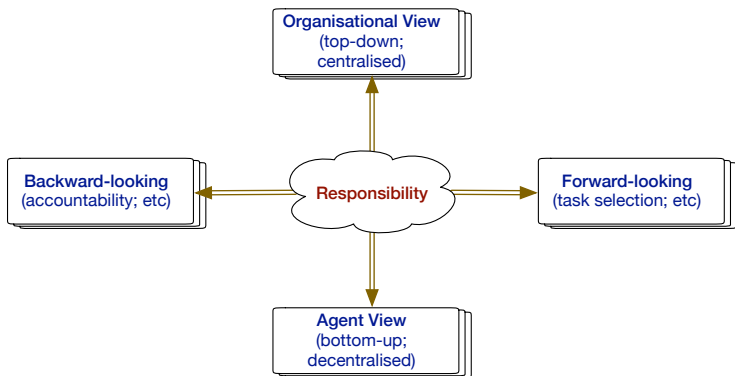


Towards Forward Responsibility in Belief-Desire-Intention Agents

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29th of May, 2023

Introduction



- ▶ **Forward-looking** responsibilities: agents use responsibilities to aid in the process of task selection

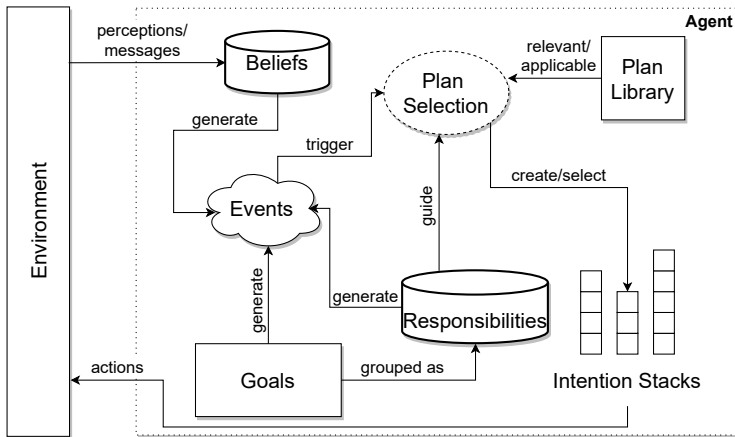
Related Work

- ▶ Backward-looking responsibilities
 - ▶ Yazdanpanah, V., Dastani, M., Jamroga, W., Alechina, N., Logan, B.: Strategic responsibility under imperfect information. In: AAMAS 2019
- ▶ Accountability
 - ▶ Baldoni, M., Baroglio, C., Micalizio, R., Tedeschi, S.: Robustness based on accountability in multiagent organizations. In: AAMAS 2021
- ▶ Missions in JaCaMo
 - ▶ Boissier, O., Bordini, R.H., Hübner, J.F., Ricci, A., Santi, A.: Multi-agent oriented programming with JaCaMo. In: Science of Computer Programming 78(6), 747–761, 2013
- ▶ Maintenance goals
 - ▶ Duff, S., Thangarajah, J., Harland, J.: Maintenance goals in intelligent agents. In: Computational Intelligence 30(1), 71–114, 2014

Responsibility-Aware Agents

- ▶ Focus on extending the syntax, grammar, and operational semantics of AgentSpeak(L) and Jason
- ▶ Belief-Desire-Intention agents
 - ▶ **Belief:** knowledge about the world
 - ▶ **Desire:** goals to achieve
 - ▶ **Intention:** means of achieving committed goals
- ▶ **Responsibility:** task containing a collection of goals that relate to an overarching topic
- ▶ Agents can adopt/drop responsibilities, which in turn trigger events

Reasoning Cycle



Grammar

$$\begin{array}{ll}
 \text{agent} & ::= \text{bb } \text{rb } \text{pl} \\
 \text{bb} & ::= \text{belief}_1 \dots \text{belief}_n \quad (n \geq 0) \\
 \underline{\text{rb}} & ::= \underline{\text{resp}_1 \dots \text{resp}_n \text{ h}} \quad (n \geq 0) \\
 \text{pl} & ::= \text{plan}_1 \dots \text{plan}_n \quad (n \geq 1) \\
 \text{belief} & ::= \text{at} \\
 \text{g} & ::= \text{at} \\
 \text{at} & ::= P(t_1, \dots, t_n) \quad (n \geq 0) \\
 \underline{\text{resp}} & ::= \underline{P([g_1, \dots, g_n], \text{na}, \text{rec})} \quad (n \geq 1) \\
 \underline{\text{h}} & ::= \underline{\text{hierarchy}([hl_1 \dots hl_n])} \quad (n \geq 1) \\
 \underline{\text{hl}} & ::= \underline{[P_{\text{resp}_1} \dots P_{\text{resp}_n}]} \quad (n \geq 1) \\
 \text{plan} & ::= \text{te} : \{\text{context}\} \leftarrow \text{body} \\
 \text{te} & ::= +!g \quad | \quad +\text{belief} \quad | \quad -\text{belief} \\
 & \quad | \quad \underline{+/\text{resp}} \quad | \quad \underline{-/\text{resp}} \\
 \text{context} & ::= \text{ctl} \quad | \quad \top \\
 \text{ctl} & ::= \text{belief} \quad | \quad \neg\text{belief} \quad | \quad \underline{\text{resp}} \\
 & \quad | \quad \underline{\neg\text{resp}} \quad | \quad \text{ctl} \wedge \text{ctl} \\
 \text{body} & ::= \text{bd1}, \top \quad | \quad \top \\
 \text{bd1} & ::= +!g \quad | \quad \text{action} \quad | \quad \text{bbupdate} \\
 & \quad | \quad \underline{\text{rbupdate}} \quad | \quad \text{bd1}; \text{bd1} \\
 \text{action} & ::= A(t_1, \dots, t_n) \quad (n \geq 0) \\
 \text{bbupdate} & ::= +\text{belief} \quad | \quad -\text{belief} \\
 \underline{\text{rbupdate}} & ::= \underline{+/\text{resp}} \quad | \quad \underline{-/\text{resp}}
 \end{array}$$

Example

Domestic robot with BDI agent for decision-making

- ▶ Example of a responsibility:

$$\text{cleaning}([\text{clean}(\text{bathroom}), \text{clean}(\text{bedroom})], 0, 1)$$

- ▶ Corresponding plan:

```
+ /cleaning : { T }  
  ← +!clean(bathroom),  
    +!clean(bedroom),  
    - /cleaning .
```

Operational Semantics

- ▶ Inference rules define transitions between **agent configurations**

$$Conf = \langle agent, C, M, T, rule \rangle$$

- ▶ agent = belief base, responsibility base, and plan library
- ▶ C = \langle Intention stacks, Events, Actions \rangle
- ▶ M = messages (in and out)
- ▶ T = various temporary information (e.g. relevant plans, a particular event, intention selected for execution, etc.)
- ▶ rule = current reasoning cycle step

Inference Rules

- ▶ Adopting a responsibility:

$$(A\text{Resp}) \frac{T_{si} = i[\text{head} \leftarrow +/\text{resp}; \text{body}]}{\langle \text{agent}, C, M, T, A\text{Resp} \rangle \rightarrow \langle \text{agent}', C', M, T', C\text{Int} \rangle}$$

$$\text{where} \quad \begin{aligned} \text{agent}'_{rb} &= (\text{agent}_{rb} \setminus \text{resp}) \cup \text{UpdateAdopt}(\text{resp}) \\ C'_E &= C_E \cup \{+/\text{resp}\} \\ C'_I &= C_I \setminus \{T_{si}\} \\ T'_{res} &= \text{resp} \end{aligned}$$

- ▶ Dropping a responsibility:

$$(D\text{Resp}) \frac{T_{si} = i[\text{head} \leftarrow -/\text{resp}; \text{body}]}{\langle \text{agent}, C, M, T, D\text{Resp} \rangle \rightarrow \langle \text{agent}', C', M, T', \text{DropInt} \rangle}$$

$$\text{where} \quad \begin{aligned} \text{agent}'_{rb} &= (\text{agent}_{rb} \setminus \text{resp}) \cup \text{UpdateDrop}(\text{resp}) \\ C'_E &= C_E \cup \{-/\text{resp}\} \\ C'_I &= C_I \setminus \{T_{si}\} \\ T'_{res} &= \text{resp} \end{aligned}$$

Hierarchy of Responsibilities

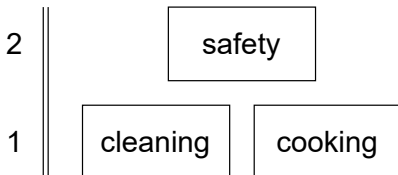
- ▶ Defines priority ordering between responsibilities
- ▶ Implicit values, starts at 1 at the bottom-most hierarchical order, and increases by 1 at each hierarchical level
- ▶ Changes to the intention selection function to prioritise intention stacks that have responsibilities at a higher hierarchical level
- ▶ Can lead to **starvation**

Hierarchy Example

► Domestic robot example

```
cleaning ([ clean ( bathroom ) , clean ( bedroom ) ] , 0 , 1)  
safety ([ locks ( frontdoor ) , search ( triphazards ) ] , 0 , 2)  
cooking ([ cook ( breakfast ) , makelist ( grocery ) ] , 0 , 1)
```

```
hierarchy ([ [ safety ] , [ cleaning , cooking ] ] )
```



Shared responsibilities

- ▶ Shared responsibilities are responsibilities that appear in more than one agent's responsibility base
- ▶ Agents keep up-to-date information about shared responsibilities using broadcast communication via *tell(adopt(resp))* or *tell(drop(resp))* speech act
- ▶ Agents that try to adopt a responsibility after the recommended number has been reached will be added as **backup**
- ▶ Backup agents add the respective responsibility to the **idle** hierarchical level

Conclusion

- ▶ Individual agent view of forward-looking responsibilities
 - ▶ Hierarchy of responsibilities and its impact in intention selection
 - ▶ Shared responsibilities using communication

- ▶ **Future Work**
 - ▶ Implementation in a BDI language
 - ▶ Consider different relations between responsibilities, such as conflicts



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