Semantically Steered Clinical Decision Support Systems

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- Recommendations generation
- Clinical Experience Handling
- S-CDSS architecture

Case study: Early diagnosis of Alzheimer’s Disease

Case study: Breast Cancer Decision Support System

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Future work
Motivation and context

Semantically Steered Clinical Decision Support Systems

• Medicine and decision making
  • Human factor and success
  • Medical errors
  • High cost
  • Preventable

• Clinical Decision Support Systems (CDSS)

"Active intelligent systems that use patient clinical data to generate case specific advice".
Motivation and context

Semantically Steered

Clinical Decision Support Systems

Challenges of Clinical Decision Support Systems (CDSS)

1. Computerization of CDSS

- Traditional decision support recommendations
  - Medical books and journals
  - Specialized conferences
  - Clinical protocols and guidelines
  - Clinical working groups meetings

- Problem
  - Requires high effort for knowledge retrieval
Motivation and context

Semantically Steered
Clinical Decision Support Systems

Challenges of Clinical Decision Support Systems (CDSS)

1. Computerization of CDSS

2. Timely advice

• Recommendations provided at
  – the **place** and **time**
  – when they are **needed**

• Need of
  – Making recommendations available
  – Fast reasoning process of recommendations generation
Semantically Steered Clinical Decision Support Systems

Challenges of Clinical Decision Support Systems (CDSS)

1. Computerization of CDSS
2. Timely advice
3. Maintainability and extensibility

- When new knowledge is fed to the system
  - Easy to maintain
  - Easy to extend

- Medical knowledge is continuously changing
  - Frequently found new discoveries
  - New techniques proved validity

- Affordable solution needed

- New knowledge provided by
  - Medical and scientific community
  - Experience of medical experts
Motivation and context

Semantically Steered Clinical Decision Support Systems

Challenges of Clinical Decision Support Systems (CDSS)

1. Computerization of CDSS
2. Timely advice
3. Maintainability and extensibility
4. Clinical workflow integration

- Decision support integrated into the clinical workflow
  - Minimization of time consumption during the introduction of patient data and results.
  - Assist clinicians during all different tasks of their daily duties
    » Not only during specific activities.
Motivation and context

Semantically Steered

Clinical Decision Support Systems

Challenges of Clinical Decision Support Systems (CDSS)

1. Computerization of CDSS
2. Timely advice
3. Maintainability and extensibility
4. Clinical workflow integration
5. Architecture for CDSS

- Sharing and reusing of clinical decision support

- Needed:
  - Expressivity
  - Modularity
  - Reasoning Capabilities
Semantically Steered Clinical Decision Support Systems

This work was driven by the hypothesis that semantics and experience-based technologies can enhance CDSS making them successful in real clinical environments.
Motivation and context

Semantically Steered Clinical Decision Support Systems

How can clinical experience be modeled, acquired and reused in the context of clinical decision making?

Is it possible to develop a semantic steered clinical decision support system that allows the handling of the collective experience of a medical organization?
Objectives

- To propose a methodology for the recommendations generation process.
- To propose a methodology for the automatic evolution of a ruleset, based on the acquired decisional events.
- To present a generic model for clinical tasks in the context of clinical decision making.
- To present a generic architecture for S-CDSS that fits in the clinical task model.
- To present a framework for the management of the clinical experience of a medical organization.
Contents and structure

Motivation and context

Recommendations generation
Recommendations generation

- **Recommendations are...**
  - a set of alternative options
  - Ranked and presented to system users with their proofs

- Knowledge-based approach needed

- Reasoning system
Recommendations generation
Recommendations generation
If (( CLASS GeneralSurgery with the PROPERTY GeneralSurgery_InterventionType EQUALS TO Conservative ))
then ( CLASS Radiotherapy with the PROPERTY Radiotherapy_ProtocolName EQUALS TO MAMA-50 )
Recommendations generation

REQUEST

• Patient
• Decisional category

Reasoning system

RECOMMENDATIONS

Opt-1: 65% - Rule 1
Opt-2: 20% - Rule 2, 3
Opt-3: 10% - Rule 5
Opt-4: 5% - Rule 12
Fast querying: Reflexive Ontologies
Fast querying: Reflexive Ontologies

Recommendations generation

Query Engine
- Reflexive Ontologies
- Query specification
- Set of matching Instances

Reasoning Engine
- Rule conditional queries
- Consequence actions
- Recommendations generation

Speed up in the medical domain: same questions are repeated frequently
Fast querying: Reflexive Ontologies

- Performance of Reflexive Ontologies

Efficiency gain 60%
Fast querying: Reflexive Ontologies

- Performance of Reflexive Ontologies
Extended Reflexive Ontologies

- Reflexive ontology containing also
  - Rules
  - The matching recommendations for each set of individuals

- Speed up of the reasoning process
  - Previously made rules do not need to be calculated again
Recommendations generation

Extended Reflexive Ontologies

Reasoning Engine
- Rule conditional queries
- Consequence actions
- Recommendations generation

Query Engine
- Reflexive Ontologies
- Query specification
- Set of matching instances

Ruleset
Extended Reflexive Ontologies

- Implementation of Extended Reflexive Ontologies
Contents and structure

Motivation and context

Recommendations generation

Clinical Experience Handling
Clinical Experience handling

• Final decision
  - Reusable to improve recommendations
Clinical Experience handling

Ruleset evolution

1. Rule weight evolution

Combine 2 criteria:

- **QUANTITY**: number of times a rule matches the conditions
- **QUALITY**: number of times when recommendation becomes a final decision

\[
W_k (\alpha) = \frac{\sum_m \sum_t (x_{mtk} - \alpha_{mt} e_{mtk})}{\sum_m \sum_t \sum_k (x_{mtk} - \alpha_{mt} e_{mtk})}
\]
Clinical Experience handling

Ruleset evolution

2. Fine tuning of rules (rule conditional query clauses)

- **Activation count**: Total amount of times that a query clause is active in a rule that matches conditions

\[ \mu_{kl} = \# \{ S_t \mid M(A_k, S_t) \land M(q_{kl}^s, S_t), q_{kl}^s \in A_k \} \]

- **Agreement count**: Total of times that being a query clause active in a rule that matches conditions, the recommendation = final decision

\[ \rho_{kl} = \# \{ S_t \mid M(A_k, S_t) \land M(q_{kl}^s, S_t) \land (S_k = f_t), q_i^s \in A_k \} \]

- **Ratio**: Error prone query clauses

\[ \frac{\rho_{kl}}{\mu_{kl}} > \text{Threshold} \]
Clinical Experience handling

Ruleset evolution

3. New rule generation

• **Final decision:** validate the set of variables that are relevant
  – Include
  – Remove

• Generate a new rule
  – **Antecedent** (IF): new set of relevant values
  – **Consequent** (THEN): final decision
Clinical Experience handling

Experience consolidation

Knowledge Model
- Rule inclusion
- Domain experts committee
- Rule set evolution

Ontology
- Recommendations generation

Experience Model
- Decision maker
- Final decision
Contents and structure

Motivation and context

- Recommendations generation
- Clinical Experience Handling
- S-CDSS architecture
S-CDSS architecture

- Clinical Task Model
  - Cyclic process

  ![Diagram of S-CDSS architecture]

  - Symptoms: cough, mucosity
  - Diagnosis: "cold"
  - Prognosis: "3 days for recovery"
  - New diagnosis: "flu"
  - New prognosis: "1 week for recovery"

  - Treatment: "pills against mucosity and cough, rest if needed"
  - New treatment: "paracetamol for fever and pain, abundant liquids, rest"

  - Evolution: "high fiber has arisen"
  - New evolution: "as expected, patient recovered and discharged"
S-CDSS architecture

- Clinical Task Model
  - Cyclic process
  - Federated management
S-CDSS architecture

S-CDSS architecture

User

Decision recommendations

Experience management

S-CDSS Multi-agent architecture

Data repository

Knowledge repository

Collective experience
S-CDSS architecture

- Multi-Agent System
  - Modularity
  - Scalability
  - Extensibility
S-CDSS architecture

- Sequence diagram
Contents and structure

Motivation and context

Recommendations generation

Clinical Experience Handling

S-CDSS architecture

Case study: Early diagnosis of Alzheimer’s Disease
Early diagnosis of Alzheimer’s Disease

- Research project MIND

- Alzheimer’s Disease
  - Neurodegenerative
  - Cause and mechanisms still unknown
  - Challenges:
    - Discovery of new knowledge
    - Knowledge handling

- CDSS for early diagnosis
Early diagnosis of Alzheimer’s Disease
Early diagnosis of Alzheimer’s Disease
Case study: Breast Cancer

Breast Cancer Decision Support System

- Project LIFE

- Breast cancer
  - Multidisciplinary
  - Challenges
    - Personalized therapies
    - Knowledge maintenance

- S-CDSS for breast cancer functional unit
  - Radiology (diagnosis)
  - Nuclear medicine
  - Pathologic anatomy
  - Surgery
  - Medical Oncology
  - Radiation Oncology
  - Psychology
  - Rehabilitation
LIFE Ontology

Breast Cancer Decision Support System

- LIFE Ontology
Breast Cancer Decision Support System

- Implementation (demo video)
Contents and structure

Motivation and context

- Recommendations generation
  - Case study: Early diagnosis of Alzheimer’s Disease
- Clinical Experience Handling
- S-CDSS architecture

Conclusions
Conclusions

• Research question and objectives accomplishment

  ❑ We have demonstrated that clinical experience can be modeled, acquired and reused in the context of clinical decision making.

  ❑ In order to allow the handling of the collective experience within a medical organization, we have proposed and developed
    • a theoretical framework
    • its specific recommendations
    • associated methodologies
    • practical tools
Conclusions

• We presented a methodology for the generation of decision recommendations.

• We presented a methodology for the acquisition and consolidation of decisional events in the system.

• In particular, we have provided a methodology for the automatic evolution of a ruleset based on the acquired decisional events.

• The integration of such contributions into a CDSS allowed us to present an innovative architecture for Semantically steered CDSS (S-CDSS).

• The architecture fits in the Clinical Task Model (CTM), a generic model for clinical tasks which we also presented.

• We have achieved an operational implementation of such architecture and methodologies in the framework of two case studies: early diagnosis of AD and breast cancer treatment.
Contents and structure

Motivation and context

Recommendations generation → Clinical Experience Handling → S-CDSS architecture

Case study: Early diagnosis of Alzheimer’s Disease → Case study: Breast Cancer Decision Support System

Conclusions → Future work
Future Work

Future work

• Short term
  • Design more refined algorithms in order to extract implicit knowledge from the reflexive structure
  • Evaluate the performance of RO in different domains and use cases

• Mid term
  • Perform a formal evaluation of our architecture in a real clinical environment

• Long term
  • Study how to develop decision traceability in the clinical domain
  • Develop automatic knowledge retrieval tools to provide knowledge maintenance
  • Integrate the proposed S-CDSS with hospital EHR
    • EHR semantization
Thank you for your attention