THE HANDLING OF UNCERTAINTY

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ABSTRACT
We argue that evidential logics based on a variety of non-classical frameworks, implementable with such machinery as extensions of logic programming and neural networks, will play an increasing role over the coming decades. These logics will provide frameworks for further improving both the intelligence of AI-related computer-based systems, and the fit of human discourse systems to the mainly evidential knowledge, which we most often have. Further, by increasingly adopting such evidential knowledge representation and processing frameworks, computer-based domains and human domains will come to increasingly *share the same language and logic*, which in turn will lead to substantial improvements in the problematic computer-human interface.

Theories are nets cast to catch what we call "the world": to rationalize, to explain, and to master it. We endeavor to make the mesh ever finer and finer. - Karl Popper, *The Logic of Scientific Discovery*, p. 59

INTRODUCTION

Our knowledge is often less than certain. Indeed, it is regularly the case, both in scientific domains and in the myriad circumstances of daily human interaction, that what we have to deal with is *evidence*. This evidence is often only partial and tentative (Faust, 1999) and consists of both "evidence in favour" and "evidence against". It is these evidential predications with which we routinely deal.

Yet, for over two thousand years the logic, and its language, for dealing with this uncertainty, has been the logic of *absolute certainty*. This logic of absolute certainty, usually called Classical Logic (CL), allows us to assert a statement only in absolute terms. Let P be such a statement.

For example, in the realm of a computer-based robotic environment, P might be the assertion that "repair #47 is required on robotic arm #23". Sensors will have provided data on the condition of the robotic arm and the nature of its malfunctioning, and from these data evidence in favor (confirmatory evidence) and evidence against (refutatory evidence) the appropriateness of repair #47 on robotic arm #23 will have been derived. That is, we have in hand confirmatory evidence regarding P and refutatory evidence regarding P. This is in fact the knowledge we have. Yet CL requires us to know *with absolute certainty*, a level of certainty we do not often, if indeed ever, have: CL does NOT meet our needs.

Similarly, in the realm of daily human interaction, P might be the assertion that "social justice can be better advanced by implementing plan A than plan B". Careful analyses of the complex web of human conditions and potentialities, together with extensive public debate, will have provided data relevant to P. From these data, evidence in favor (confirmatory evidence) and evidence against (refutatory evidence) assertion P will be distilled. That is, we have both confirmatory and refutatory evidence regarding P: that is the knowledge with which we have to work. Yet CL requires unrealistically that we have knowledge of P at the level of *absolute certainty*. Again here as well, this is a level of certainty we just do not have: again CL does NOT meet our needs.

This misfit, between our knowledge, which is so often less-than-certain, and the Classical Logic of absolute certainty we have traditionally used to represent that knowledge, is a misfit we are finally making some progress in overcoming. In this paper we will try to gain a perspective on this progress which will help us to better see where, over the coming decades, we may be able to continually move forward, in both the computer-based and human domains, in building and utilizing improved knowledge representation frameworks which better fit the evidential knowledge with which we most often have to deal. First we will survey some of the history of this progress, helping us to be able to discern productive future directions. Then we will briefly describe a new logic, called Evidence Logic (EL), which allows for the representation and processing of evidential knowledge. Following this, we will use EL to help us look to the near-term future in computer-based domains and human domains respectively. Finally, we will synthesize the evidential perspective for computer-based systems and the broader human context, arguing the essential role this perspective will play in any future progress at the level of the computer-human interface.

IMPROVING ON A 2000 YEAR-OLD TRADITION

Although our historical survey will be brief, we must start with Aristotle who, over two thousand years ago, observed "to say of what is that it is or of what is not that it is not, is true; to say of what is that it is not or of what is not that it is, is false". Thus begins, roughly, the first steps in Man's analysis of the nature of truth and the development of logics for representing our knowledge (Faust, 1999). Classical Logic (CL) provides a framework for representing absolute knowledge: every statement is true or false.

Aristotle's "syllogistic logic" presented, and analyzed the nature of, the logic of 'all' and 'some' with respect to unary (one-place) predications. Regarding the latter, his logic considered only predications like Hx: x is a horse or Gx: x is green; it did not consider at all binary predications like Bxy: x is the brother of y, ternary predications like Txyz: x is a friend of a child of y and z, or indeed n-ary predications for any n > 1. Further, throughout the Middle Ages, this very limited analysis continued in excruciating detail. Excellent work was done regarding the complex nature of the problematic concept of negation, especially by the Indian logicians of the Nyaya tradition (Matilal, 1968), but the focus continued to be on just one-place predicates and on the Classical Logic of absolute certainty.

Initial attempts to broaden the scope and depth of logic can be seen throughout the Renaissance, and certainly Leibniz deserves mention for his valiant attempts to develop a "universal logical language". However, it was not until the nineteenth century did we begin to take giant steps forward. For example, George Boole, in The Laws of Thought first published in 1854, although primarily focused on the algebraic structure of Classical Logic, ruminates seminally over the relationship between evidence and knowledge, that "with the degree of information which we possess concerning the circumstances of an event, the reason that we have to think that it will occur ... will vary", that as the evidence for a proposition increases so will our confidence in the possibility of the occurrence of the event described by that proposition (Boole, 1958, p. 244).

This progress, during the second half of the 19th century, continued apace throughout the twentieth century. Let us first note the Polish logician Jan Lukasiewicz and two of his many seminal contributions. Early in the century, he published a paper (Lukasiewicz, 1910) wherein