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Extended Algorithm for Causal Ordering Analysis

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Many models for physical systems used in research related to qualitative reasoning can be represented in the form of constraints, such as equations, inequalities, predicates. A constraint is a declarative expression which contains multiple procedural functions: bidirectional dependencies between physical variables. However, in the actual problem solving based on the physical model, the notion of causality between variables, which is not explicitly described in the constraint expression, plays an important role. The basic principle of the causality is the determination of an order among the variables that are acquired by analyzing a set of constraints. Then an algorithm is necessary to derive the causal relations from the bidirectional constraint expression.

For this purpose, Iwasaki proposed a theory which analyzes the device behavior by means of causal ordering. The algorithm can deal with constraints in the forms of equilibrium and of differential equations. All constraints are assumed to be always effective. Actual physical models can be represented by constraints by using inequalities and relations between components other than equations. Some of these constraints are conditional: they are applied only if all of the conditions are satisfied.

We intended to construct an extended causal ordering algorithm that can analyze causality between variables in a qualitative model represented by various types of constraints.

First, we classify the types of constraints that represent qualitative physical models in currently available qualitative reasoning systems.

Next, we extend the causal ordering algorithm by Iwasaki until it is able to analyze the following types of constraints besides equations:

1. Inequalities: We define two types of causal propagation in arithmetic reasoning. One is that a value of a variable is determined by solving equalities. The other is that upper/lower bound of a variable is limited by inequalities.
2. Predicates describing relations between components: We regard each predicate that describes a relation between components as an extended physical variable.

We propose an algorithm that analyzes potential causality between physical variables that has been derived from a set of constraints with application conditions. The causal ordering algorithm uses only qualitative information of each constraint, that is, the information concerning which variables appear in each constraint. It cannot specify which conditions are actually true, because of the ambiguity of the qualitative value. However, the algorithm reasons all possible potential causal relations between variables by using sets of exclusive conditional constraints. The algorithm finds sets of exclusive conditions from the antecedents of all conditional constraints, and assigns an environment selector switch for each set of exclusive conditions. Each selector switch becomes active when all values of the variables in the set of the exclusive conditions are determined. The selector activates every environment under itself. Then conditional constraints are activated and are effective in the causal analysis, if all conditions in their antecedents become active. The algorithm can analyze all possible causal relations between variables for each combination of environments.

We implemented a prototype causal ordering utility based on this algorithm. Causal analyses for many sets of constraints were executed on this system to confirm the ability of the algorithm.