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Picture: Christian Geist, Ulle Endriss

Christian Geist and Ulle Endriss win IJCAI-JAIR Best Paper Prize

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Christian Geist and Ulle Endriss will receive the 2016 IJCAI-JAIR Best Paper Prize for their paper 'Automated Search for Impossibility Theorems in Social Choice Theory: Ranking Sets of Objects'. The paper is based on Christian Geist's Master of Logic thesis and was published in the Journal of Artificial Intelligence Research (JAIR) in 2011.

This prize is awarded annually to an outstanding paper published in the journal in the preceding five calendar years. Funding for the award is provided by the International Joint Conference on Artificial Intelligence (IJCAI). The prize will be formally announced during an awards ceremony at IJCAI in New York City this July.

Reasoning about rational decision making

The paper develops a methodology to automatically discover mathematical theorems in an area of Economics known as 'ranking sets of objects'. Economists, who have worked on this topic since the 1980's, have formulated general principles, so-called axioms, for modelling the behaviour of rational decision makers with known preferences over individual objects who need to choose between two sets of such objects.

For example, a *risk-averse* decision maker who prefers wine, to beer, to milk should prefer being served beer with certainty to facing the uncertain prospect of getting either wine or milk. Similarly, a decision maker preferring wine to beer whose behaviour satisfies the so-called *independence* axiom should prefer uncertainty between wine and milk to uncertainty between beer and milk. A third example is the *dominance* axiom, according to which adding a strictly worse option always makes things worse: you should prefer uncertainty between wine and beer to uncertainty between all three beverages.
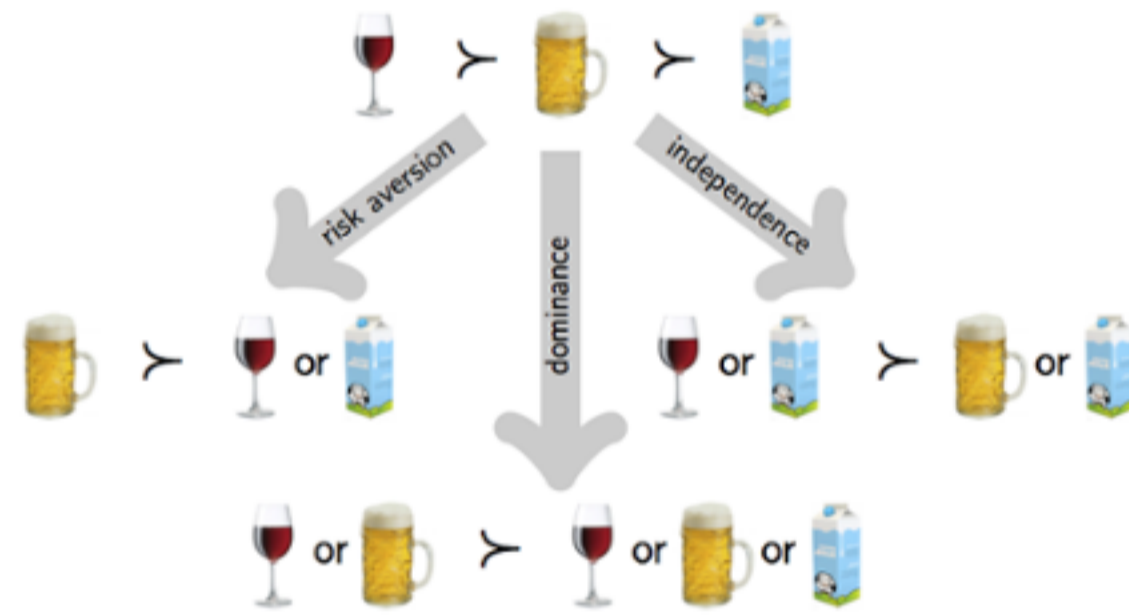

Illustration of three types of axioms, the risk-averse: the independence, and dominance axiom. c: Ulle Endriss

The seminal result in the field, a theorem by mathematician Yakar Kannai and economist Bezalel Peleg published in 1984, shows that -against all intuition- it is a mathematical impossibility for a decision maker's rational preferences to satisfy both the independence axiom and the dominance axiom when there are six or more objects to choose between.

Three-step methodology

The methodology for automatically discovering such theorems developed in the award-winning paper has three components. First, Geist and Endriss showed that, if all the axioms considered are of a certain syntactic form when expressed in a so-called many-sorted first-order logic, then any impossibility found for a specific number of objects immediately generalizes to all larger numbers objects. Thus, proving general impossibility theorems reduces to the much simpler task of proving theorems for specific numbers of objects.

Second, for fixed numbers of objects, they showed how to express axioms in the much simpler classical propositional logic. For this logic, very powerful tools, so-called SAT-solvers, are available to automatically check the logical consistency of a given set of formulas. Now any inconsistency spotted by a SAT-solver corresponds to a general impossibility theorem. Thus, the first two components together provide a method for verifying known theorems.

Third, they devised an algorithm for systematically searching through all possible combinations of axioms from a given set, to be able to automatically discover and prove new theorems.

84 Impossibility theorems

When applied to a space of 20 axioms from the Economics literature, after a night of heavy computation on the Dutch national compute cluster *Lisa*, this approach yielded 84 impossibility theorems, including both known and nontrivial new results. Amongst the known results re-discovered in this way is the Kannai-Peleg Theorem.

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