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Picking Up the Best Goal

An Analytical Study in Defeasible Logic

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Motivation: BDI Agents

BDI is a popular architecture to model autonomous agents:

- **B** Beliefs: How the agents perceives the environment
- **D** Desires: What the agent wants to achieve
- **I** Intentions: What the agent commits to

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Intentions and Desires are also **motivational attitudes**.

Issues with BDI agents

- Is there anything missing in the BDI architecture?

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- Is there something redundant in the BDI architecture?

BIOlogical Agents

Why BIOlogical agents? self-evident

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- B Beliefs: the description of the environment
- I Intentions: the internal constraints/motivational attitudes
- O Obligations: the external constraints/motivational attitudes

I wish U were here

Desires, Goals, Intentions, Social Intentions are nuances of a more general concept: oUtcomes (the objectives of an agent)

Design Principles

- An agent is modelled by a set of rules;
- When an agent faces alternative outcomes in a given context, it is natural to rank them in a preference order;
- Beliefs prevail over conflicting motivational attitudes, thus avoiding various cases of wishful thinking;
- Norms and obligations are used to filter social motivational states (**social intentions**) and compliant agents;
- Goal-like attitudes can be derived via **conversion** using other mental states, such as beliefs (e.g., believing that Madrid is in Spain may imply that the goal to go to Madrid implies the goal to go to Spain).

Rule Types

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- Belief rules

$$a_1, \ldots, a_n \Rightarrow c$$

- Obligation rules

$$a_1, \ldots, a_n \Rightarrow_O C$$

- Outcome rules

$$a_1, \ldots, a_n \Rightarrow_U C$$

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$$C = c_1 \odot c_2 \odot \cdots \odot c_n$$

Example

$$holiday \Rightarrow_{\cup} visit\_friend \odot visit\_parents \odot stay\_home$$

Desires as acceptable outcomes

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$$r : a_1, \ldots, a_n \Rightarrow_{\mathsf{U}} b_1 \odot \cdots \odot b_m$$
$$s : a'_1, \ldots, a'_n \Rightarrow_{\mathsf{U}} b'_1 \odot \cdots \odot b'_k$$

where $a_1, \ldots, a_n$ and $a'_1, \ldots, a'_n$ are mutually compatible
b_1 and b'_1 are mutually incompatible ($b'_1 = \neg b_1$).

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$b_1, \ldots, b_m, b'_1, \ldots, b'_k$ are all desires (acceptable outcomes)

If $s > r$, then $b_2, \ldots, b_m, b'_1, \ldots, b'_k$ are desires (acceptable outcomes)

Goals as preferred outcomes

$$r : a_1, \ldots, a_n \Rightarrow_U b_1 \odot \cdots \odot b_m$$
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b_2 and $\neg b_1$ are the goals (most preferred outcomes)

Intentions as feasible outcomes

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Intentions as feasible outcomes (2)

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$s > r$
and the agent knows b_1

b_1 and b'_2 are the intentions (the preferred feasible outcomes)

Intentions as legal outcomes

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$$r : a_1, \ldots, a_n \Rightarrow_{\mathsf{U}} b_1 \odot \cdots \odot b_m$$
$$s : a'_1, \ldots, a'_n \Rightarrow_{\mathsf{O}} b'_1 \odot \cdots \odot b'_k$$

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$\neg b_1$ is obligatory and b_2 is socially intended (most preferred feasible outcome that does not violate the obligations)

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If the agent knows $\neg b_2$, then b_3 is socially intended

Proving Beliefs

To prove that an agent beliefs p.

There is a belief rule

$$a_1, \ldots, a_n \Rightarrow_{\mathrm{B}} p$$

- all a_i are provable
- and all rules for $\neg p$ are either not applicable or weaker than an applicable rule for p

Proving Obligations

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To prove that p is obligatory

There is an obligation rule

$$a_1, \ldots, a_n \Rightarrow_O c_1 \odot \cdots \odot c_m$$

- $p = c_j$, $1 \leq j \leq m$
- all a_i are provable
- for all c_i, $i < j$:
  - c_i is obligatory and
  - the agent does not belief c_i
- defeasibility

Proving Desires

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To prove that an agent desires p

There is an outcome rule

$$a_1, \ldots, a_n \Rightarrow_{\mathsf{U}} c_1 \odot \cdots \odot c_m$$

- $p = c_j$, $1 \leq j \leq m$
- all a_i are provable
- defeasibility

Proving Goals

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To prove that p is a goal of the agent

There is an outcome rule

$$a_1, \ldots, a_n \Rightarrow_{\mathsf{U}} c_1 \odot \cdots \odot c_m$$

- $p = c_j$, $1 \leq j \leq m$
- all a_i are provable
- for all c_i, $i < j$, c_i is not a goal of the agent
- defeasibility

Proving Intentions

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To prove that the agent intends p

There is an outcome rule

$$a_1, \ldots, a_n \Rightarrow_{\mathsf{U}} c_1 \odot \cdots \odot c_m$$

- $p = c_j$, $1 \leq j \leq m$
- all a_i are provable
- for all c_i, $i < j$,
  - c_i is not an intention of the agent
  - the agent does not belief $\neg c_i$
- defeasibility

Proving Social Intentions

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To prove that the agent intends p

There is an outcome rule

$$a_1, \ldots, a_n \Rightarrow_U c_1 \odot \cdots \odot c_m$$

- $p = c_j$, $1 \leq j \leq m$
- all a_i are provable
- for all c_i, $i < j$,
  - c_i is not an intention of the agent
  - c_i is not forbidden (i.e., $\neg c_i$ is not obligatory)
  - the agent does not belief $\neg c_i$
- defeasibility

Results

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Theorem

The logic is coherent, i.e., it is not possible to prove Xp and $\neg Xp$ (and Xp and $X\neg p$) for $X \in \{\mathsf{G}, \mathsf{I}, \mathsf{SI}, \mathsf{O}\}$

Theorem

The extension of the logic can be computed in $O(|D|)$, where D is the number of symbols occurring in a theory.

Conlcusion

- A novel account of the notions of goals like attitudes for agents
- We have argued that the notions of desires, goals, intentions are facets of a more general concept (i.e., outcome/objective)
- The account can be formalised in Defeasible Logic in a computationally feasible way

Questions?