Integrating Semantic Annotations in Bayesian Causal Models

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1 Introduction

Probabilistic reasoning has been powered by the formalization of causality theory through Bayesian causal models[1]. Even when its semantic is flexible enough to model complex problems, it has to deal with the problem of interoperability between models. In the research community the necessity of contexts for these models has been pointed out. We need means to represent the context on which the causal model is developed and the meaning of causal model events in the real world.

2 Semantic Bayesian Causal Models

We introduce *Semantic Bayesian Causal Models*(SBCM) which integrate a causal model with a semantic layer into an intelligent agent. An SBCM works as an inference engine in an intelligent agent in stochastic environments and is basically constituted by a Bayesian causal model to represent and reason about causal relationships among events, and semantic annotations in an ontology recognized by other agents that describe these events. A SBCM is represented by:

$$M = \langle V, U, G_{VU}, P(v_i|pa_i, u_i), P(u), C, Z, F, A, O, B \rangle \tag{1}$$

where V is the set of endogenous variables, U is the set of exogenous variables, G_{VU} is a causal graph consisting of variables in $V \times U$, $P(v)$ is the Bayesian probabilistic distribution, $P(u)$ is a probabilistic distribution used to explain bias in the system or interference produced by external factors, $C \subset V$ represents endogenous variables that can be manipulated by agent (control variables), Z is the subset of endogenous variables that cannot be manipulated by agent (covariates), $F \in Z$ represents agent objectives which we interpret as final cause in Causality theory, A is the set of semantic annotations over V expressed through Description Logics (DL) statements in terms of OWL ontology O, and B is the set of current beliefs expressed as interventions $(V_i = v_i)$[1].

Agent inference process is performed at two levels: semantic and causal. Former enables common understanding between agents meanwhile the latter summarizes agent experience and guides its behavior. In the first phase, agent perceives the environment through its sensors and transforms its perceptions into

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[1] Capital letters represent variables (V_i) meanwhile small letter represents values(v_i)

DL statements expressed in a given ontology. Then perceptions are compared against annotations over variables in Z to determine if any covariate can be instantiated (node instantiation phase). The result of this process is a set of interventions over Z that are integrated with current beliefs (B). Annotations associated to every variable (A_i) will be expressed as queries in triplet format (SPARQL). The result of running a variable query over current perceptions will determine if the variable is activated (intervened). A special variable in the query will be bind to the variable value in the intervention. If A_i doesn't contain this special variable, Z variable is made true when perceptions match annotations. Otherwise, is made false using a kind of negation as failure.

In the second phase beliefs are revised with current perceptions and resulting interventions are applied to the causal model producing an instantiated causal model used to perform the inference. Plans aligned to reach F are identified and through a heuristic the most feasible plan and action are selected. Selected action is represented by an intervention over a control variable ($C_w = c_w$). Annotations over C_w are instantiated with c_w and triplets resulting are used to encode action.

3 Conclussions

Having annotations over causal model variables enables matching variables among different causal models and calculating a distributed causal effect[2] through nodes sharing the same semantic content. Agents will be in position to exchange information about causal relationships influencing other agents behavior to enforce cooperation.

Besides, semantic information associated to variables presenting an irregular behavior (noise) would lead to causal relationships discovery. Semantic information dismissed in the node instantiation phase can be used for this purpose. This way, we are in a position of not just learning probabilistic distributions but the causal structure too[3].

The final purpose of this model is to develop agents that reason over a network of causal relationships guided by Causality theory introduced by Aristotle and mathematical models developed by J. Pearl. We call this architecture *Causal Agent*.

References

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