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Toward a Petri Net Based Approach to Support Risk Analysis of Dissonances between Human and Machine

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Abstract: Autonomy of a system is defined by its knowledge, its availability and its prescription to achieve goals. Different conflicts may occur between these parameters. They are called dissonances and the paper focuses on conflicts between individual or collective knowledge related to a predefined task allocation. Two kinds of dissonances will be studied: affordances and inconsistencies. Affordances relates to knowledge discovery when new links can exist between goals and conditions to achieve goals. Inconsistencies occur when opposite goals can be achieved in a given operational context. Contradictions concern individual inconsistencies related to the knowledge content of a decision-maker. Interferences are inconsistencies between the prescriptions of different decision-makers. The mathematical formalism of the Petri Net is then adapted to identify automatically affordances and inconsistencies. Knowledge is modeled by Petri net implementing the goals, the conditions of activation of a goal and the links between the goals and the conditions, taking into account the elements of interactions and the prescriptions of the decision-makers. The approach is applied to transportation domain by identifying possible affordances by using existing elements of interactions for achieving new goals, or by identifying inconsistencies between human drivers and on-board assistance systems.

Keywords: Affordance, Petri Net, Risk analysis, Inconsistency, Interference, Contradiction, Knowledge discovery, Dissonance

1. INTRODUCTION

The autonomy of a human-machine system relates to three mains requirements (Vanderhaegen, 2012): the knowledge to achieve a goal, the availability of the resources to apply this knowledge and the prescription regarding the allocation of knowledge application. A lack of autonomy can be solved by cooperating (Vanderhaegen, 1997, 1999; Zieba et al., 2010, 2011) or by learning (Polet et al., 2012; Ouedraogo et al., 2013; Vanderhaegen, Zieba, 2014). It can be due to a lack of knowledge, a lack of availability or a lack of prescription to control events (Vanderhaegen, Caulier, 2011). Other conflicts, called dissonances, may occur between these parameters and they may provoke unsafe perturbations.

Whatever the occurrence or the consequences of perturbations, a human-machine system remains resilient if no accident occurs. Dissonances can be sources of perturbations that may affect the system functioning. Cognitive or organisational dissonances occur when something sounds wrong, may be wrong or was wrong (Vanderhaegen, 2014). There are conflicts between knowledge of a decision-maker or of several decision-makers from a given organisation or from different organisations. The barrier removal, i.e. intentional non-respect of a safety barrier (Vanderhaegen, 2010; Vanderhaegen et al., 2011), the automation surprise, i.e., conflicts of intention between human and machine (Inagaki, 2008), the tunnelling effect, i.e. cognitive blindness of human experts (Dehais, et al., 2012), competition or erroneous cooperation activities (Vanderhaegen, et al., 2006) are examples of dissonances.

Affordances and inconsistencies are other examples of dissonances. Initially, affordances relates to the opportunities of action and direct perception (Gibson, 1986). They consist in making relationship between actions and objects used to realize these actions. The concept is used for studying dissonance discovery and for identifying possible achievement of a known goal with new conditions. Inconsistencies are conflicts between knowledge. Contradictions are inconsistencies of the knowledge of a decision-maker, and interferences are inconsistencies between decision-makers.

Petri nets are adapted for detecting such dissonances. Sequences between two distinguished places and a transition are studied in order to study possible affordances and inconsistencies. The section 2 of the paper presents the Petri net based approach to identify and analyse dissonances. The section 3 presents a feasibility study of such an approach for analysing risks of dissonance between knowledge of a car driver and knowledge of an automated speed control system.

2. THE PETRI NET BASED APPROACH FOR DISSONANCE ANALYSIS

A Petri net, noted *PN*, is a state-transition system represented by an oriented graph composed by a triplet *(P, T, L)* where *P* is the set of places, *T* is the set of transitions, and *L* is the set of the links between places and transitions. The transitions

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relate to the occurrence of particular conditions to achieve a goal and places are the goals that are achieved or have to be achieved. When a place is marked, i.e. contains at least one token, then this corresponding goal is achieving. Graphically, if a place is activated and if a transition is true, then a token disappears from this place and appears into the following places with which this transition is linked, Figure 1.

A given configuration of tokens into the places of a Petri net is called a marking. This marking can evolve dynamically regarding the initial activation of places and the modification of the conditions of activation. The links are sequences of possible evolution between places. They gather the arcs between a place toward a transition and between a transition toward a place. Therefore, a link L_{ijk} of a Petri net PN is a triplet (P_i, T_j, P_k):

$$L_{ijk} \leftrightarrow (P_i, T_j, P_k),\ L_{ijk} \in PN,\ P_i \in P,\ T_j \in T, \text{ and } P_k \in P \quad (1)$$

The links identify all the paths the tokens can follow. There are limited to the identification of all the possible sequences of three parameters: the previous place of a sequence, the corresponding transition to transfer a token from this previous place to the following one, and the next place. If several places exist after or before a transition, then several separate links are listed.

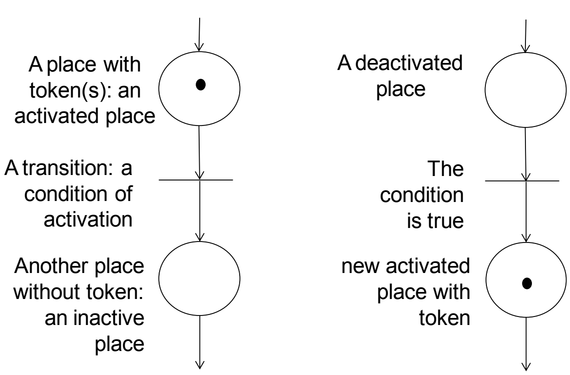

Fig. 1. Places, tokens and transitions of a Petri net.

Such a link implements a rule. A couple of links is then a rule-based knowledge RK taking into account the activation of P_i and T_j to activate P_k:

$$RK: \forall L_{ijk} \in PN,\ RK = RK \cup (P_i \text{ and } T_j \rightarrow P_k) \quad (2)$$

Two sets of links are considering: links for which the transition is controlled by the human behaviour, and links for which the transition is controlled by the machine. The decision-maker $A(L_{ijk})$ concerned by each link is required. It comes from the set noted *DM* of the decision-makers of a given organisation or of several organisations:

$$\forall L_{ijk} \in PN,\ A(L_{ijk}) \in DM,$$
$$DM = \{DM_1, DM_2, DM_3, ...DM_m\} \quad (3)$$

Possible consecutive links of a Petri net exist when a final place of a link is equal to an initial place of another link:

$$\forall L_{ijk} \in PN,\ \forall L_{lmn} \in PN,\ L_k = L_l$$
$$\text{Consecutive}(L_{ijk}, L_{lmn}) = \text{true} \quad (4)$$

Figure 2 gives an example of the modelling of the human behaviour related to the manual control of a car speed. The presence of a token on the place entitled "To control speed manually" means that this goal is activated. The activation of the braking system or of the acceleration system makes the reduction or the increasing of the car speed respectively. The possible links of the Petri net of the Figure 2 and the corresponding decision-maker are then given on Table 1. The couple of links (To control speed manually, Braking system activated, To decrease the speed) and (To decrease the speed, Required speed achieved, To control speed manually) is a example of two consecutive links.

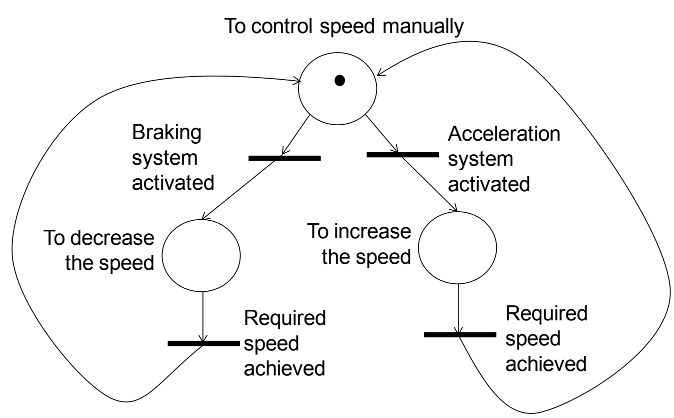

Fig. 2. Example of a Petri net of a manual control of the car speed.

Table 1. Links and the decision-maker for the manual control of the car speed.

$A(L_{ijk})$	P_i	T_j	P_k
Human driver	To control speed manually	Braking system activated	To decrease the speed
Human driver	To control the speed manually	Acceleration system activated	To increase the speed
Human driver	To decrease the speed	Required speed achieved	To control speed manually
Human driver	To increase the speed	Required speed achieved	To control speed manually

Figure 3 represents the behaviour of an Automated Speed Control System (ASCS) for the automated control of the speed. The goal "To control speed automatically with the ASCS" is activated because there is a token. The ASCS activates the acceleration or the braking systems depending on the value of the current speed regarding the speed setpoint.