A Simple Language for Cognitive Planning

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Scenarios: persuasive technology for healthcare and assistance

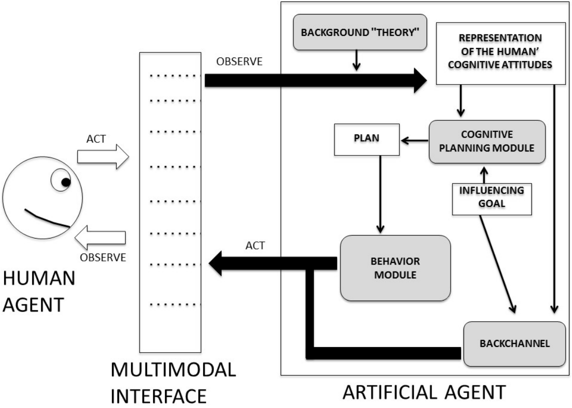
Scenario 1

R2-D2 is an artificial companion which takes care of an elderly person called Bob and keeps him company. Bob has to do regular physical activity to be in good health. In this situation, R2-D2 has to play a tutor role: it has to ensure that Bob will do regular physical activity in his interest. To this aim, R2-D2 needs to use its persuasive capabilities in order to induce Bob to adopt a healthy lifestyle.

Scenario 2

A virtual assistant providing useful advices about nutrition.

General architecture



Example of dialogue

- Thanks to its previous interactions with Bob, R2-D2 has learnt that:
  - *Bob is willing to go out for a walk if and only if:*
    - *he is not tired,*
    - *he believes that it is a sunny day, and*
    - *he believes that the outside temperature is above 10° C;*
  - *Bob trusts R2-D2's judgment about weather conditions.*
- R2-D2 knows that Bob has done no physical activity in the last two days. Thus, it deduces that Bob is not tired. R2-D2's goal is to motivate Bob to go out for a walk. Thus, it plans the execution of the following utterance and performs it:

  "Hey Bob! It is a great sunny day. You should take advantage of it and go out for a walk before the end of the day".

- Bob expresses dislikes about R2-D2's suggestion: 
- From Bob's facial expression and its prior beliefs, R2-D2 deduces that Bob does not believe that the outside temperature is above 10°C. Then, R2-D2 plans the execution of the following new utterance and performs it:

  "Bob, you shouldn't worry so much. If you go out, you won't feel cold: the outside temperature is above 10° C."

Formal language

- 2-agent logic explicit and implicit belief
  - Agent A: artificial agent
  - Agent H: human agent
- Operators with $i \in \{A, H\}$:
  - $\triangle_i \alpha$: agent i explicitly believes that α
    $\Rightarrow$ Information in i's belief base
  - $\Box_A \alpha$: A implicitly believes that α
    $\Rightarrow$ Information deducible from A's belief base
  - $\Diamond_A \alpha$: α is compatible with A's explicit beliefs
  - $+_i \alpha$: agent i learns that α

$$
\begin{array}{llll}
\mathcal{L}_0 & \alpha & ::= & p \mid \neg\alpha \mid \alpha_1 \wedge \alpha_2 \mid \triangle_i \alpha \\
\mathcal{L} & \varphi & ::= & \alpha \mid \neg\varphi \mid \varphi_1 \wedge \varphi_2 \mid \Box_A \alpha \mid \Diamond_A \alpha \mid [+_i \alpha]\varphi
\end{array}
$$

where α ranges over $\mathcal{L}_0$ and $i \in \{A, H\}$

Set of events $Act = \{+_H \alpha : \alpha \in \mathcal{L}_0\} \cup \{-_H \alpha : \alpha \in \mathcal{L}_0\}$

Formal language (cont.)

- Speech act "informing" (from the speaker's perspective):

$$\mathit{inform}(i, j, \alpha) \overset{\texttt{def}}{=} +_i \triangle_j \triangle_i \alpha$$

- Sets of informative events:

$$\begin{aligned} \mathit{Act}_i &= \{\mathit{inform}(i, j, \alpha) : \alpha \in \mathcal{L}_0 \text{ and } i \neq j\} \\ \mathit{Act} &= \mathit{Act}_A \cup \mathit{Act}_H \end{aligned}$$

- Executability precondition:

$$\mathcal{P} : \mathit{Act} \longrightarrow \mathcal{L}$$

- Successful execution operator:

$$\langle\langle \epsilon \rangle\rangle \varphi \overset{\texttt{def}}{=} \mathcal{P}(\epsilon) \wedge [\epsilon]\varphi$$

with $\epsilon \in \mathit{Act}$

Reasoning schemes

- It is common knowledge between A and H that H uses a variety of reasoning rules for:
  - deducing new beliefs $\Rightarrow$ Theoretical reasoning
  - assessing whether an action is right/good (or wrong/bad) and forming new intentions $\Rightarrow$ Practical reasoning
- Theory Θ
- This aspect of the model is customizable, depending on the application

Theoretical reasoning schemes

1. $\triangle_H \alpha$
2. $\triangle_H (\alpha \rightarrow \beta)$

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3. $\triangle_H \beta$

Practical reasoning schemes

- $$\frac{\begin{array}{l}1.\ \mathit{desire}(H,\alpha)\\ 2.\ \triangle_H(\mathit{done}(H,a)\rightarrow\alpha)\end{array}}{3.\ \triangle_H \mathit{goodAct}(H,a)}$$
- $$\frac{\begin{array}{l}1.\ \mathit{undesire}(H,\alpha)\\ 2.\ \triangle_H(\mathit{done}(H,a)\rightarrow\alpha)\end{array}}{3.\ \triangle_H \mathit{badAct}(H,a)}$$
- $$\frac{\begin{array}{l}1.\ \mathit{desire}(H,\alpha)\\ 2.\ \triangle_H(\neg\mathit{done}(H,a)\rightarrow\alpha)\end{array}}{3.\ \triangle_H \mathit{goodInact}(H,a)}$$
- $$\frac{\begin{array}{l}1.\ \mathit{undesire}(H,\alpha)\\ 2.\ \triangle_H(\neg\mathit{done}(H,a)\rightarrow\alpha)\end{array}}{3.\ \triangle_H \mathit{badInact}(H,a)}$$

REMARK: in most situations we can safely define

$$\mathit{undesire}(H,\alpha) \stackrel{\text{def}}{=} \mathit{desire}(H,\neg\alpha)$$

Practical reasoning schemes (cont.)

- $$\begin{array}{l} 1.\ \triangle_H \mathit{badInact}(H, a) \\ 2.\ \triangle_H \neg \mathit{badAct}(H, a) \\ \hline 3.\ \mathit{intend}(H, a) \end{array}$$

- $$\begin{array}{l} 1.\ \triangle_H \mathit{goodAct}(H, a) \\ 2.\ \triangle_H \neg \mathit{badAct}(H, a) \\ \hline 3.\ \mathit{intend}(H, a) \end{array}$$

k-bounded cognitive planning problem

- INPUT
  - Finite set of operations $Op \subset Act_A$
  - Agent A's goal α_G
  - Agent A's initial belief base Γ
- OUTPUT
  - YES: if there is a sequence of operations $\epsilon_1, \ldots, \epsilon_m$ from Op such that $m \leq k$ and

$$\models_{\Theta} Plan(\Gamma, \alpha_G, \epsilon_1, \ldots, \epsilon_m)$$

    with

$$Plan(\Gamma, \alpha_G, \epsilon_1, \ldots, \epsilon_m) \stackrel{\text{def}}{=} \bigwedge_{\gamma \in \Gamma} \triangle_A \gamma \rightarrow \langle\!\langle \epsilon_1 \rangle\!\rangle \ldots \langle\!\langle \epsilon_m \rangle\!\rangle \Box_A \alpha_G$$

  - NO: otherwise

Solution: $\epsilon_1, \ldots, \epsilon_m$ with $m \leq k$ such that $\models_{\Theta} Plan(\Gamma, \alpha_G, \epsilon_1, \ldots, \epsilon_m)$

Example

- Agent A's initial belief base $\Gamma = \{\alpha_1, \alpha_2, \alpha_3\}$ with:

$$\alpha_1 \stackrel{\text{def}}{=} \mathit{undesire}\big(H, \mathit{badHealth}(H)\big)$$

$$\alpha_2 \stackrel{\text{def}}{=} \triangle_H\big(\neg \mathit{coldOut} \rightarrow \neg \mathit{badAct}(H, \mathit{goOut})\big)$$

$$\alpha_3 \stackrel{\text{def}}{=} \triangle_H \mathit{reliable}(A)$$

- Agent A's goal: $\alpha_G \stackrel{\text{def}}{=} \mathit{intend}(H, \mathit{goOut})$
- $\epsilon_1, \epsilon_2 \in \mathit{Op}$ with

$$\epsilon_1 \stackrel{\text{def}}{=} \mathit{inform}(A, H, \neg \mathit{coldOut})$$

$$\epsilon_2 \stackrel{\text{def}}{=} \mathit{inform}\big(A, H, \neg \mathit{done}(H, \mathit{goOut}) \rightarrow \mathit{badHealth}(H)\big)$$

- Executability preconditions: $\mathcal{P}(\epsilon) = \triangle_A \triangle_H \mathit{reliable}(A)$ for all $\epsilon \in \mathit{Op}$

We have:

$$\models_{\Theta} \mathit{Plan}(\Gamma, \alpha_G, \epsilon_1, \epsilon_2)$$

Therefore, sequence ϵ_1, ϵ_2 is a solution to every k-bounded cognitive planning problem such that $k \geq 2$