An Ontology Design Pattern for supporting behaviour arbitration in cognitive agents

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Abstract. In this paper we present an Ontology Design Pattern for the definition of situation-driven behaviour selection and arbitration models for cognitive agents. The proposed pattern relies on the descriptions and situations ontology pattern, combined with a frame-based representation scheme. Inspired by the affordance theory and behaviour-based robotics principles, our reference model enables the definition of weighted relationships, or affordances, between situations (representing agent's perception of the environmental and social context) and agent's functional and behavioral abilities. These weighted links serve as a basis for supporting runtime task selection and arbitration policies, to dynamically and contextually select agent's behaviour. The pattern is at the heart of the behaviour-based cognitive approach adopted in the EU H2020 MARIO project for the design of an autonomous service robot (i.e., the cognitive agent) to support elderly people with cognitive impairments.

Keywords: ontology design patterns, behaviour arbitration, affordance, robotics

1 Introduction

In the design of cognitive agents like robots, *behaviour selection* (also called behaviour arbitration) is the process of deciding which action to execute at each point of time. For the sake of simplicity, most implemented systems use a built-in fixed priority ordering of behaviours, i.e. the agent's control strategy is embedded into a collection of preprogrammed condition-action pairs. This strategy, called *purely reactive*, has proven effective for a variety of problems that can be completely specified at design-time [10]. However, it is inflexible at run-time due to its inability to store new information in order to adapt the robot's behaviour on the basis of its experience. Moreover, the burden of predicting all possible input states and choosing the corresponding output actions is completely left to the designer.

Behaviour-based approaches to action selection can be considered as an extension of purely reactive strategy. These approaches are related to the concept of *affordance*. The notion of affordance has been introduced by Gibson [7] who devised a theory of how animals perceive opportunities for action. Gibson called these opportunity affordance. He suggested that the environment offers the agents (people or animals) opportunities for action. For instance, a door can have the affordance of "openability". These action opportunities are latent in the environment and independent from individual's ability to recognize them, but affordances are always dependent on agent's capability. For example, to a thief an open window can afford the "steal" action, but not so to a waitress who may simply be afforded by the "close" action if outside the temperature is too cold.

In this paper we present the Affordance Ontology Design Pattern (ODP) that extends the classical notion of affordance, which suggests that the physical objects (e.g., a door) offer the opportunity of performing an action (e.g., open). In fact, our ODP is designed by relying on the assumption that, not only physical objects, but also complex situations (e.g., the user want to listen to some music) afford actions (e.g., play music). A complex situation can be seen as the fullfilment at a certain time of certain conditions. These conditions may involve temporal aspects (e.g. lunchtime may afford the task remember the user to take the pills), the perception of certain physical objects, the receiving of a command (e.g. I want to listen to some music), or, even the existence of certain state-of-affairs (e.g. the situation the user is sitting on a chair for a long while may afford the task entertain the user).

The rest of the paper is organised as follows: Section 2 introduces the related work, Section 3 presents the overview of the pattern, Section 4 provides the formalisation of the pattern by using description logics, Section 5 presents a usage scenario. Finally, Section 6 concludes the paper and foresees possible future works.

2 Related Work

There exist few examples of ontologies conceptualising the idea of affordances. In literature, the notion of affordance has been seen as the relation between the environment and an agent [16] or as qualities of objects in the environment taken with reference to an observer [14, 13, 15]. Our approach is closer to the characterisation proposed by Stoffregen [16], albeit we abstract the notion environment to a more general concept of situation as conceived by [4]. Namely, a situation embeds all the environments characteristics perceived by the robot and possibly other conditions (e.g. involving time, the receiving of a commands etc.).

3 Pattern overview

The proposed pattern relies on the Descriptions and Situations ODP[4] [4], combined with a frame-based representation scheme [12].

[4] Aldo Gangemi, Description and Situation ODP `http://ontologydesignpatterns.org/wiki/Submissions:DescriptionAndSituation`

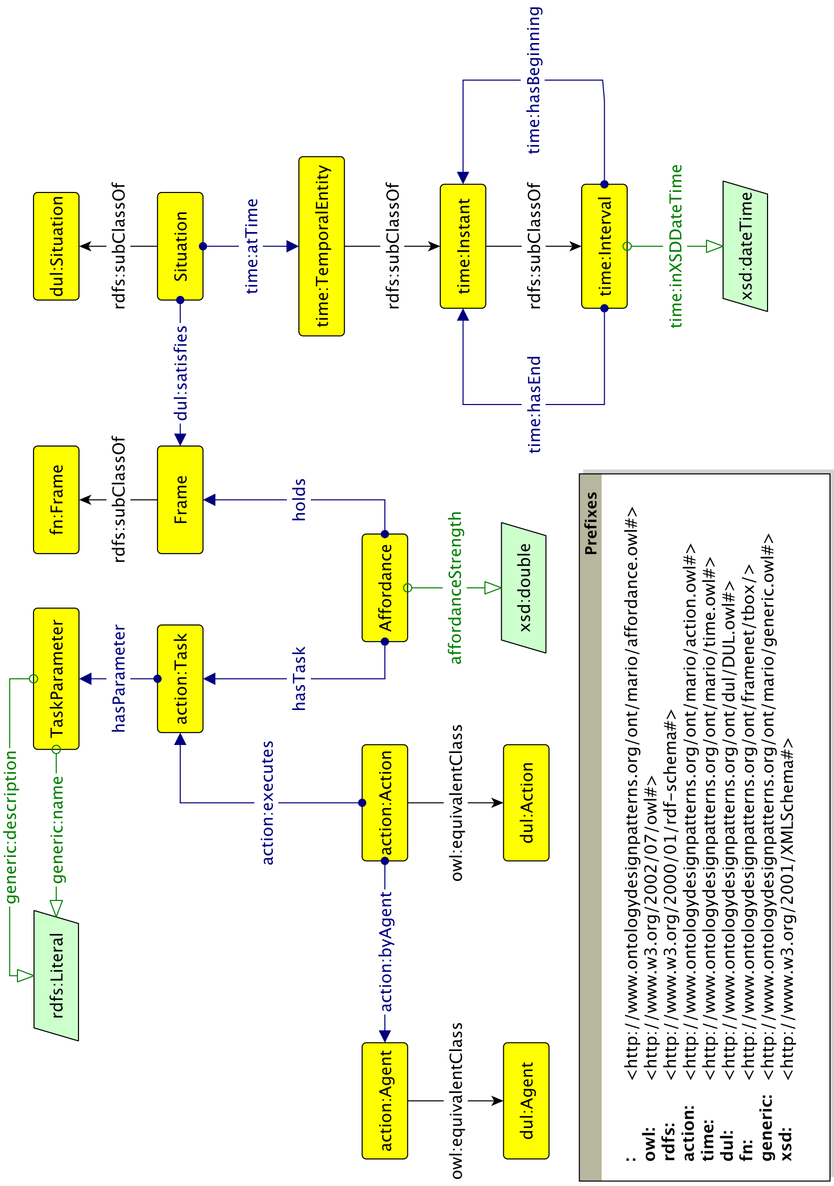

Fig. 1. The diagram of the Affordance ontology expressed with the Graffoo [2] notation.

Table 1 reports the competency questions [8] that drove the designed of the Affordance ODP.

ID	Competency question
CQ1	Which is the strength of an Affordance?
CQ2	Which tasks are afforded in a certain situation?
CQ3	How should an agent behave in a certain situation?
CQ4	Which are the parameters involved in certain task?

Table 1. Competency questions answered by the Affordance ODP.

Figure 1 shows the UML class diagram of the ontology. The base namespace is associated with the value `http://www.ontologydesignpatterns.org/ont/mario/affordance.owl#`. The page of the proposed pattern as submitted to the ontologydesignpatterns.org portal is `http://ontologydesignpatterns.org/wiki/Submissions:Affordance`.

Affordances are represented as individuals of the class `Affordance`, which is modelled as a n-ary relation connecting:

- a class of situations that represents states of the world (i.e., any individual of the class `Frame`). This relation is expressed by means of the object property `holds`;
- an agent's behaviour (aka a task), which is any individual of the class `action:Task`. This relation is expressed by the object property `hasTask`.
- a quantity that indicates how much a behaviour is relevant for the occurrence of a certain frame. This relation is expressed by the datatype property `affordanceStrength`, whose range is `xsd:double`.

According to [5], the intended meaning of a frame (represented in our ODP by the class `Frame`) can be summarised as a small-sized and richly interconnected structure, used to organize our knowledge, as well as to interpret, process or anticipate information. Frames identify classes of situations and have been investigated in linguistics by Fillmore [3], in AI by Minsky [11], and more recenty in the Semantic Web [5, 12]. We modelled the class `Frame` as a sub-class of `fn:Frame`[5], which is a class re-used from the OWL version [12] of FrameNet [1].

Situations are states of the world fulfilling certain conditions. These conditions may involve: temporal aspects, the perception of physical entities, the receiving of a command or the existence of certain state-of-affairs. Following the Description and Situation ODP we made a basic distinction, between a `Frame` (or description) and a `Situation`, which is a frame occurence. The class `Situation` is modelled as sub-class of the class `dul:Situation`[6] that is re-used

[5] The prefix `fn:` stands for the namespace `http://www.ontologydesignpatterns.org/ont/framenet/tbox/`.

[6] The prefix `dul:` stands for the namespace `http://www.ontologydesignpatterns.org/ont/DUL.owl#`.

from DOLCE Ultra-lite [6]. Any individual of `Situation` is modelled as a time indexed situation, i.e., a state of the world anchored to a certain time point (e.g. at 11am the user expresses the willingness to listen to jazz music). We re-used the time-indexed situation ODP[7] for modelling time constraints for situations. Hence, a `Situation` is related to `time:TemporalEntity`[8] that allows to represent the notion of time either as a time interval (i.e., any individual of the class `time:TimeInterval`), which has a start and an end temporal instant, or an instant itself (i.e., any individual of the class `time:Instant`) that is associated with temporal values by means of the datatype property `time:inXSDDataTime` whose range is `xsd:dateTime`[9].

Our ODP models agent's behaviours as tasks. Those tasks are represented as individuals of the class `action:Task` that can be parameterised by specific parameters represented as individuals of the class `TaskParameter`. The relarions between tasks and task parameters are expressed by the object property `hasParameter`. For example, a certain task "Play music" can be associated with a parameter "Jazz" that specifies the genre of the music to play.

Tasks are always executed by actions. An action is represented as an individual of the class `action:Action` and can expect the execution of multiple tasks. The association between tasks and actions is represended by the object property `executes`. This design reflects the way actions and tasks are modelled in DOLCE. Hence, the classes `action:Action` and `action:Task` are represented as sub-classes of `dul:Action` and `dul:Task`, respectively.

Actions are performed by agents. An agent is represented as an individual of the class `action:Agent`, which in turn is designed to be sub-class of `dul:Agent`. The relation between an action and an agent is expressed by the object property `action:byAgent`.

4 Pattern formalisation

The following is the formalisation of the OWL pattern described in Section 3. The formalisation is expressed in Description Logics.

$$
\begin{aligned}
\texttt{Affordance} \sqsubseteq\ & \exists\texttt{affordanceStrength}.\mathit{xsd}\text{:}\texttt{Double} \\
\sqcap\ & =1\texttt{hasTask}.\mathit{action}\text{:}\texttt{Task} \\
\sqcap\ & =1\texttt{holds}.\texttt{Frame} \\
\texttt{Frame} \sqsubseteq\ & \mathit{fn}\text{:}\texttt{Frame} \\
\sqcap\ & \forall\texttt{isHeldBy}.\texttt{Affordance} \\
\texttt{Situation} \sqsubseteq\ & \mathit{dul}\text{:}\texttt{Situation} \\
\sqcap\ & \forall\mathit{dul}\text{:}\texttt{satisfies}.\texttt{Frame}
\end{aligned}
$$

[7] `http://www.ontologydesignpatterns.org/cp/owl/timeindexedsituation.owl`.

[8] The prefix `time:` stands for the namespace `http://www.ontologydesignpatterns.org/ont/mario/time.owl#`.

[9] The prefix `xsd:` stands for the namespace `http://www.w3.org/2001/XMLSchema#`.

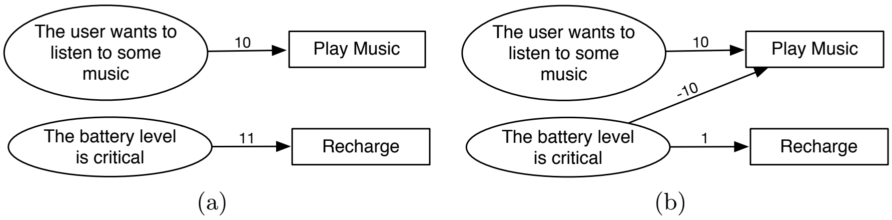

Fig. 2. Two equivalent action-selection schemes.

$$
\begin{aligned}
& \sqcap\ \forall \textit{time:}\texttt{atTime}.\textit{time:}\texttt{TemporalEntity} \\
\texttt{TaskParameter} & \sqsubseteq \forall \texttt{description}.\textit{rdfs:}\texttt{Literal} \\
& \sqcap\ \textit{generic:}\texttt{name}.\textit{rdfs:}\texttt{Literal} \\
\textit{action:}\texttt{Task} & \sqsubseteq \forall \texttt{hasParameter}.\texttt{TaskParameter} \\
\textit{action:}\texttt{Action} & \equiv \textit{dul:}\texttt{Action} \\
\textit{action:}\texttt{Action} & \sqsubseteq \forall \textit{action:}\texttt{byAgent}.\textit{action:}\texttt{Agent} \\
\textit{action:}\texttt{Agent} & \equiv \textit{dul:}\texttt{Agent} \\
\textit{time:}\texttt{Instant} & \sqsubseteq \textit{time:}\texttt{Interval} \\
& \sqcap\ \forall \textit{time:}\texttt{inXSDDateTime}.\textit{xsd:}\texttt{dateTime} \\
\textit{time:}\texttt{Interval} & \sqsubseteq \textit{time:}\texttt{TemporalEntity} \\
& \sqcap\ \forall \textit{time:}\texttt{hasBeginning}.\textit{time:}\texttt{Instant} \\
& \sqcap\ \forall \textit{time:}\texttt{hasEnd}.\textit{time:}\texttt{Instant}
\end{aligned}
$$

5 Usage scenario

The affordance, as introduced by Gibson [7], has been investigated in robotics in the context of behaviour-based approaches to action selection. We are experimenting with behaviour-based approaches in a EU H2020 project named MARIO[10]. MARIO is tackling the ambitious goal of studying and designing a robot able to support older people affected by dementia in their daily life. To the best of our knowledge this is the firsts attempt to formalise the notion of affordance as an Ontology Design Pattern and to use it in the context of behaviour-based robotics. In fact, MARIO uses a behaviour-based approach to action selection which relies on both the notion of affordance devised by Gibson [7] and the proposal of Pattie Maes [9]. MARIO exploits the Affordance ODP for dynamically decide which action to perform in specific situations.

Figure 2 shows a simple example scenario. This scenario is about two alternative configurations of an affordance model (i.e., Figures 2(a) and 2(b), respectively) of a cognitive agent (i.e., the MARIO robot in our case). Both config-

[10] www.mario-project.eu/portal/.

urations are composed of associations of known frames (represented as ovals) with (possibly) some actions that the agent can perform to react to such situation descriptions. The associations are weighted relations that convey affordance strengths. A configuration is determined by the recognition of some situation (i.e., a frame occurence) by the agent that satisfies a known frame. The first configuration (i.e., Figures 2(a)) comes from the recognition of two distinct and concurrent situations, e.g., (i) the patient asks the robot to play her favourite music and (ii) the robot battery status is at 1%. In this configuration the robot is caused to prefer to recharge its battery instead of playing some music. In fact, the affordance strength with value 11 and associated with the battery level frame is greater than the affordance strength with value 10 associated with the play music frame. Instead, in the second configuration (i.e., Figures 2(b)) the robot does not recognise a critical battery situation (e.g., the battery status is 40%). Hence, the robot is caused to prefer to play the patient's favourite music.

The following RDF triples, serialised as TURTLE, model the configuration represented in Figure 2(b) according to the Affordance ODP.

```
:UserWantsToListenToSomeMusic a aff:Frame;
    fn:hasFrameElement :genre, :user.

:genre a fn:FrameElement, aff:TaskParameter .

:BatteryInCritalLevel a aff:Frame;
    fn:hasFrameElement :batteryLevel, :agent .

:batteryLevel a fn:FrameElement .

:agent a fn:FrameElement .

:user a fn:FrameElement .

:PlayMusic a action:Task;
    aff:hasParameter :genre .

:Recharge a aff:Task.

:affordancePlayMusicBatteryCritical a aff:Affodance ;
    aff:affordanceStrength "-10"^^xsd:double ;
    aff:holds :BatteryInCritalLevel ;
    aff:hasTask :PlayMusic  .

:affordancePlayMusicUserWantsToListenToSomeMusic a aff:Affodance ;
    aff:affordanceStrength "10"^^xsd:double ;
    aff:holds :UserWantsToListenToSomeMusic ;
    aff:hasTask :PlayMusic  .

:affordanceRechargeBatteryCritical a aff:Affodance ;
    aff:affordanceStrength "1"^^xsd:double ;
    aff:holds :BatteryInCritalLevel ;
```

```
    aff:hasTask :Recharge  .

:sitTime1 a aff:Situation ;
    :user :Freddy ;
    :genre :Jazz ;
    aff:satisfies :UserWantsToListenToSomeMusic

:actPlayAtTime1 a action:Action ;
    action:byAgent :MARIO ;
    action:executes :PlayMusic.
```

`:UserWantsToListenToSomeMusic` represents the frame where a `:user` request to listen to some music of a particular `:genre`. `:BatteryInCritalLevel` represents the frame where the `:batteryLevel` of a certain `:agent` is critical. `:affordancePlayMusicBatteryCritical`, `:affordancePlayMusicUserWantsToListenToSomeMusic` and `:affordanceRechargeBatteryCritical` represent the three affordance relations depicted in figure 2(b) as arrows. `:sitTime1` represents the situation at time 1. `:actPlayAtTime1` is the action carried out by `:MARIO` to cope with the situation `:sitTime1`.

6 Conclusion and future work

This paper proposes an Ontology Design Pattern (ODP) to represent action selection of cognitive agents following the notion of affordance as devised by Gibson [7] and the proposal of Pattie Maes [9]. Our ODP relies on the descriptions and situations ODP[11] [4], and is combined with a frame-based representation scheme [12]. This allows to extend the notion of affordance not only to physical objects, but also to complex situations. We conceived our ODP in order to design a robot (i.e., MARIO) able to support older people affected by dementia. In our future work we aim at connecting the Affordance ODP with a complex ontology network that covers all the knowledge areas helpful to provide MARIO with the cognitive capabilities it requires to address its tasks. These areas include the personal sphere (e.g., people information), the life events (e.g., information about memories, scheduling, plans, etc.), the environment sphere (e.g., information about rooms, furniture, objects, etc.), the health sphere (e.g., living patterns, health patterns, vital signs, etc.), and the emotional sphere (e.g., emotions, sentiments, opinions, etc.).

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[11] Aldo Gangemi, Description and Situation ODP `http://ontologydesignpatterns.org/wiki/Submissions:DescriptionAndSituation`

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