6th International Conference on Human System Interaction
June 06-08 2013

AGH University of Science and Technology

Application of Fuzzy Ontological Reasoning in an Implementation of Medical Guidelines

Piotr Szwed
AGH University of Science and Technology
Department of Applied Computer Science
e-mail: pszwed@agh.edu.pl

Agenda

1. Goal
2. SWOP e-health system
3. Fuzzy rules and reasoning
4. Rules formalizing a guideline for asthma assessment
5. Solution:
    - Ontology with extensions required for fuzzy reasoning
    - Software architecture
    - SWRL rules
6. Conclusions

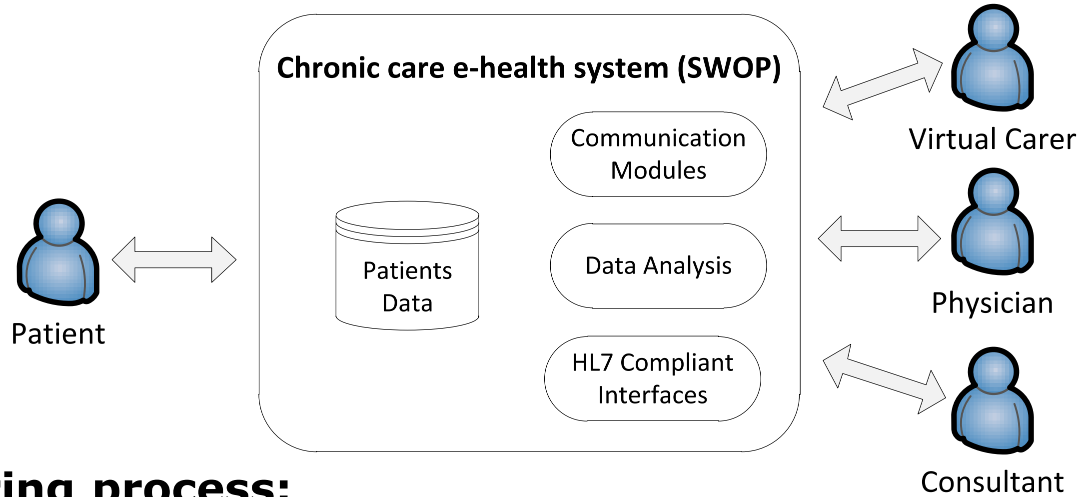
Goal

- Implementation of medical guidelines in an e-health system:
  - Reuse of ontologies
  - Approach based on fuzzy rules

- **Application of available crisp Semantic Web tools and technologies to perform fuzzy reasoning**

SWOP system

SWOP (in Polish: *System Wspomagania Opieki Przewlekłej*) an e-health system supporting patients suffering from chronic conditions by: self-assessment, telemonitoring and interactions with health care professionals.

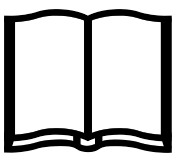


Telemonitoring process:

- Patients manually or automatically send results of self-observations or self-measurements specific for their chronic disease.
- Entered data are automatically analyzed to determine patients' status, trends in disease course and a risk of symptoms exacerbation.
- Patient or a family member is notified about results of the assessment (in a web browser or via e-mail/SMS)

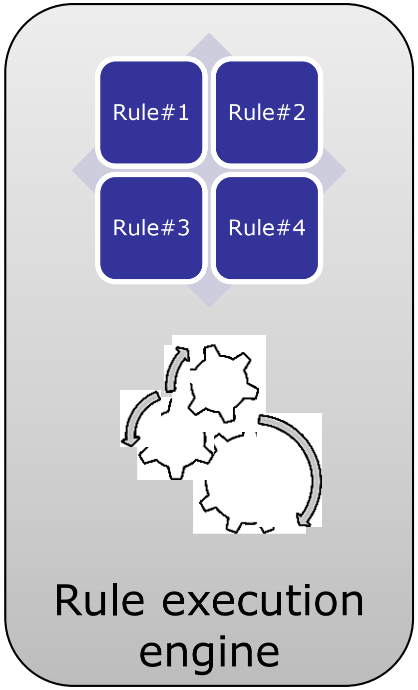
Data analysis component

- Rule based implementation
- Rules formalize a guideline
- Fuzziness is introduced to cope with uncertainty resulting from self-observations bias, low quality of sensors and limited patients skills



Guideline

- Questionaire data
- Subjective symptoms
- Measurements
- Prescribed medications
- Other relevant patient data



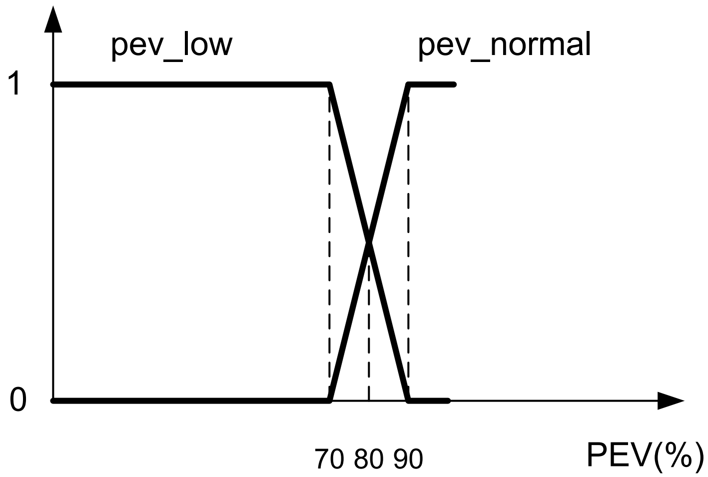
- Patient state assessment
- Notifications
- Alerts
- Recommendations

Fuzzy reasoning (1)
Mamdani rules

$$IF\ var_1 = \ value_{11} AND\ var_2 = \ value_{21} \ldots$$
$$THEN\ var_{out} = \ out$$

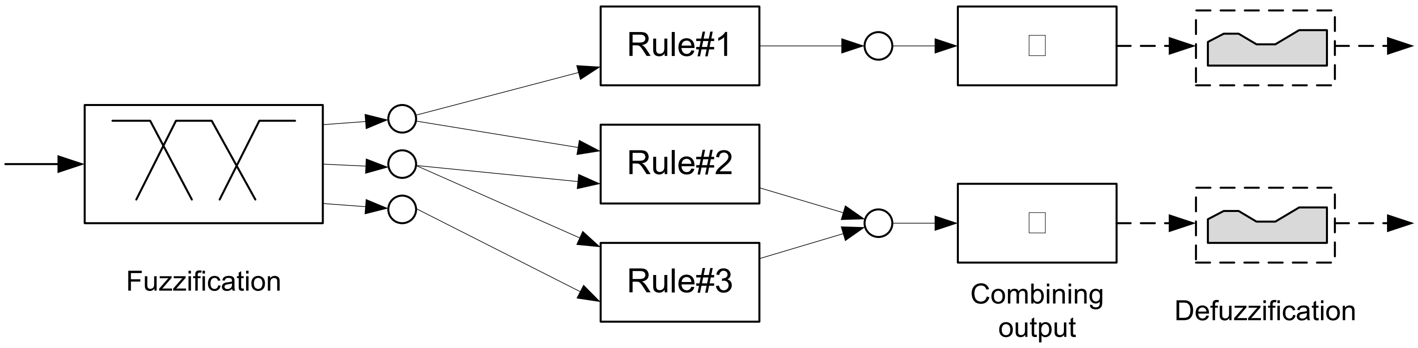
var_i- linguistic variable

$value_{ij}, out$ - fuzzy sets



- Fuzzy sets are described by membership functions defining the confidence factor from the interval [0,1] that a particular element is a member of the set.
- At left: an example of two fuzzy sets *pev_low* and *pev_normal* representing classes of PEV (peak expiratory volume) values.

Fuzzy reasoning (2)



- *Fuzzification* - values of the parameters are mapped to fuzzy sets according to defined membership functions and assigned to linguistic variables. (A variable can be bound to multiple values).
- *Inference*: - applying defined rules and assigning values to output variables;
- *Aggregation*: the contents of the output variables is combined (typically based on maximal on average membership value).
- *Defuzzification* - converting fuzzy values to crisp

Guideline for asthma assessment (1)

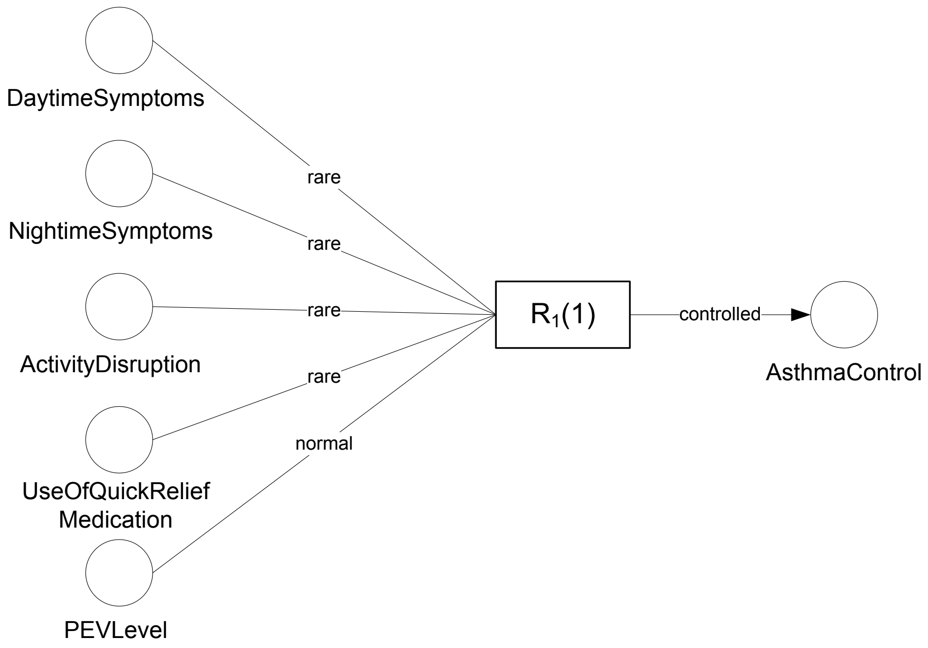
Guideline issued by Global Initiative for Asthma (GINA) 2011

Assessments of asthma control should be performed on a weekly basis considering the following features:

- presence of daytime or nocturnal symptoms (including awakening),
- disruption of daily activities,
- need for reliever treatment and
- evaluation of lung function (based on PEV measurement).

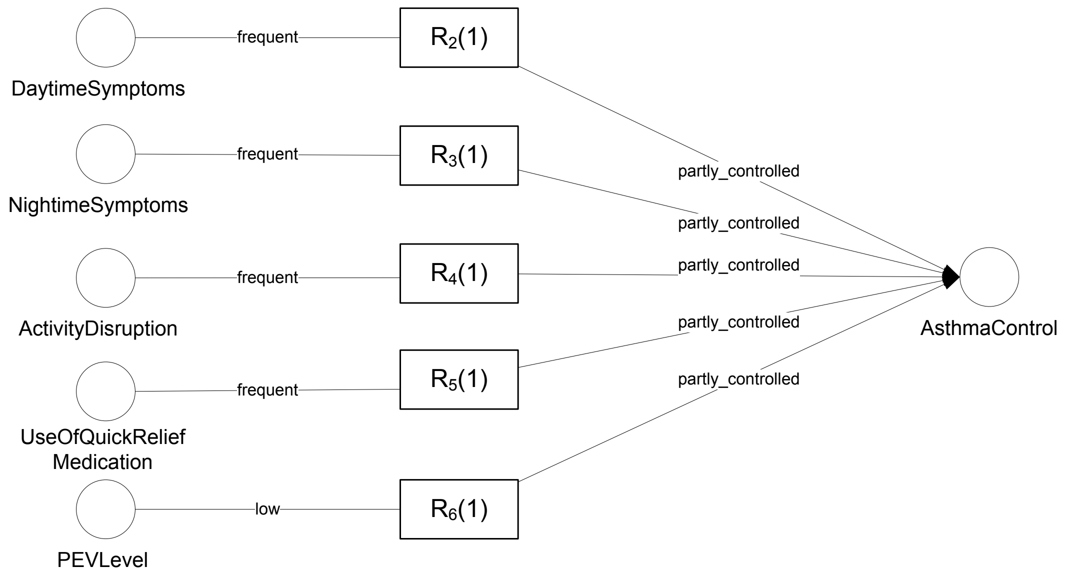
Customization of the system to bronchial asthma was selected as one of the proof-of-concept exemplifications of the system.

Guideline for asthma assessment (2)



IF DaytimeSymptoms IS rare AND NighttimeSymptoms IS rare AND ActivityDisruptions IS rare AND UseOfQuickReliefMedication IS rare AND PEVLevel IS normal THEN AsthmaControl IS controlled

Guideline for asthma assessment (3)



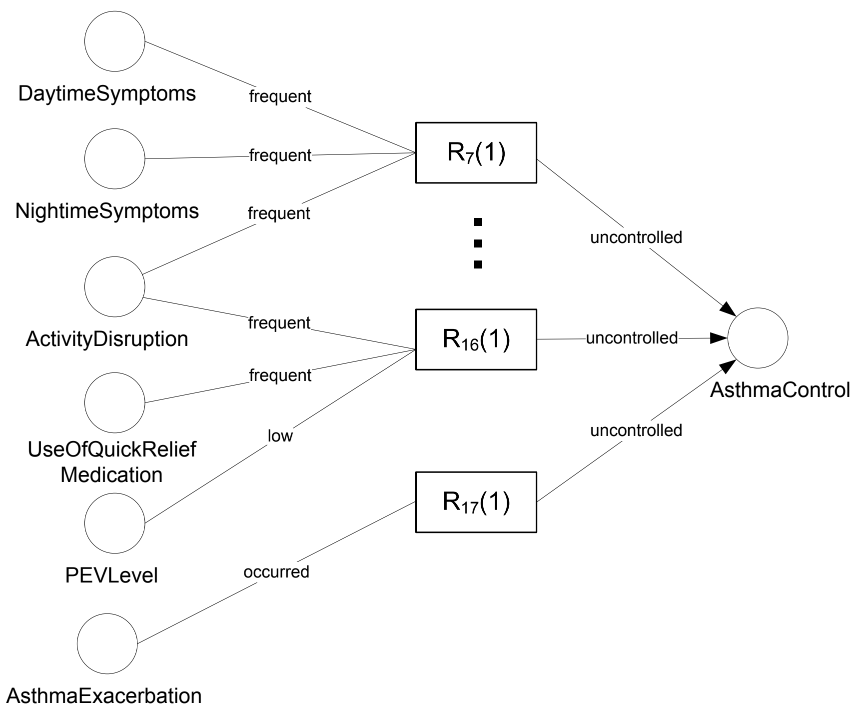
Asthma is partly controlled if any of symptoms exceeds a save level, e.g.

Rule R_4(1):

IF ActivitiDisruption IS frequent THEN AsthmaControl IS partly_controlled

Guideline for asthma assessment (2)

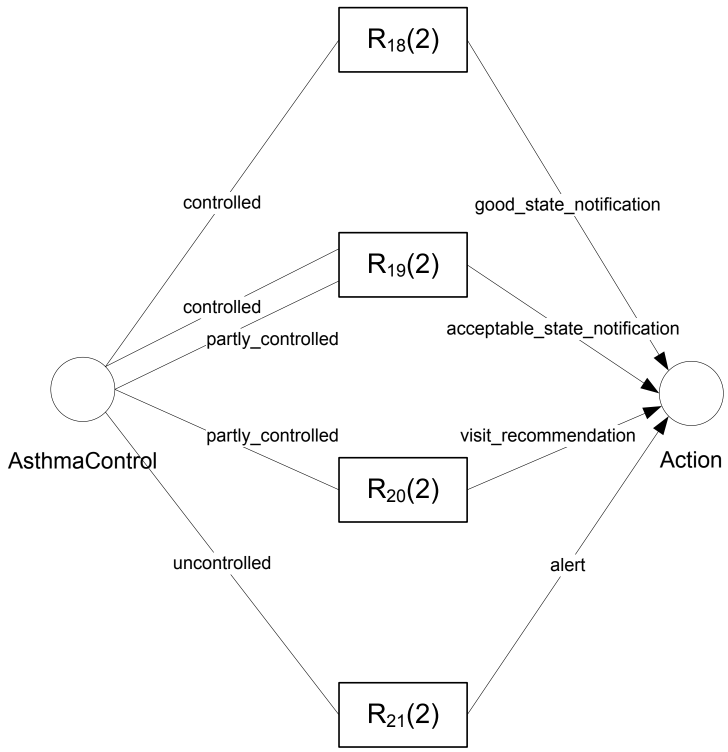
Asthma is considered uncontrolled if there are three or more indications of partial control or an exacerbation occurs in the analyzed period.



Rule R_7(1):
IF DaytimeSymptoms IS frequent
AND NightimeSymptoms IS frequent
AND ActivitiDisruption IS frequent THEN
AsthmaControl IS uncontrolled

$\binom{5}{3} + 1 = 11$ rules required

Rules for actions



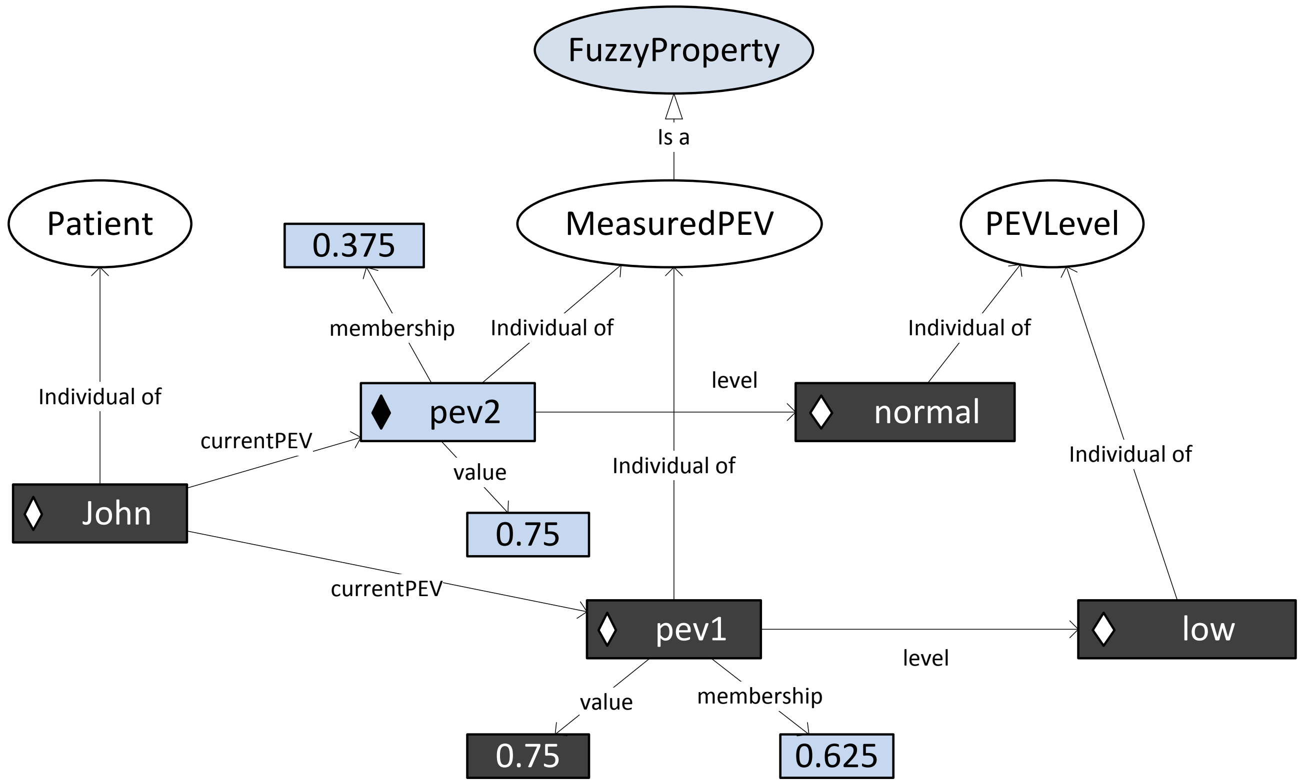
These rules are responsible for selecting actions: notifications, recommendations, alerts.

AGH

Implemented solution

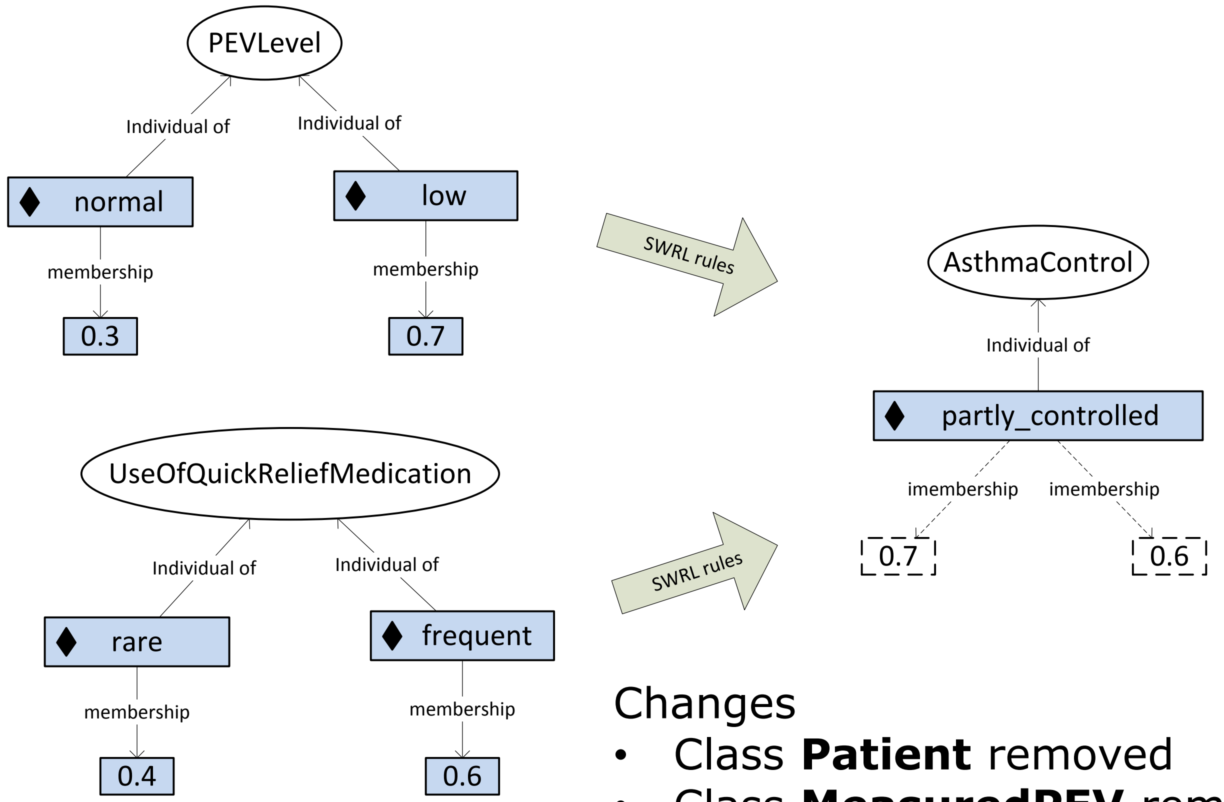
- Reusing a domain knowledge formalized in OWL ontologies and introducing extensions required to perform fuzzy reasoning
- Rewritting fuzzy rules in *Semantic Web Rule Language* (SWRL)
- Building a software responsible for fuzzification, aggregation of results and coordination of the whole process.

Ontology extended with properties expressing fuzzy relations and weights



- Object property **level** used to link with a fuzzy set
- Datatype property **membership** is used to assert fuzzy set membership
- Cardinality restriction **Patient currentPEV [max 1] MeasuredPEV** must be relaxed.

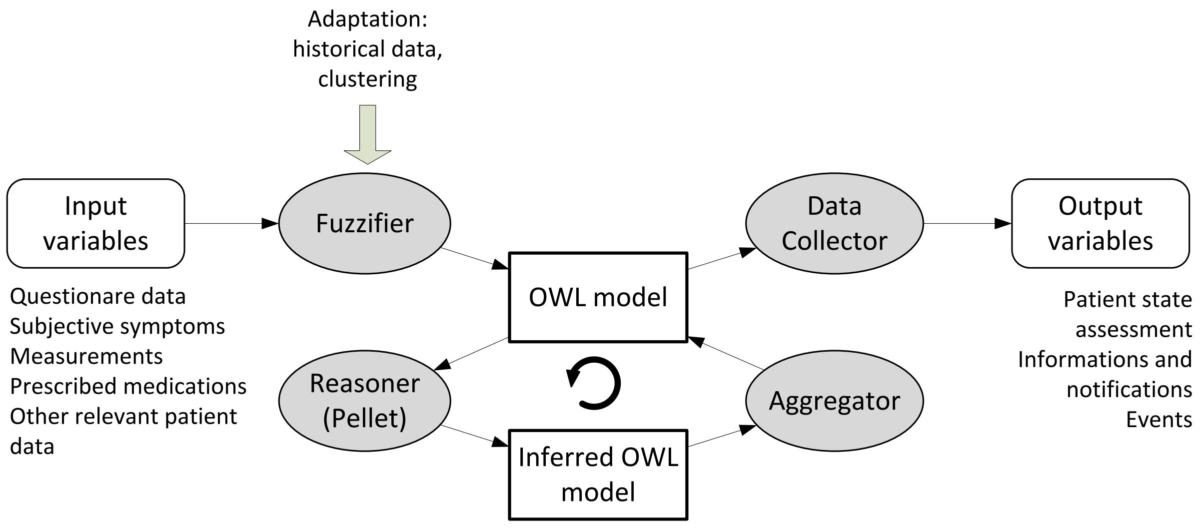
Refactored ontology



Changes

- Class **Patient** removed
- Class **MeasuredPEV** removed and **membership** property moved to a class representing a symptom
- Added **imembership** (inferenced membership) property

Architecture of the reasoning engine



- *Fuzzifier* converts input data into values in the range [0,1] and asserts **membership** values.
- *Reasoner* executes SWRL rules to process assertions defined in input model and yields **imembership** inferences.
- *Aggregator* collects arguments of **imembership** statements for an individual, calculates aggregated (maximum) values and asserts **membership** values.
- At the end, *DataCollector* is responsible for reading the values asserted by *Aggregator* and setting output variables.

SWRL based implementation of fuzzy rules

Rule R_1(1)[a-e]

```
hasValue(Step.current, 1),
membership(DaytimeAsthmaSymptom.rare, ?m1),
membership(NightimeAsthmaSymptom.rare, ?m2),
membership(ActivityDisruption.rare, ?m3),
membership(UseOfQuickReliefMedication.rare, ?m4),
membership(PEVLevel.normal, ?m5),
lessThanOrEqual(?m1, ?m2), lessThanOrEqual(?m1, ?m3),
lessThanOrEqual(?m1, ?m4), lessThanOrEqual(?m1, ?m5)
-> imembership(AsthmaControl.controlled, ?m1)
```

- The premise `hasValue(Step.current, number)` activates a rule at a certain iteration,
- Binary predicates `membership` map property values to variables
- The conclusion assigns `imembership` value to the target individuals.
- Problem: calculate the rule activation level: $\min(?m1, ?m2, ?m3, ?m4, ?m5)$
  - Multiple `lessThanOrEqual` predicates referencing the built-in SWRL function are used,
  - To calculate a minimum of 5 variables – 5 SWRL rules are required!

SWRL based implementation of fuzzy rules

Rule R_2(1)

```
hasValue(Step.current, 1),
membership(DaytimeAsthmaSymptom.frequent, ?m)
-> imembership(AsthmaControl.partly_controlled, ?m)
```

Rule R_7(1) [a-c]

```
hasValue(Step.current, 1),
membership(DaytimeAsthmaSymptom.frequent, ?m1),
membership(NightimeAsthmaSymptom.frequent,?m2),
membership (ActivityDisruption.frequent, ?m3),
lessThanOrEqual(?m1, ?m2), lessThanOrEqual(?m1, ?m3)
-> imembership(AsthmaControl.uncontrolled, ?m1)
```

Rule	Number of SWRL rules
Asthma controlled	5
Asthma partly controlled	5
Asthma uncontrolled	31
Actions	5
Total	46

Testing

- Multiple random tests covering 2000 cases (with the assumed garanularity over 1000000 combinatons of input values are possible)
- Results were analyzed, then errors in manually encoded SWRL rules were corrected and introduced changes to membership functions
- Execution time for each test case: about 300ms

Conclusions

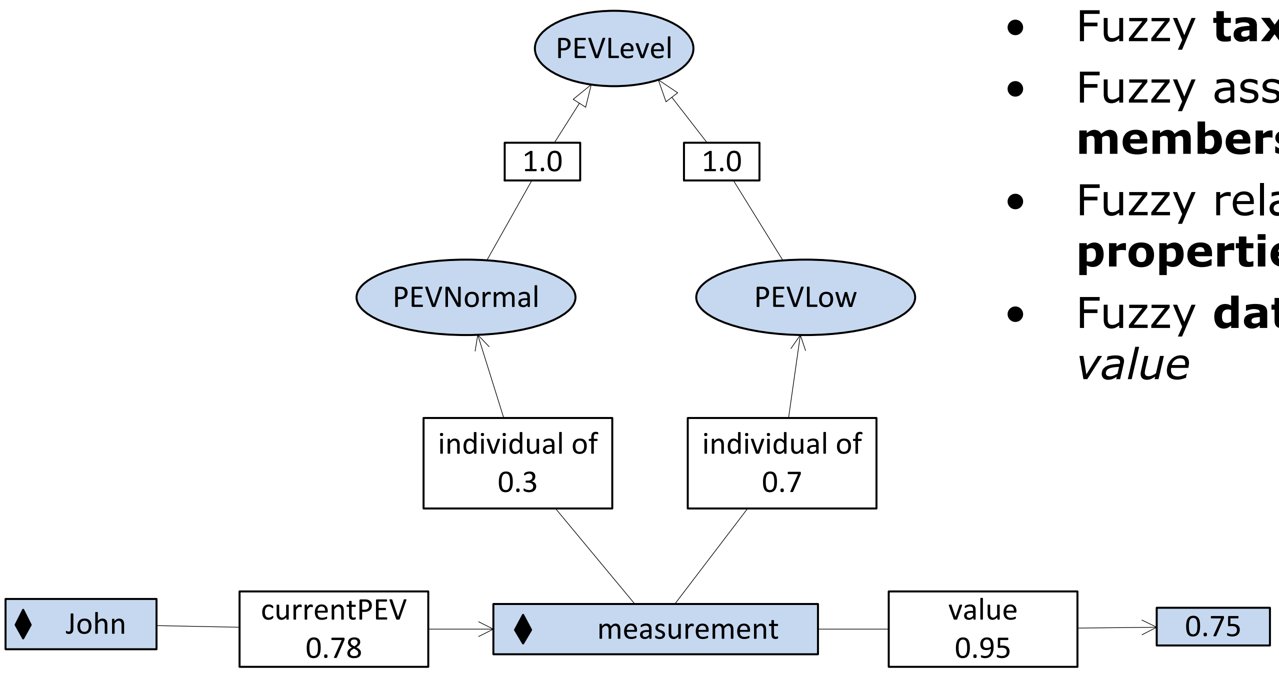
- Commonly used Semantic Web languages and supporting tools are not intended to handle fuzzy reasoning.
- The work is an attempt to apply them to specify and execute a set of fuzzy rules.
- The proposed approach consists in
  - refactoring a domain ontology
  - introducing additional relations expressing fuzzy properties,
  - encoding Mamdani fuzzy rules in SWRL language
  - executing them with use of Pellet reasoner.
- The approach was discussed on a set of rules formalizing a medical guideline for asthma control assessment

Thank you

Appendix

Fuzzy ontologies (1)

Relations of crisp ontologies extended by adding weights from [0,1]

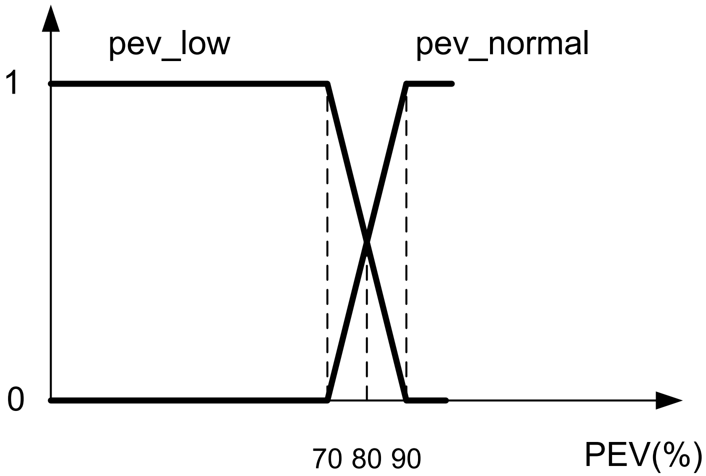


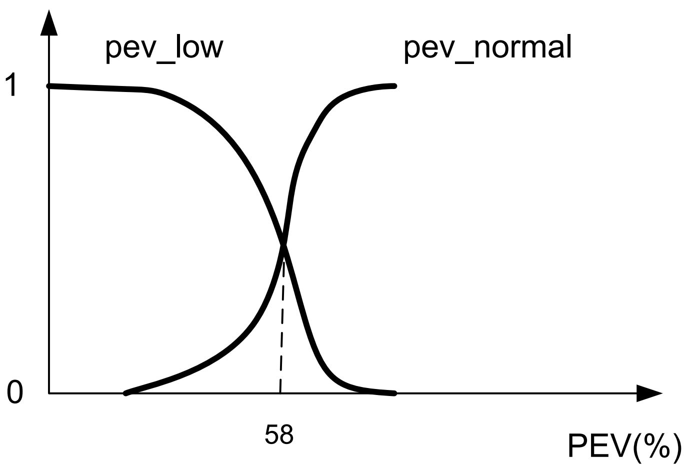
- **Fuzzy concepts** (equivalents of fuzzy sets): PEVLevel, PEVNormal, PEVLow
- Fuzzy **taxonomic relations**
- Fuzzy assertions on **class membership**: *individual of*
- Fuzzy relations (**object properties**): currentPEV
- Fuzzy **datatype properties**: *value*

Fuzzy ontologies (2)

- Typical extensions: membership functions are part of an ontology language or a Description Logic (Calegari and Ciucci 2007) or (Lukasiewicz and Straccia,2008)
- Weak resoning support. Reported fuzzy reasoning engines:
  - FiRE (closed)
  - fuzzyDL (publicly available)
    Can be used to implement Mamdani rules.

Externalized membership functions Suport for adaptation





- It was assumed that the set of defined fuzzy rules applies to all patients.
- Adaptation can be achieved at the level of membership functions:
  - individual, i.e. related to a particular patient,
  - related to a group based on a common characteristic, e.g. patients using common hardware, exposed to similar environment factors or belonging to a particular age range.