Chapter 8
On Cognitive Models of Causal Inferences and Causation Networks

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ABSTRACT

Human thought, perception, reasoning, and problem solving are highly dependent on causal inferences. This paper presents a set of cognitive models for causation analyses and causal inferences. The taxonomy and mathematical models of causations are created. The framework and properties of causal inferences are elaborated. Methodologies for uncertain causal inferences are discussed. The theoretical foundation of humor and jokes as false causality is revealed. The formalization of causal inference methodologies enables machines to mimic complex human reasoning mechanisms in cognitive informatics, cognitive computing, and computational intelligence.

1. INTRODUCTION

Causal inference is one of the central capabilities of human brains that play a crucial role in thinking, perception, reasoning, and problem solving (Zadeh, 1975; Payne & Wenger, 1998; Smith, 2001; Sternberg, 1998; Wang, 2003, 2007b, 2009b; Wang et al., 2009). Inferences are a cognitive process that reasons a possible causality from given premises between a pair of cause and effect. A causal inference can be conducted based on empirical observations, formal inferences, and/or statistical norms (Bender, 1996; Wang, 2007a, 2007b, 2008; Wilson & Keil, 2001).
**Definition 1:** A *causation* is a relationship between a sole or multiple causes and a single or multiple effects.

A causation is usually a pair of *(cause, effect)*. The causal relations may be 1-1, 1-n, n-1, and n-m, where \( n \) and \( m \) are integers greater than 1 that represent multiple relations. The *cause* in a causation is a premise state such as an event, phenomenon, action, behavior, or existence; while the *effect* is a consequent or conclusive state such as an event, phenomenon, action, behavior, or existence.

**Definition 2:** An *inference* is a cognitive process that deduces a conclusion, particularly a causation, based on evidences and reasoning.

Formal logic inferences may be classified as deductive, inductive, abductive, and analogical inferences (Hurley, 1997; Ross, 1995; Schoning, 1989; Smith, 2001; Sternberg, 1998; Tomassi, 1999; van Heijenoort, 1997; Wang, 2007b, 2007c; Wang et al., 2009; Wilson & Keil, 2001). **Deduction** is a cognitive process by which a specific conclusion necessarily follows from a set of general premises. **Induction** is a cognitive process by which a general conclusion is drawn from a set of specific premises based on a set of samples in reasoning or experimental evidences. **Abduction** is a cognitive process by which an inference to the best explanation or most likely reason of an observation or event. **Analogy** is a cognitive process by which an inference about the similarity of the same relations holds between different domains or systems, and/or examines that if two things agree in certain respects then they probably agree in others.

Although logic inferences may be carried out on the basis of abstraction and symbolic reasoning with crisp sets and Boolean logic, more human inference mechanisms and rules such as those of intuitive, empirical, heuristic, and perceptive inferences, are fuzzy and uncertain, which are yet to be studied by fuzzy inferences on the basis of fuzzy sets and fuzzy logic (Zadeh, 1965, 1975, 2006; Wang, 2008).

This paper presents a theory of causation network toward machine-enabled inference and reasoning in cognitive informatics and computational intelligence. In the remainder of this paper, the taxonomy and mathematical models of causations are explored in Section 2 based on the causation network. The framework and properties of causal inferences are described in Section 3. Methodologies for uncertain causal inferences are elaborated in Section 4, followed by the analysis of humor and jokes as false causality.

### 2. THE TAXONOMY AND NETWORKS OF CAUSATIONS

Causality is a universal phenomenon because any rational state, event, action, or behavior has a cause. Further, any sequence of states, events, actions, or behaviors may be identified as a series of causal relations. It is recognized that the most general form of causations is that of many-to-many, i.e., a network relationship among the causes and effects. Therefore, this section puts emphases of causality modeling on the framework of causal inferences and the formal causal representation technology known as causation networks.

#### 2.1 The Taxonomy of Causations

This section explores the taxonomy of causations and their generic properties. The simplest causation known as the binary or pairwise causation is analyzed below.

**Definition 3:** A *binary causation* \( \kappa_b \) is a binary relation that links a pair of events or states as the cause \( P \) and effect \( Q \), i.e.:

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\kappa_{b} \triangleq (P \BL \Leftrightarrow Q \BL) \BL
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