Decision Support and Knowledge Management in Oncology using Hierarchical Classification

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Overview of the talk

- Introduction: the Kasimir research project
  - Knowledge Management of medical protocols in oncology
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- Reasoning and knowledge representation in Kasimir
  - Syntax and semantics of a simple formalism for medical protocols
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  - Usefulness of this representation formalism
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  - Taking into account the threshold effect
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- Ongoing researches of the Kasimir project
Introduction: The Kasimir research project

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- Knowledge Management of medical protocols in oncology
- Multidisciplinary research project with
  - experts in oncology from the centre Alexis Vautrin (Nancy);
  - researchers in psycho-ergonomics of the Laboratoire d’ergonomie du CNAM (Paris);
  - researchers in informatics from the Orpailleur research group of the Loria (Nancy);
  - members of the health network Oncolor (Lorraine region).
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- Main decision problem studied in the project: treatment of the breast cancer without metastasis.
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- Main decision problem studied in the project: treatment of the breast cancer without metastasis.
- The decision is based on a protocol.
KR in Kasimir

- A formalism inspired from object-based representation formalisms and description logics
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- Building blocks: primitive concepts and numerical intervals
• A formalism inspired from object-based representation formalisms and description logics

• In this formalism, a concept $C$ represents a set of individuals $C^\mathcal{I}$, for an interpretation $\mathcal{I}$.

• Building blocks: primitive concepts and numerical intervals

• A class of patients is represented by a defined concept based on
  – functional role restriction and
  – conjunction

\[
\text{small-int-tumour} \equiv (\text{size}: [0; 4] \sqcap \text{localisation}: \text{internal})
\]

\[
\text{WA}_{40-80}\text{SIT} \equiv (\text{sex}: \text{female} \sqcap \text{age}: [40, 80] \sqcap \text{tumour}: \text{small-int-tumour})
\]
KR in Kasimir

- A formalism inspired from object-based representation formalisms and description logics
- In this formalism, a concept C represents a set of individuals C^I, for an interpretation I.
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- A treatment is represented by a primitive concept
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- A class of patients is represented by a defined concept based on
  - functional role restriction and
  - conjunction
- A treatment is represented by a primitive concept
- A protocol can be defined by a set of rules $R = (CP \rightarrow Ttt)$ where
  - $CP$ represents a class of patients and
  - $Ttt$ represents a treatment.
- $R$ means that, for any patient of $CP^I$, a treatment of $Ttt^I$ is proposed by the protocol.
Reasoning in Kasimir

- The reasoning is based on the subsumption relation between concepts:

\[ C \sqsubseteq D \iff \text{for every } I, \; C^I \subseteq D^I \]
Reasoning in Kasimir

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\[ C \sqsubseteq D \quad \text{iff} \quad \text{for every } \mathcal{I}, C^\mathcal{I} \subseteq D^\mathcal{I} \]

- \( \sqsubseteq \) is a partial ordering that allows to organise a set of concepts representing classes of patients, including \( \top \), in a hierarchy \( \mathcal{H} \):

\[ \text{for } CP_1 \text{ and } CP_2 \text{ in } \mathcal{H}, \quad CP_1 \sqsubseteq CP_2 \quad \text{iff} \quad CP_1 \rightarrow^*_{\mathcal{H}} CP_2 \]
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• If \( tgt \) is a concept representing a patient, the hierarchical classification of \( tgt \) in \( \mathcal{H} \) highlights the concepts \( CP \) of \( \mathcal{H} \) such that \( tgt \sqsubseteq CP \).
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- Then, the treatments associated thanks to protocol rules with these concepts \( CP \) are returned:

\[
\begin{align*}
\text{tgt} & \quad \text{tgt} \sqsubseteq \text{CP} & \quad \text{CP} \rightarrow \text{Ttt} \\
\hline
\text{Ttt is proposed to tgt}
\end{align*}
\]
Reasoning in Kasimir

• The reasoning is based on the subsumption relation between concepts:

\[ C \sqsubseteq D \quad \text{iff} \quad \text{for every } \mathcal{I}, \mathcal{C}^{\mathcal{I}} \subseteq \mathcal{D}^{\mathcal{I}} \]

• \( \sqsubseteq \) is a partial ordering that allows to organise a set of concepts representing classes of patients, including \( \top \), in a hierarchy \( \mathcal{H} \):

\[ \text{for } CP_1 \text{ and } CP_2 \text{ in } \mathcal{H}, \quad CP_1 \sqsubseteq CP_2 \quad \text{iff} \quad CP_1 \rightarrow^*_{\mathcal{H}} CP_2 \]

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\[
\begin{array}{ccc}
tgt & tgt \sqsubseteq CP & CP \rightarrow Ttt \\
\hline
Ttt \text{ is proposed to } tgt
\end{array}
\]

• Algorithm: depth-first search in \( \mathcal{H} \).
Example of protocol representation

For a woman with $N = -$, $RH = +$ and tumour grade = 1:

- **age** ≤ 35?
  - yes
    - **tumour size** < 1 cm?
      - yes
        - chemotherapy of level 1
      - no
        - ...
  - no
    - **age** < 70?
      - yes
        - chemotherapy of level 1
      - no
        - ...

Example of protocol representation

For a woman with $N = -$, $RH = +$ and tumour grade = I:

```
\text{age} \leq 35? \\
\text{yes} \\
\text{tumour size} < 1 \text{ cm?} \\
\text{yes} \\
\text{chemotherapy of level 1} \\
\text{no} \\
\text{age} < 70? \\
\text{yes} \\
\text{chemotherapy of level 1} \\
\text{no} \\
\text{no chemotherapy}
```

Introduction of primitive concepts:
- any-boolean $\sqsubseteq \top$
- true $\sqsubseteq$ any-boolean
- false $\sqsubseteq$ any-boolean
- any-grade $\sqsubseteq \top$
- grade-I $\sqsubseteq$ any-grade
- any-treatment $\sqsubseteq \top$
- level-1-chemotherapy $\sqsubseteq$ any-treatment
- no-chemotherapy $\sqsubseteq$ any-treatment
Example of protocol representation

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\begin{align*}
\text{age} \leq 35? & \\
\text{yes} & \quad \text{tumour size < 1 cm?} \quad \text{(chemotherapy of level 1)} \\
\text{no} & \quad \text{age} < 70? \\
\text{yes} & \quad \text{no chemotherapy} \\
\text{no} & \quad \text{...}
\end{align*}
\]

Introduction of defined concepts:

\[
\begin{align*}
\text{WN}_-\text{RH}_+\text{G}_I & \equiv (\text{sex: female} \sqcap \text{N: false} \sqcap \text{RH: true} \sqcap \text{tumour: grade: grade-I}) \\
A_{\leq 35} & \equiv \text{WN}_-\text{RH}_+\text{G}_I \sqcap (\text{age:}[0, 35]) \\
A_{>35} & \equiv \text{WN}_-\text{RH}_+\text{G}_I \sqcap (\text{age: }]35, +\infty[) \\
T_{\geq 1} & \equiv A_{\leq 35} \sqcap (\text{tumour: (size:}[1; +\infty[)) \\
A_{\geq 70} & \equiv A_{>35} \sqcap (\text{age:}[70, +\infty[)
\end{align*}
\]
Example of protocol representation

For a woman with $N = −$, $RH = +$ and tumour grade = 1:

```
age ≤ 35?
  yes
  tumour size < 1 cm?
    yes
    ⋮
    (chemotherapy of level 1)
  no
  age ≤ 70?
    yes
    ⋮
    (no chemotherapy)
  no
```

Introduction of protocol rules:

\[
R_1 = (T_{\geq 1} \rightarrow \text{level-1-chemotherapy})
\]

\[
R_2 = (A_{\geq 70} \rightarrow \text{no-chemotherapy})
\]
The Kasimir user interface
Editing and maintenance of knowledge

- Use of the Protégé system to edit Kasimir protocols.
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- Use of the Kasimir reasoner, connected with Protégé, to avoid editing mistakes.
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\[ W_{\geq 16} = (\text{sex:female} \sqcap \text{age:}[16, +\infty]) \]
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  - Detection of mismatches between
    * The hierarchy declared in Protégé
    * The hierarchy calculated in Kasimir
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- Two hierarchy visualisation modules connected with Protégé: Palétuvier and Hypertree
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HyperTree
HyperTree
KILT: comparison of protocol versions
**KILT: comparison of protocol versions**

- **Given:** two versions of the protocol
  - $P_{\text{before}}$: “before updating”
  - $P_{\text{after}}$: “after updating”
- Two hierarchies organising classes of patients CP, possibly related with treatments.
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  - What is unchanged: the rest
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  - What is **new**: the concepts CP representing the classes of patients appearing in $P_{\text{after}}$ but not in $P_{\text{before}}$
  - The classes of patients CP appearing in both $P_{\text{before}}$ and $P_{\text{after}}$, but associated with different solutions
  - What is **unchanged**: the rest

- **KILT** is used during an editing session:
  - $P_{\text{before}}$: the protocol at the beginning of the session
  - $P_{\text{after}}$: the protocol at the current time
KILT: comparison of protocol versions
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Decision Support and Knowledge Management in Oncology using Hierarchical Classification – p. 11
• Let $CP_1$ and $CP_2$ be the following following concepts:

$$CP_1 = (\text{sex:female} \sqcap \text{tumour:}(\text{size:}[0;4]))$$

$$CP_2 = (\text{sex:female} \sqcap \text{tumour:}(\text{size:}]4;7]))$$
• Let $CP_1$ and $CP_2$ be the following following concepts:

$$CP_1 = (\text{sex: female} \sqcap \text{tumour:(size:}[0;4]))$$
$$CP_2 = (\text{sex: female} \sqcap \text{tumour:}(\text{size: }]4;7)))$$

• They are assumed to be related to different treatments:

$$R_1 = (CP_1 \rightarrow Ttt_1) \quad R_2 = (CP_2 \rightarrow Ttt_2) \quad \text{with} \ Ttt_1 \neq Ttt_2$$
Let \( CP_1 \) and \( CP_2 \) be the following concepts:

\[
CP_1 = (\text{sex: female} \land \text{tumour:(size: [0; 4])})
\]

\[
CP_2 = (\text{sex: female} \land \text{tumour:(size: ]4; 7])})
\]

They are assumed to be related to different treatments:

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R_1 = (CP_1 \rightarrow Ttt_1) \quad R_2 = (CP_2 \rightarrow Ttt_2) \quad \text{with } Ttt_1 \neq Ttt_2
\]

Let \( tgt \) be the following patient:

\[
tgt = (\text{sex: female} \land \text{age: [56, 56]} \land \text{tumour:(size: [3.8; 3.8])})
\]
Fuzzy Kasimir

- Let $CP_1$ and $CP_2$ be the following following concepts:

  \[
  CP_1 = (\text{sex: female} \sqcap \text{tumour: (size: } [0; 4]))
  \]
  \[
  CP_2 = (\text{sex: female} \sqcap \text{tumour: (size: } ]4; 7]))
  \]

- They are assumed to be related to different treatments:

  \[
  R_1 = (CP_1 \rightarrow Tt_{t1}) \quad R_2 = (CP_2 \rightarrow Tt_{t2}) \quad \text{with } Tt_{t1} \neq Tt_{t2}
  \]

- Let $tgt$, be the following patient:

  \[
  tgt = (\text{sex: female} \sqcap \text{age: } [56, 56] \sqcap \text{tumour: (size: } [3.8; 3.8]))
  \]

- **Kasimir** (classical) reasoning:

  since $tgt \sqsubseteq CP_1$ and $tgt \not\sqsubseteq CP_2$

  $Tt_{t1}$ is proposed but not treatment $Tt_{t2}$
Fuzzy Kasimir

• **Kasimir** (classical) reasoning:

\[
\text{since } \text{tgt} \subseteq \text{CP}_1 \quad \text{and} \quad \text{tgt} \not\subseteq \text{CP}_2
\]

\(\text{Tt}_1\) is proposed but not treatment \(\text{Tt}_2\)

• **Kasimir** fuzzy reasoning:

both treatments are proposed, with a preference for \(\text{Tt}_1\)
• **KASIMIR** fuzzy reasoning is based on fuzzy concepts and fuzzy subsumption.
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• Fuzzy concepts:
• **Kasimir** fuzzy reasoning is based on 
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• Fuzzy concepts:
  – concepts $C$ that are interpreted by fuzzy sets $C^I$. 

Fuzzy *Kasimir*
**Fuzzy Kasimir**

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- Fuzzy concepts:
  - concepts $C$ that are interpreted by fuzzy sets $C^I$.
  - In **Kasimir**, the fuzziness is introduced by substituting intervals $I$ by fuzzy sets $\mathcal{F}I$.
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  - concepts $C$ that are interpreted by fuzzy sets $C^I$.
  - In **Kasimir**, the fuzziness is introduced by substituting intervals $I$ by fuzzy sets $\mathcal{F}I$.
- Fuzzy subsumption:
  - $\varphi(C,D) \in [0;1]$
  - $\varphi$ is a fuzzification of $\sqsupseteq$
    $$\varphi(C,D) = 1 \quad \text{iff} \quad C \sqsupseteq D$$
Fuzzy Kasimir

- **Kasimir** fuzzy reasoning is based on fuzzy concepts and fuzzy subsumption.
- Fuzzy concepts:
  - concepts $C$ that are interpreted by fuzzy sets $C^I$.
  - In Kasimir, the fuzziness is introduced by substituting intervals $I$ by fuzzy sets $FI$.
- Fuzzy subsumption:
  - $S(C,D) \in [0;1]$  
  - $S$ is a fuzzification of $\sqsubseteq$
- Fuzzy reasoning:

\[
\begin{array}{rcl}
\text{tgt} & S(pb,tgt) = s & \text{Sol(pb) is a solution of pb} \\
\text{Sol(tgt)} & = \text{Sol(pb)} & \text{is an s-solution of tgt}
\end{array}
\]
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\begin{align*}
tgt \quad S(pb, tgt) = s \quad \text{Sol(pb) is a solution of pb} \\
\text{Sol(tgt) = Sol(pb) is an } s\text{-solution of tgt}
\end{align*}
\]

- Algorithm: best-first search of the hierarchy $H$ according to $S(C, tgt)$. 
The fuzzy Kasimir user interface
Ongoing researches of the Kasimir project
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- Towards a Semantic Web portal for oncology
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  - Translation of Kasimir representation language to OWL Lite
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  - Useful when the straightforward application of the protocol raises problems (e.g., contraindications).
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- Protocol adaptation
  - Useful when the straightforward application of the protocol raises problems (e.g., contraindications).
  - Researches for adaptation knowledge acquisition for Kasimir:
    * supervised
    * automatic