Probabilistic Description Logics for Context Awareness in Mobile Robotics: A Case Study in Imprecisely Specified Probabilities

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Abstract

This work addresses a context awareness problem in mobile robotics, where an autonomous robot must identify the nature of its environment on the basis of isolated features detected from images. Context awareness is a broad term that refers to the use, by computational devices, of any information that characterizes the status (that is, the "context") of the device [4]. As such, it is a broad term; we say that a mobile robot displays context awareness if it can use information from its sensors to characterize the status of its location. More precisely, we wish to employ the set of objects in the environment, detected by sensors, to infer the type of environment in which the robot is located. We take the context of the robot to be summarized by a high-level label such as "office", "parking lot" and "kitchen". We need to express relationships between objects; for instance, we must state that a location containing "chairs" and "refrigerator" and "oven" should be labeled "kitchen". We also have to address uncertainties in the description of contexts and in sensor data. To do that, we resort to a *probabilistic description logic* that adds probabilistic assessments to the well-known $\mathcal{ALC}$ logic. The resulting logic, called CR$\mathcal{ALC}$ [1, 3], allows probabilistic inclusions such as $P(C|D) \in [\alpha, \beta]$ for two concepts C and D. For instance, we can express $P(\mathsf{Couch}|\mathsf{RestingObject}) \in [0.5, 0.95]$ indicating that an object is a couch, given that is a resting object, with probability between 0.5 and 0.95. Even though some needed probabilities can easily be obtained while modeling domains and objects in them, some cannot. For instance, if an inclusion $\mathsf{Bed} \sqsubseteq \mathsf{HomeObject}$ is given, we learn only that for each object x, $P(\mathsf{Bed}(x)|\neg\mathsf{HomeObject}(x)) = 0$ but $P(\mathsf{Bed}(x)|\mathsf{HomeObject}(x))$ is free within the interval $[0, 1]$.

We have developed a probabilistic ontology describing contexts and objects, containing sentences such as

$$\mathsf{Office} \equiv \exists\mathsf{contains.Desk} \wedge \exists\mathsf{contains.Computer} \wedge \neg\exists\mathsf{contains.HomeObjects} \wedge \neg\exists\mathsf{contains.OutdoorObjects}$$

and probabilistic assessments such as $P(\mathsf{contains}) \in [0.6, 0.95]$ (meaning that two objects satisfy the relation $\mathsf{contains}$ with probability between 0.6 and 0.95). We then instantiate concepts in the ontology with the objects successfully identified by the robot, and run probabilistic inference so as to compute the lower probability of various contexts. Due to the complexity of the inference process, exact inference is computationally unfeasible and approximate inference must be applied. We use the L2U algorithm [2], a *loopy propagation* algorithm that deals with imprecise probabilities. We also have at our disposal a *first-order* extension of loopy propagation that allows inference in even bigger networks [1]. Our experiments indicate that probabilistic inference does produce meaningful probabilities even if substantial probabilistic imprecision is present in the domain ontology.

Keywords. Context awareness in mobile robots, probabilistic description logics, $\mathcal{ALC}$ and CR$\mathcal{ALC}$.

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