A Computational Argumentation Framework for Decision-Making in Multimorbidity

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Overview

Motivation
Multimorbidity

- **Multimorbidity** is the state of a patient when he/she presents two or more medical conditions.
- It poses challenges:
  - **drug-drug** interactions;
  - **drug-disease** interactions.
- Complex treatment regimens with uncertain consequences.

Motivation

Clinical Decision Support Systems

- Mostly based on Computer-Interpretable Guidelines.
- **Reason about each medical condition individually.**
- Limited in the dimensions of multimorbidity they consider, namely when it comes to: patient preferences, patient-specific prioritized goals, and decidable mechanisms for conflict resolution.
  - *Fox and Thomson 1998, Fox et al. 2003*
  - *Wilk et al. 2017*
  - *Zamborlini et al. 2017*
- Unable to properly handle cases of multimorbidity.
- Several works call for the use of **Multiple Criteria Decision-Making**, but it **is not explanatory**.

Ongoing projects to deploy argumentation for Health

- **ROAD2H** Collaborative project with Imperial College London (IGHI and DoC), King's College London, University of Serbia and China National Health Development Research Center (CNHDRC). Develop novel Learning Health System techniques to facilitate Universal Health Coverage (UHC) in low- and middle-income countries.

- **CONSULT** King's College London. Aims to establish an intelligent mobile system that uses health and medical data from a number of sources to help patients suffering from chronic diseases and associated conditions self-manage their treatment.

Example

Patient A has type 2 diabetes, obesity, hypertension, and chronic kidney disease.

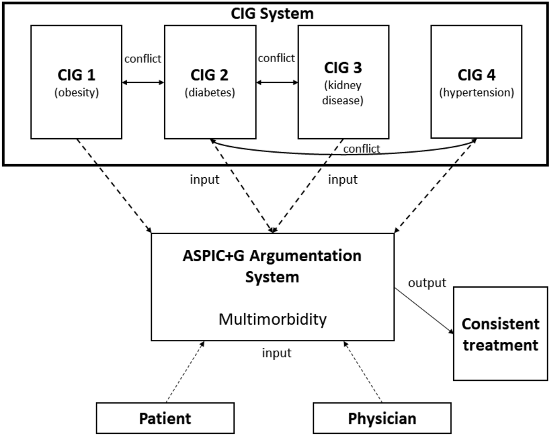
- **CIG 1 (for obesity):** *Define weight decrease (w_decrease) as a therapy goal. To reduce weight, the patient should practice diet and exercise (diet_ex).*
- **CIG 2 (for diabetes):** *Define blood glucose decrease (gluc_decrease) as a therapy goal. Sulfonylurea (sulf) or meglitinide (meg) can reduce blood glucose elevations, but they cause weight increase (w_increase). Metformin (met) can lower blood glucose, but its use in the presence of chronic kidney disease (chron_kid_dis) should be avoided as it may accelerate chronic kidney disease (accelerate_kid). The patient should only take one of the drugs.*
- **CIG 3 (for kidney disease):** *Define delay chronic kidney disease (delay_kid) as a therapy goal. The patient is advised to take angiotensin converting enzyme inhibitors (ang_conv_enz_in) as they delay the progression of chronic kidney disease to kidney failure.*
- **CIG 4 (for hypertension):** *Define blood pressure decrease (blood_pres_decrease) as a therapy goal. Administer an angiotensin converting enzyme inhibitor (ang_conv_enz_in) or a calcium channel blocker (cal_channel_bloc) to decrease blood pressure. However, a calcium channel blocker compromises the effectiveness of glucose control drugs such as meglitinide or metformin.*

Motivation
Case Example

- When merging **CIG1 and CIG2**, there is a **conflict** with the use of sulfonylurea and meglitinide.
- When merging **CIG3** with the other two, **additional conflicts are created**. The use of metformin for the treatment of diabetes is compromised.
- When adding **CIG4** we realize that the use of calcium channel blocker compromises the use of meglitinide or metformin.

Motivation
Contribution

A computational argumentation framework for reasoning in multimorbidity.



Modelling of problems as natural discussions and analysis of conflicts

$$A \longrightarrow B \longrightarrow C$$

Admissible sets (conflict-free): $\{A, C\}$ and $\{B\}$

The ASPIC+G Argumentation System

- ASPIC+ is a system for structured argumentation. In it, arguments ate built from axioms and premises as well as from defeasible rules.
- We propose an adaptation of ASPIC+ called ASPIC+G that allows the incorporation of goals and goal preferences in hypothetical reasoning.
- The intuition behind ASPIC+G is that **argumentation is often driven by goals** which reflect the multiple objectives that may be achieved in a discussion.

Definition

An argumentation theory in ASPIC+G is a tuple $\langle \mathcal{L}, \mathcal{R}, n, \leqslant_{\mathcal{R}_d}, \mathcal{G}, \leqslant_{\mathcal{G}} \rangle$, where:

- $\mathcal{L}$ is a logical language closed under negation ($\neg$).
- $\mathcal{R} = \mathcal{R}_s \cup \mathcal{R}_d$ is a set of strict ($\mathcal{R}_s$) and defeasible ($\mathcal{R}_d$) rules of the form $\phi_1, ..., \phi_n \rightarrow \phi$ and $\phi_1, ..., \phi_n \Rightarrow \phi$ respectively, where $n \geq 0$ and $\phi_i, \phi \in \mathcal{L}$;
- n is a partial function such that $n : \mathcal{R} \rightarrow \mathcal{L}$;
- $\leqslant_{\mathcal{R}_d}$ is a partial pre-order over defeasible rules $\mathcal{R}_d$, denoting a preference relation, with a strict counterpart $<_{\mathcal{R}_d}$ given by $X <_{\mathcal{R}_d} Y$ iff $X \leqslant_{\mathcal{R}_d} Y$ and $Y \nleqslant_{\mathcal{R}_d} X$;
- $\mathcal{G} \subseteq \mathcal{L}$ is a set of goals that the arguments will try to fulfil s.t. $\forall\ \theta \in \mathcal{G}$, there exists a rule $\phi_1, ..., \phi_n \rightarrow \phi$ in $\mathcal{R}_s$ or $\phi_1, ..., \phi_n \Rightarrow \phi$ in $\mathcal{R}_d$ s.t. $\phi = \theta$;
- $\leqslant_{\mathcal{G}}$ is a total pre-order on $\mathcal{G}$, denoting preferences over goals, with $<_{\mathcal{G}}$ given by $\phi <_{\mathcal{G}} \psi$ iff $\phi \leqslant_{\mathcal{G}} \psi$ and $\psi \nleqslant_{\mathcal{G}} \phi$, and $\simeq_{\mathcal{G}}$ given by $\phi \simeq_{\mathcal{G}} \psi$ iff $\phi \leqslant_{\mathcal{G}} \psi$ and $\psi \leqslant_{\mathcal{G}} \phi$.

Definition

An argument A *fulfils* goal $\theta \in \mathcal{G}$ iff $\mathrm{Conc}(A) = \theta$. We write $\mathrm{Goal}(A)$ for the set of goals that A fulfils.

Definition

A set S is a *preferred* extension iff it is a set inclusion maximal admissible extension.

Definition

Let $S = \{A_1, ..., A_n\}$ be a preferred extension. Then GE_S is the goal extension of S s.t. $GE_S = \mathrm{Goal}(A_1) \cup ... \cup \mathrm{Goal}(A_n)$.

Definition

[Preferred Extension Ordering $\trianglelefteq_P$] Let GE_A be the goal extension of preferred extension A and GE_B be the goal extension of preferred extension B. We define the *preferred extension ordering* $\trianglelefteq_P$ to be such that $A \trianglelefteq_P B$ iff $GE_A \trianglelefteq_{GE} GE_B$.

Definition

[Top Preferred Extension] Let $\mathbb{P}$ be a set of preferred extensions. A preferred extension $P \in \mathbb{P}$ is a *top preferred extension* iff $\forall P' \in \mathbb{P}, P' \trianglelefteq_P P$.

Modelling Multimorbidity in ASPIC+G

We now instantiate ASPIC-G for the Example 1 according to the tuple $\langle \mathcal{L}, n, \mathcal{R}, \leqslant_{\mathcal{R}_d}, \mathcal{G}, \leqslant_{\mathcal{G}} \rangle$. $\mathcal{L}$ consists of knowledge patterns 1 to 6. $\mathcal{R}$, $\leqslant_{\mathcal{R}_d}$, $\mathcal{G}$, and $\leqslant_{\mathcal{G}}$ are:

- $\mathcal{R}_d$ is the following set of defeasible rules:
  (pattern 1)
  $\Rightarrow diet\_ex$.
  $\Rightarrow sulf$.
  $\Rightarrow meg$.
  $\Rightarrow met$.
  $\Rightarrow ang\_conv\_enz\_in$.
  $\Rightarrow cal\_channel\_bloc$.
  (pattern 2)
  $diet\_ex \Rightarrow w\_decrease$.
  $sulf \Rightarrow gluc\_decrease$.
  $r_1 : meg \Rightarrow gluc\_decrease$.
  $r_2 : met \Rightarrow gluc\_decrease$.
  $chron\_kid\_dis, ang\_conv\_enz\_in \rightarrow delay\_kid$.
  $ang\_conv\_enz\_in \Rightarrow blood\_pres\_decrease$.
  (pattern 2)
  $cal\_channel\_bloc \Rightarrow blood\_pres\_decrease$.
- $\mathcal{R}_s$ is the following set of strict rules (note that these rules can be transposed):
  (pattern 3)
  $sulf \rightarrow w\_increase$.
  $meg \rightarrow w\_increase$.
  $met, chron\_kid\_dis \rightarrow accelerate\_kid$.
  $cal\_channel\_bloc \rightarrow \neg r_1$.
  $cal\_channel\_bloc \rightarrow \neg r_2$.
  (pattern 4)
  $sulf \rightarrow \neg meg$.
  $sulf \rightarrow \neg met$.
  $meg \rightarrow \neg met$.

Modelling Multimorbidity in ASPIC+G

(pattern 4)
$ang\_conv\_enz\_in \rightarrow \neg cal\_channel\_bloc.$
(pattern 5)
$w\_decrease \rightarrow \neg w\_increase.$
$accelerate\_kid \rightarrow \neg delay\_kid.$
(pattern 6)
$\rightarrow chron\_kid\_dis.$

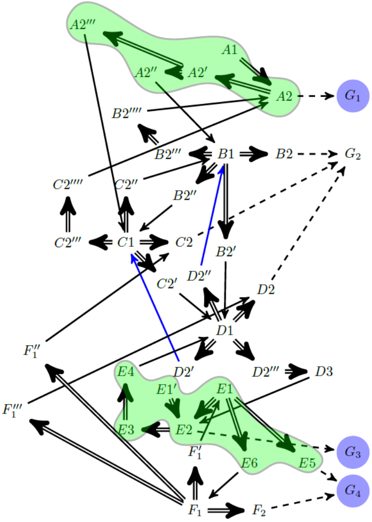
- $\mathcal{R} = \mathcal{R}_d \cup \mathcal{R}_s$;
- $\leqslant_{\mathcal{R}_d}$ is the following partial pre-order over elements in $\mathcal{R}_d$:
$(\Rightarrow met) <_{\mathcal{R}_d} (\Rightarrow sulf), (\Rightarrow met) <_{\mathcal{R}_d} (\Rightarrow meg)$;
- $\mathcal{G} = \{w\_decrease, gluc\_decrease, delay\_kid, blood\_press\_decrease\}$;
- $\leqslant_{\mathcal{G}}$ is the following total pre-order over elements in $\mathcal{G}$:
$delay\_kid <_{\mathcal{G}} gluc\_decrease \simeq_{\mathcal{G}} blood\_pres\_decrease <_{\mathcal{G}} w\_decrease.$

Modelling Multimorbidity in ASPIC+G

It is possible to build the following set of arguments $\mathcal{A}$:

$\mathcal{A} = \{A_1 :\Rightarrow diet\_ex,$
$A_2 : A_1 \Rightarrow w\_decrease,$
$A_2' : A_2 \rightarrow \neg w\_increase,$
$A_2'' : A_2' \rightarrow \neg sulf,$
$A_2''' : A_2' \rightarrow \neg meg,$
$B_1 :\Rightarrow sulf,$
$B_2 : B_1 \Rightarrow gluc\_decrease,$
$B_2' : B_1 \rightarrow \neg met,$
$B_2'' : B_1 \rightarrow \neg meg,$
$B_2''' : B_1 \rightarrow w\_increase,$
$B_2'''' : B_2''' \rightarrow \neg w\_decrease,$
$C_1 :\Rightarrow meg,$
$C_2 : C_1 \rightarrow gluc\_decrease,$
$C_2' : C_1 \rightarrow \neg met,$
$C_2'' : C_1 \rightarrow \neg sulf,$
$C_2''' : C_1 \rightarrow w\_increase,$
$C_2'''' : C_2''' \rightarrow \neg w\_decrease,$
$D_1 :\Rightarrow met,$
$D_2 : D_1 \rightarrow gluc\_decrease,$
$D_2' : D_1 \rightarrow \neg meg,$
$D_2'' : D_1 \rightarrow \neg sulf,$
$E_1 :\Rightarrow ang\_conv\_enz\_in,$
$E_1' :\rightarrow chron\_kid\_dis,$
$D_2''' : D_1, E_1' \rightarrow accelerate\_kid,$
$D_3 : D_2''' \rightarrow \neg delay\_kid,$
$E_2 : E_1, E_1' \Rightarrow delay\_kid,$
$E_3 : E_2 \rightarrow \neg accelerate\_kid,$
$E_4 : E_1', E_3 \rightarrow \neg met,$
$E_5 : E_1 \Rightarrow blood\_pres\_decrease,$
$E_6 : E_1 \Rightarrow \neg cal\_channel\_bloc,$
$F_1 :\Rightarrow cal\_channel\_bloc,$
$F_2 : F_1 \Rightarrow blood\_pres\_decrease,$
$F_1' : F_1 \rightarrow \neg ang\_conv\_enz\_in,$
$F_1'' : F_1 \rightarrow \neg r_1,$ (r_1 used by argument C_2)
$F_1''' : F_1 \rightarrow \neg r_2\}$ (r_1 used by argument D_2)
$\mathcal{G} = \{G_1 : w\_decrease,$
$G_2 : gluc\_decrease,$
$G_3 : delay\_kid,$
$G_4 : blood\_pressure\_decrease\}$

Modelling Multimorbidity in ASPIC+G



Detailed graph for the argumentation theory of the Example with all arguments. The single black arrow represents a successful attack, i.e. a defeat, single blue arrow represents an unsuccessful attack, the double arrow represents the sub-argument (support) relation and the dashed arrow represents the fulfillment relation. The top preferred extension is highlighted in green and the goals it fulfils in blue.

Modelling Multimorbidity in ASPIC+G

Preferred extensions

- $S_1 = \{\mathtt{A}_1, \mathtt{A}_2, \mathtt{A}'_2, \mathtt{A}'''_2, \mathtt{E}_1, \mathtt{E}'_1, \mathtt{E}_2, \mathtt{E}_3, \mathtt{E}_4, \mathtt{E}_5, \mathtt{E}_6\}$, $\mathrm{Goal}(S_1) = \{\mathtt{G}_1, \mathtt{G}_3, \mathtt{G}_4\}$;
- $S_2 = \{\mathtt{A}_1, \mathtt{A}_2, \mathtt{A}'_2, \mathtt{A}'''_2, \mathtt{D}_1, \mathtt{D}'_2, \mathtt{D}''_2, \mathtt{D2}''', \mathtt{D}_3, E'_1, F_1, \mathtt{F}'_1, \mathtt{F}''_1, \mathtt{F1}''', \mathtt{F}_2\}$, $\mathrm{Goal}(S_2) = \{\mathtt{G}_1, \mathtt{G}_4\}$;
- $S_3 = \{\mathtt{A}_1, \mathtt{B}_1, \mathtt{B}_2, \mathtt{B}'_2, \mathtt{B}'''_2, \mathtt{B}''''_2, \mathtt{E}_1, \mathtt{E}'_1, \mathtt{E}_2, \mathtt{E}_3, \mathtt{E}_4, \mathtt{E}_5, \mathtt{E}_6\}$, $\mathrm{Goal}(S_3) = \{\mathtt{G}_2, \mathtt{G}_3, \mathtt{G}_4\}$;
- $S_4 = \{\mathtt{A}_1, \mathtt{B}_1, \mathtt{B}_2, \mathtt{B}'_2, \mathtt{B}'''_2, \mathtt{B}''''_2, \mathtt{E}'_1, \mathtt{F}_1, \mathtt{F}'_1, \mathtt{F}''_1, \mathtt{F1}''', \mathtt{F}_2\}$, $\mathrm{Goal}(S_4) = \{\mathtt{G}_2, \mathtt{G}_4\}$;
- $S_5 = \{\mathtt{A}_1, \mathtt{C}_1, \mathtt{C}_2, \mathtt{C}'_2, \mathtt{C}'''_2, \mathtt{C}''''_2, \mathtt{E}_1, \mathtt{E}'_1, \mathtt{E}_2, \mathtt{E}_2, \mathtt{E}_3, \mathtt{E}_4, \mathtt{E}_5, \mathtt{E}_6\}$, $\mathrm{Goal}(S_5) = \{\mathtt{G}_2, \mathtt{G}_3, \mathtt{G}_4\}$;
- $S_6 = \{\mathtt{A}_1, \mathtt{C}_1, \mathtt{C}'_2, \mathtt{C}'''_2, \mathtt{C}''''_2, \mathtt{E}'_1, \mathtt{F}_1, \mathtt{F}'_1, \mathtt{F}''_1, \mathtt{F}'''_1, \mathtt{F}_2\}$, $\mathrm{Goal}(S_6) = \{\mathtt{G}_4\}$.

Modelling Multimorbidity in ASPIC+G

Patient A should:

- practice diet and exercise;
- take angiotensin converting enzyme inhibitor.

This treatment plan addresses obesity, hypertension, and chronic kidney disease.

Relation with Multiple Criteria Decision-making

- ASPIC+G can be used to solve MCDM problems.
- There are numerous variations of MCDM methods, but there is no clear method proposed for health care.
- Only a set of guidelines on how to conduct such an analysis, mainly criteria elicitation.

Relation with Multiple Criteria Decision-making

Definition

A multiple-criteria decision problem $P = (D, C, agg)$ consists of:

- A sequence of decisions $D = (d_1, ..., d_n)$;
- A sequence of criteria $C = (c_1, ..., c_k)$, where each $c_i \in C$ is a function $c_i : D \to \mathbb{R}$;
- An aggregation function $agg : \mathbb{R}^{|D|\times|C|} \to \mathbb{R}^{|D|}$.

We denote with V_P the two-dimensional vector of the criteria values for each decision:

$$V_P = \begin{bmatrix} c_1(d_1) & \dots & c_k(d_1) \\ \vdots & \ddots & \\ c_1(d_n) & & c_k(d_n) \end{bmatrix}$$

Relation with Multiple Criteria Decision-making

Definition

Given a multiple-criteria decision problem $P = (D, C, agg)$, a decision $d_i \in D$ is *preferred* iff for all $d_j \in D$

$$agg(V_P)_j \leq agg(V_P)_i$$

Relation with Multiple Criteria Decision-making

Mapping to translate a multiple-criteria decision problem into an argumentation theory in ASPIC+G.

Definition

Let $P = (D, C, agg)$ be a multiple-criteria decision problem. We construct the argumentation theory $P' = \langle \mathcal{L}, \mathcal{R}, n, \leq_{\mathcal{R}_d}, \mathcal{G}, \leq_{\mathcal{G}} \rangle$, such that:

1. $\mathcal{L}$ is the smallest set closed under negation which contains all elements of D and $\mathbb{R}$;
2. $\mathcal{R} = \mathcal{R}_1 \cup \mathcal{R}_2 \cup \mathcal{R}_3 \cup \mathcal{R}_4$, where:
    1. $\mathcal{R}_1 = \{\Rightarrow d_i \mid d_i \in D\}$;
    2. $\mathcal{R}_2 = \{d_i \rightarrow \neg d_j \mid d_i, d_j \in D\}$;
    3. $\mathcal{R}_3 = \{d_i \rightarrow v_{i,j} \mid d_i \in D, v_{i,j} \in V_P\}$;
    4. $\mathcal{R}_4 = \{v_{i,1}, ..., v_{i,k} \rightarrow agg(V_P)_i \mid v_{i,j} \in V_P, k = |C|\}$.
3. n is the empty function;
4. $\leq_{\mathcal{R}_d} = \emptyset$;
5. $\mathcal{G} = \{agg(V_P)_i \mid d_i \in D\}$;
6. $agg(V_P)_i \leq_{\mathcal{G}} agg(V_P)_j$ iff $agg(V_P)_i \leq agg(V_P)_j$.

In the resulting argumentation theory P', each decision d_i gives rise to a series of arguments which eventually lead to the fulfilment of the respective goal $agg(V_P)_i$. The preferred decisions are then retrieved in ASPIC+G in the form of *top preferred extensions* thanks to the ordering on the goals.

Comparison with Multiple Criteria Decision-making

Theorem

Let $P = (D, C, agg)$ be a multiple-criteria decision problem and P' its mapping into an argumentation theory in ASPIC+G as defined in Def. 9. Then, for all $d \in D$, d is a preferred decision in P iff there exists a top preferred extension in P' containing the argument $\Rightarrow d$.

The proof of this theorem lies in the fact that all decisions are in conflict with each other thanks to the rules in $\mathcal{R}_2$. These being the only conflicts present in the framework, together with the lack of preferences over defeasible rules, ensures that every preferred extension represents exactly one decision and its consequences.

Relation with Multiple Criteria Decision-making

- **ASPIC+G subsumes multiple-criteria decision-making**.
- The argumentative approach provides **more transparency** in the reasoning process with the explicit interplay of conflicts.
- The argumentative approach is **more explanatory** as it allows to build sets with arguments supporting, attacking, and defending another argument.

Conclusions

- The purpose of ASPIC+G is to **model discussions driven by goals**, where it is not only important to have explanatory arguments in favour or against a position, but also to know where argumentation paths lead to.
- Within the field of computational argumentation, the contribution is equipping structured argumentation with **goal seeking mechanisms**.
- This makes the proposed argumentation system fit for solving one of the important challenges in CDSSs, reasoning in multimorbidity. This is done by combining the recommendations of agents and **deriving conflicts** that arise from them.
- This specification of goals can be used to **accommodate human-centric aspects of decisions in practical reasoning**, such as the preferences of physicians and patients, and the severity of health conditions.

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