

ADVANCED METHODS OF REASONING UNDER UNCERTAINTY

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ABSTRACT

The ultimate aim of this research is to develop computer systems capable of operating autonomously in dynamic and uncertain environments. The objectives of the current project were to conduct theoretical and experimental studies in the following areas:

1. Learning and utilizing causal structures, including the identification of hidden causes and feedback mechanisms using optimal combination of observations and manipulations, and the evaluation of actions from past performance records.
2. Information fusion, diagnosis and planning under uncertainty using qualitative approximations of probabilities, utilities, and causal relationships.

SUMMARY OF RESULTS

Starting with functional description of physical mechanisms we were able to derive the standard probabilistic properties of Bayesian networks and to show:

- how the effects of unanticipated actions can be predicted from the network topology,
- qualitative causal judgments can be integrated with statistical data,
- how actions interact with observations,
- how counterfactuals sentences can be interpreted and evaluated,
- how explanations and single-event causation can be defined in a given causal model.

Additionally, we have established an axiomatic characterization of causal dependencies, analogously to the characterization of informational dependencies, and we have demonstrated that network-based identification techniques, in the presence of hidden variables, have a broad scope of new applications, ranging

from skill acquisition by autonomous agents, to the analysis of treatment effectiveness in clinical trials.

The following specific results were obtained during the period of performance:

- Computer programs were developed to assist clinicians with assessing the efficacy of treatments in experimental studies for which subject compliance is imperfect
- Methods were developed for selecting sufficient set of measurements that permit unbiased estimation of causal effects in observational studies
- Polynomial algorithms were developed for finding minimal separators in a directed acyclic graphs.
- A formal model has been developed, based on modifiable structural equations, which generalizes and unifies the structural and counterfactual approaches to causal inference, explicates their conceptual and mathematical bases and resolves their technical difficulties
- We proved that the structural and counterfactual formalisms are equivalent in recursive causal models (i.e., systems without feedback) but not when feedback is considered possible.
- Simple rules was devised for translating a problem back and forth, between the structural and counterfactual representations. item A new semantics for “actual causation” was developed based on a construct named “causal beam,” that is, a minimally modified causal model, in reference to which the standard counterfactual criterion is adequate for identifying causes of singular events.
- Formal semantics was developed, based on structural models of counterfactuals, for the probabil-

ities that event x is a necessary or sufficient cause (or both) of another event y

- Conditions were discovered under which probabilities of necessary and sufficient causation can be learned from a combination of actions and observations. It was found that data from both experimental and nonexperimental studies can be combined to yield information that neither study alone can provide
- New definition of causal explanation was formulated in which explanation is treated as a fragment of knowledge needed to support causation.

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