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TRANSFORMATION OF STRUCTURAL PATTERNS OR DISCRETE EVENTS?

An Application of Structural Methods in Discrete Event Systems

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An interesting analogy can be found between recognition of noisy, distorted, or incomplete structural patterns and analysis, modelling and control of actual discrete event systems, where different types of uncertainty can occur.

1. INTRODUCTION

Different methods and techniques have been proposed in pattern recognition to handle noisy, distorted, or incomplete patterns. New possibilities appeared in this field when the approach called linguistic, syntactic, or structural was introduced. Many patterns described numerically in the decision-theoretic or discriminant approach could be alternatively viewed as syntactic or structural ones and represented in terms of non-numerical features. Contributions to the structural approach have come from many disciplines, including linguistics, information theory, computer science, statistics, and taxonomy.

An analogous dichotomy concerning numerical and non-numerical data has appeared in analysis, modelling, and control of systems. A need to consider the systems and processes, whose terms correspond to logical or symbolic rather than numerical values, has initiated a considerable growth of interest in problems of this field. The systems, called discrete event ones, are widely considered in numerous applications ranging from flexible manufacturing systems to communications networks, traffic systems, distributed databases, and computer systems. A number of approaches to the analysis, modelling and control of the discrete event systems have been proposed to reflect the different aspects of their behaviour and the many areas where they arise. The different formalisms are utilized, e. g., finite state machines, Markov chains, Petri nets, calculus of communicating systems, communicating sequential processes, and finitely recursive processes belong to them, [7].

A number of methods have been proposed for processing of uncertainty in discrete event systems. Partial observations of the events specified by a mask or observation

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function have been introduced in [2], uncertain transitions or states of a deterministic finite automaton model are studied in [8], and an event deformation model is presented in [4].

To deal with uncertainties in actual discrete event systems, we are faced to handle noisy, distorted, or incomplete data. As this problem is very closely related to the similar one of structural pattern recognition or processing of non-numerical data in general, we believe it is useful to adopt some methods and techniques from these fields for discrete event systems.

2. BASIC CONCEPTS

The considered transformation of strings is based on a proper use of symbol–to–symbol operations needed to change the one string into the other. The following operations are utilized to transform a string X into a string Y, both X and Y are over an alphabet E: (1) deleting one symbol from X, (2) inserting one symbol into Y, (3) substituting one symbol of X for another single symbol. The considered operations can be written as a pair of symbols $s = (a, b) \neq (\lambda, \lambda)$, $a, b \in E \cup \{\lambda\}$, where (1) $b = \lambda$, (2) $a = \lambda$, (3) $a, b \neq \lambda$, respectively.

To reflect a difference in the application of the operations, a nonnegative real number is associated with each operation.

A discrete event system is defined here as a finite state machine

$$\mathcal{G} = (\Sigma, E, \delta, \sigma_0),$$

where

Σ	is an alphabet of states,
E	is an alphabet of events partitioned into $E = E_o \cup E_{uo}$,
δ	is a transition function, $\delta : \Sigma \times E \to \Sigma \cup \{\lambda\}$,
σ_0	is an initial state,

E_o and E_{uo} are the sets of observable and unobservable events, respectively, and λ is used to indicate an undefined transition.

Such $\mathcal{G}$ is also called a logical (untimed) discrete event system to distinguish it from the system where the event occurrence time is taken into account.

3. STRUCTURAL TRANSFORMATION OF DISCRETE EVENT SEQUENCES

To model event uncertainty in discrete event systems, the symbol-to-symbol operations utilized in recognition of imperfectly specified structural patterns have been adopted from structural approach and the event deformation model has been built in [4]. The model is based on an equivalence relation over the set of event subsequences. To define it, a partition on this set can be introduced by non-numerical clustering and/or by transformation of event sequences.

3.1. Transformation

Two modifications of the transformation are considered.

The former is based on a stochastic mapping $T : E \cup \{\lambda\} \rightarrow E \cup \{\lambda\}$, E is an alphabet of events, $T(a) = b$, $(a, b) \neq (\lambda, \lambda)$, with a probability $p(b/a)$ associated with each event–to–event operation $s = (a, T(a)) = (a, b)$.

Assume at most one transformation of each event, the operation probabilities are consistent if $\Sigma_{b \in E \cup \{\lambda\}}\ p(b/a) = 1$ for all $a \in E \cup \{\lambda\}$. Following [3], the probability of the transformation X into Y, $p(Y/X)$, $X = a_1 a_2 \ldots a_n$, is defined by

$$p(Y/X) = \max_{Y^k \in \tau}\ p(Y^k/X) = \max_{Y^k \in \tau} \left\{ \prod_{j=1}^{n}\ p(\alpha_j^k/a_j) \right\},$$

where τ is a set of all partitions of Y into n subsequences, $Y^k = \alpha_1^k \alpha_2^k \ldots \alpha_n^k$, $\alpha_j^k \in E^*$, $j = 1, 2, \ldots n$.

As follows from the definition of $p(Y/X)$, it corresponds to the most likely way of transformation of X into Y.

The latter modification introduces the Levenshtein metric for an optimal representation of the event sequences. A nonnegative real number $w(s)$ associated with each event operation is called a weight of the operation $s = (a, b)$. The notion of $w(s)$ is extended to a series of operations $S = s_1, s_2, \ldots, s_m$ using

$$w(S) = \sum_{i=1}^{m}\ w\ (s_i) \text{ and } w(S) = 0 \text{ for } m = 0.$$

The weighted distance $d_w(X, Y)$ from $X \in E^*$ to $Y \in E^*$ is defined by

$$d_w(X, Y) = \min_S \{w(S)\ :\ S \text{ is a series of operations which transforms } X \text{ into } Y\ \}.$$

A serious problem that appears is a proper setting of the probabilities $p(b/a)$ or the weights $w(s)$ of the event-to-event operations. They are usually determined heuristically to reflect our knowledge and insights into the considered problem, but another method utilizing a weight parametrisation and a given sample set of the sequences is proposed in [1]. Generally, there are $m = M(M-1) + 2M - 1 = M^2 + M - 1$ parameters for an alphabet containing M elements.

3.2. Event uncertainty in discrete event systems

Let us consider a couple of the discrete event system or generator $\mathcal{G}$ and the controller or supervisor $\mathcal{S}$. Further, let us assume occurrences of event uncertainties that are due to the possibly ambiguous event recognition, the transmission of the event sequences through a noisy channel and/or the incorrect observations of $\mathcal{S}$.

As a result of the uncertainties, the supervisor $\mathcal{S}$ observes an event sequence that is different from that of the generator $\mathcal{G}$. The distinguished differences are as follows, [4]: 1. an actual event is not observed by $\mathcal{S}$, 2. an observed event is not in the sequence of $\mathcal{G}$, 3. an actual event of $\mathcal{G}$ is observed by $\mathcal{S}$ as a different event.

The same sources of event uncertainties have been mentioned in [6], where the language-based approach to failure diagnosis of discrete event systems is presented.

In the approach, the diagnoser is a finite state machine constructed from the model of the system. The diagnosis depends on two factors: (i) the system model from which the diagnoser is synthesized, and (ii) the observation sequences considered by the diagnoser.

Owing to uncertainties, an event inconsistent with the current state of the diagnoser may be contained in the observation record. To make possible a transition following the uncertain event, an application of transformation of event sequences based on operations of deletion, insertion, and substitution has been proposed in [5]. As the probabilities or the weights are associated with event-to-event operations, the distances between the observation record and the corresponding event sequences of diagnoser are computed. Depending on a priori given the threshold value, the diagnoser enters the state following the event belonging to the more likely or optimal event sequence representation.

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