:00	111	84	67	16	93	9	75	36.1

5. Discussion

The current functionality and implementation of alert rules used for remote monitoring of cardiovascular patients in our developing decision support system of BraveHealth were discussed in this paper. Weighted alert rules are a part of a group of alert rules for a monitored measure such as systolic blood pressure. A group of alert rules gives us an alert notification when they are used with data about a patient. This is used for support to patients and clinicians. Alert rules are implemented in Java using object-oriented programming techniques. Important classes are shown using UML diagrams. Data that mimic the expected use of the alert rules were also provided. Further work will include tuning groups of alert rules for particular monitored measures according to the requirements of clinicians.

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