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Equationless and equation-based trend models of prohibitively complex technological and related forecasts

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ABSTRACT

PCF (Prohibitively Complex Forecast) models integrate several aspects, e.g. macroeconomic, ecology, sociology, engineering and politics. They are unique, partially subjective, inconsistent, vague and multidimensional. PCFs development suffers from IS (Information Shortage). IS eliminates straightforward application of traditional statistical methods. Oversimplified or highly specific PCFs are sometimes obtained. Artificial Intelligence has developed different tools to solve such problems. Qualitative reasoning is one of them. It is based on the least information intensive quantifiers i.e. trends. There are four different trends i.e. qualitative values and their derivatives: *plus*/*increasing*; *zero*/*constant*; *negative*/*decreasing*; *any value*/*any trend*. The paper studies PCF models represented by a set of NODE (nonlinear ordinary differential equations) and models based on EHE (equationless heuristics). An example of EHE is - if *GDP is increasing* then *Research and Development investment is increasing more and more rapidly*. Such verbal knowledge item cannot be incorporated into a traditional numerical model and a qualitative model must be used. The following qualitative equation eliminates all positive multiplicative constants A from PCF NODE models: $AX = (+)X = X$. Numerical values of NODEs constants are therefore qualitatively irrelevant. A solution of a qualitative model is represented by a set of scenarios and a set of time transitions among these scenarios. A qualitative model can be developed under conditions when the relevant quantitative PCF must be heavily simplified. The key information input into PCF EHE model is expert knowledge. A consensus among experts is often not reached because of substantial subjectivity of experts' knowledge. The case study analyses interactions of three technologies using modified predator/prey model. It is based on three NODEs and three EHEs. NODEs have 463 scenarios and EHEs has 79 scenarios. The results are given in details. No a prior knowledge of the qualitative model theory is required.

1. Introduction

At present, most of the formal techniques employed for various studies of TF & SC (Technological Forecasting and Social Change) are of analytical and/or statistical natures. Unfortunately these precise mathematical tools do not always contribute as much as is expected towards a full understanding of TF & SCs tasks. It is no paradox that less information-intensive methods of analysis often achieve more realistic results in cases in which the system that is being modelled is highly complex and/or little known.

Any forecast is based on a formal model, e.g. a set of differential equations. There are roughly two types of forecasting models – numerical and non-numerical models. TF & SC represents a heterogeneous mixture of different numerical and non-numerical, e.g. verbal, knowledge items mutually heavily interconnected.

TF & SCs have impacts on broad spectrum of different problems of different natures, e.g. social, economic and ecological sustainability. There are therefore many different factors, variables and parameters, see e.g. (Iskin et al., 2012). It is obvious that different factors are differently, difficult to quantify. Variables quantification is an important reason why PCF TF & SCs tasks are difficult to model using just numbers.

AI (Artificial Intelligence) has developed a large number of formal tools to solve the most difficult problems related to numerical quantifications. Many AI problems can be solved by intelligently searching through all potential solutions, see e.g. (Russell and Norvig, 1995). However, such trivial brutal force approach is not a solution to multidimensional TF & SCs tasks. Simple exhaustive searches are rarely sufficient for majority of real world problems: the search space quickly grows to astronomical numbers.

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Different research activities in AI have generated a spectrum of different methods, algorithms and methodologies which can be used to study TF & SCs multidimensional problems. Fairly frequently used tools are: neural networks, genetic algorithms, vague reasoning (fuzzy, qualitative, semi-qualitative, rough, and probabilistic), neural networks, genetic algorithms, see e.g. (Fiordaliso, 1998; Dohnal, 1991; Konecny et al., 2010; Struss, 1990).

TF & SC related decision making combines different empirical and AI techniques for the systematic investigation of trade-offs. Logic is traditionally used for knowledge representation and problem solving. Several types of logic are used, e.g. first-order logic (Yes – No), fuzzy logic, default logics, non-monotonic logics etc., see e.g. (Dohnal et al., 1996; Dohnal et al., 1993).

Fuzzy sets applications see e.g. decision-making, have attracted the attention of theoreticians and/or practitioners. Fuzzy sets represent and capture decision-making and consensual processes in a more flexible, human-like way, see e.g. (Doubravsky and Dohnal, 2015; Wang and Hsieh, 2015). The importance of fuzzy reasoning in decision-making and consensus measurement lies in modelling forms of uncertainty that cannot be fully described by the use of numerical models and probability theory.

Qualitative i.e. trend quantifiers; represent the lowest possible information intensity. If it is not possible to evaluate and consequently analyse and/or predict trends then nothing can be quantify/studied/predicted.

The most serious TF & SCs AI application restrictions are ISs. For example some TF & SCs time series are not suitable for standard statistical treatment; see e.g. (Chatterjee et al., 2016; Gardebroek et al., 2016). They are too short and/or inaccurate and/or multidimensional.

Multidimensional time series are frequently used for quantitative study of some TF & SCs aspects. There are such TF & SCs time series problems which do not suffer from ISs. Long time series and accurate measurements are examples. For example a new membrane bioreactor is a complex engineering system. Its parameters are e.g. temperatures and/or pressures. The relevant sensors generate very accurate numerical values, and sampling rates are (very) high, see e.g. (Chen et al., 2015). However, this type of forecast represents just a small fraction of TF & SCs sub problems.

AI techniques are becoming useful as alternate approaches to conventional techniques or as components of integrated systems. They have been used to solve complicated practical problems in various areas and are becoming more and more frequently used (Mellit et al., 2009).

The most widespread statistical methods of time series forecasting are mentioned in Magnus et al. (2007). The main problems of time series PCF are following see e.g. (Magnus et al., 2007; Haettenschwiler, 1999; Power, 2007):

- Lack of an efficient estimation technique to evaluate the dependences between the input parameters and the predicted value;
- Application of sophisticated statistical methods requiring a high level of user skill and knowledge.

Human brains solve such tasks which are out of reach of any algorithm which can be made computer available. Common sense formalisation has attracted attention long time ago; see e.g. ideas related to naïve physics (Lipmann and Bogen, 1923; Dohnal, 1988).

The developments related to naïve physics are a part of a general stream of artificial intelligence research. Qualitative reasoning is a part of this stream, see e.g. (Mueller, 2014). There is obviously a broad spectrum of mathematical techniques for solving problems once they have been modelled as equations. The difficulty is in formulating those models and interpreting the results of analysis: mapping real-world problems having ambiguity and imprecision into equations, and translating the obtained results expressed in the language of the formulation back into common sense terms (Hamscher et al., 1995).

Common sense reasoning algorithms e.g. qualitative reasoning will be accepted by users from TF & SC if they are simple. However, qualitative algorithms are not simple. It means that a high quality user's-friendly interface is essential; see e.g. (Bredeweg et al., 2009; De Kleer and Brown, 1984; Bredeweg et al., 2008).

2. Qualitative framework

Deep knowledge items are such laws which reflect undisputed elements of the corresponding theory, e.g. the Newton laws are examples of deep knowledge items. A deep knowledge item is usually available in a form of differential or algebraic equations (Yang and Cai, 2011). A shallow knowledge item is a heuristic or a result of a statistical analysis of observations and has (many) exceptions, see e.g. (Devezas, 2005; Michalewicz and Fogel, 2004).

Real worlds' problems are usually very difficult to solve (Devezas, 2005; Michalewicz and Fogel, 2004). There are not enough deep knowledge items to solve such tasks using traditional formal tools as e.g. statistics. Shallow knowledge items dominate information inputs into PCF TF & SC related activities.

Information intensity of traditional statistical analysis generates pressure on AI experts to develop new formal tools, see e.g. (Plant, 1993) or newly upgraded older tools, see e.g. (Tapio et al., 2011), which are not as precise as statistics but can take into consideration such information items as EHEs. An example is: *If GDP is increasing then Research and Development investment is increasing more and more rapidly*.

Experts do not use mathematical models as the basic framework for their reasoning; see e.g. (Leijonhufvud, 2000; Hendry, 1995). Experts draw heavily on common-sense; see e.g. (Mueller, 2014).

Examples of quantifier-less pair wise trend relations are given in Fig. 1.

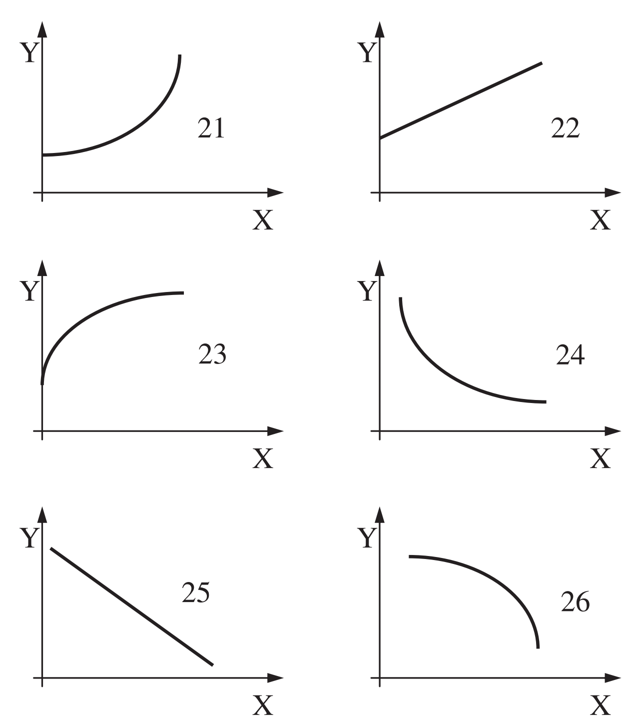

Fig. 1. Examples of qualitative pair wise relations.