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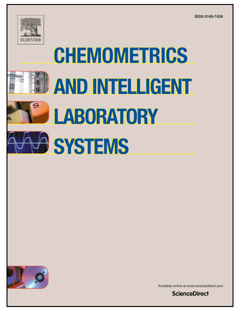

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Comparing Multiple Statistical Methods for Inverse Prediction in Nuclear Forensics Applications

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Abstract

Forensic science seeks to predict source characteristics using measured observables. Statistically, this objective can be thought of as an *inverse* problem where interest is in the unknown source characteristics or factors (X) of some underlying causal model producing the observables or responses ($Y = g(X) + error$). This paper reviews several statistical methods for use in inverse problems and demonstrates that comparing results from multiple methods can be used to assess predictive capability. Motivation for assessing inverse predictions comes from the desired application to historical and future experiments involving nuclear material production for forensics research in which inverse predictions, along with an assessment of predictive capability, are desired.

Four methods are reviewed in this article. Two are *forward modeling* methods and two are *direct inverse modeling* methods. Forward modeling involves building a forward casual model of the responses (Y) as a function of the source characteristics (X) using content knowledge and data ideally obtained from a well-designed experiment. The model is then inverted to produce estimates of X given a new set of responses. Direct inverse modeling involves building prediction models of the source characteristics (X) as a function of the responses (Y) – subverting estimation of any underlying causal relationship. Through use of simulations and a data set from an actual plutonium production experiment, it is shown that agreement of predictions across methods is an indication of strong predictive capability, whereas disagreement indicates the current data are not conducive to making good predictions.

Keywords: Inverse prediction, nuclear forensics

1. Introduction

The U.S. Government is conducting a series of experiments at the U.S. National Laboratories for nuclear forensics research. The objective is to assess the ability to infer source characteristics, ranging from material origin to production parameters, of interdicted special nuclear material from the nuclear signature, or measured observables. Statistically, this objective can be thought of as an inverse problem where the source characteristics (X) of a material are predicted from the measured observables (Y). Additionally, it is desired to assess confidence in the prediction using, for example, statistical confidence intervals or a probability distribution of plausible X values. Beyond nuclear forensics applications [1–3], inverse prediction is of interest in more general forensic science activities such as estimating time of death of homicide victims [4, 5]. Inverse prediction also spans a wide range of areas outside of forensics including computer model calibration [6, 7], chemometrics [8, 9], and geophysical applications [10, 11].

Inverse prediction methods can be divided into two categories: 1) *causal (forward) modeling* and 2) *direct inverse modeling*. *Causal models* attempt to capture the notion that 'Y is caused by X' and are often expressed in terms of a low-order polynomial, which can be thought of as a Taylor series approximation to the true but unknown underlying

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