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Using Formal Concept Analysis for Control in Cyber-Physical Systems

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Abstract

Cyber-Physical Systems (CPS) involve communication, computation, sensing, and actuating through heterogonous physical devices and computational components. A major task in artificial intelligence concerns the automatic identification of the system behavior. Following Formal Concept Analysis (FCA) approaches, we derive behavioural specifications from structural and information input by the user in the context of the intelligent control of physical systems. We will show in the present paper how concepts and techniques from the theory of Formal Concept Analysis help solve this task in the case of the intelligent control of engineering systems.

1. Introduction

Cyber-Physical Systems (CPS) are integrations of computation with physical processes. Networked embedded computers are used to monitor and control physical processes based upon local (i. e. in-network) and remote (i. e. back end) computation [1]. CPS tend to feature a tight coupling between physical and software components. CPS may operate on different spatial and temporal scales and exhibiting multiple and distinct behavioural modalities. Furthermore, CPS are continuously interacting with the physical world, as a result the behaviour of a CPS may change with the operational and environmental context.

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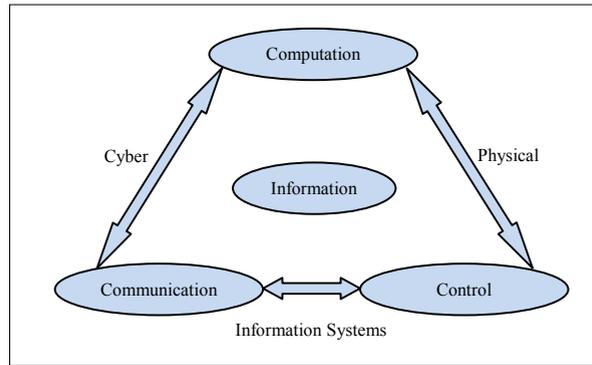*E-mail address:* klimes@fai.utb.cz

Fig. 1. Concepts in CPS.

The physical platforms which support CPS offer five capabilities: computation, communication, precise control, remote collaborative and autonomous capabilities. Fig. 1 shows the three essential concepts in CPS, that is, computation, communication and control.

CPS for avionics, robotics [2], electric power control, water resource control and defense systems ask for accurate and reliable control, which requires applying software methodologies to be extremely precise. In contrast to traditional embedded systems, CPS interface directly with physical world. The goal of this paper is to produce through a refinement process, a planning for a given control system in a given environment, i.e. spatial and temporal instances of general information.

Behaviour models play a central role in systems specifications and control [3]. A behaviour is defined as a collection of extended actions occurring according to a set of constraints. As the physical systems include artefacts, interaction with the physical system involves actions with these artefacts. This assertion reinforces the choice of a goal structure relating an action with its physical entity. As a consequence, behaviours are the result of teleological interpretation of causal relations among atomic goals (see Fig. 2).
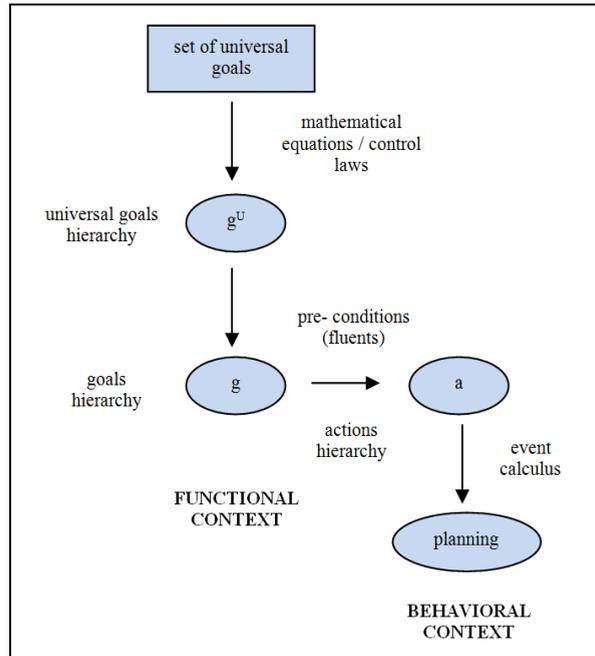

Fig. 2. The local model for Intelligent control.

2. The target application

The real-world example concerns an open-channel hydraulic system which is controlled with (at least) two intelligent control systems (ICS). The control nodes are connected with a fieldbus. Each active ICS, in the open channel irrigation channel is located near a water gate and performs two pressure measurements from a Pitot tube. In addition, it is able to react accordingly and to modify the gate position with the help of a brushless motor. Pairs of goal-program functions are the basic elements on which knowledge representation is built. While the basic functions are extracted from libraries, the goal/sub-goal representation requires a particular attention. To reach sub-goal, one of several dedicated software functions can be either extracted from libraries or defined by the user. Goals and functioning modes are user-defined. All functions handle variables whose semantic contentis extracted from the structural mereology. The hydraulic control system requires the following list of basic goals:

g_1= (to_acquire,{(pressure, 1, SF Area1)}),
g_2= (to_acquire,{(pressure, 1, DF Area1)}),
g_3= (to_compute,{(velocity, 1, Water Area1)}),
g_4= (to_compute,{(level, 1, Water Area1)}),
g_5= (to_send,{(velocity, 1, Water Area1),
   (level, 1, Water Area 1)}),
g_6= (to_receive,{(velocity, 1, ExtEntity),
   (level, 1, ExtEntity)}),
g_7= (to_compute,{(level, 2, Water Area1, ExtEntity)}),
g_8= (to_compute,{(offset, 1, Gate1)}),
g_9= (to_receive,{(offset, 1, Gate1)}),
g_{10}= (to_move ,{(position, 1, Gate1)}).

For the hydraulic system for example, we plan three services with the respective goals:

G_{11}= (to_measure ,{(speed, 1, Water Area1),
   (level, 1, Water Area1)}),
G_{12}= (to_control ,{(speed, 1, Water Area1)}),
G_{13}= (to_manuallyMove ,{(position, 1, Gate1)}).

We explain basic notions for understanding Formal Concept Analysis[4]. Based on the following definitions, FCA classifies data based on the ordinary set into concepts units which consists of objects and attributes that those objects have commonly. Formal context K= (O, A, R) consists of two finite nonempty sets O and A and relationship R between O and A. O is a set of objects and A is a set of attributes, and R ⊆ O x A is a binary relation between O and A. In order to express that an object o is in a relation R with an attribute a, we write (o, a) ∈ R and read it as the object o has the attribute a. Let K= (O, A, R) be a context, X ⊆ O and Y ⊆ A. The function intent maps a set of objects into the set of attributes common to the objects in X, whereas extent is the dual for an attributes set:
intent (X) = {a ∈ A |for each o ∈ X: (o, a) ∈ R},
extent (Y) = {o ∈O |for each a ∈ Y: (o, a) ∈ R}.

A formal concept is a pair (X, Y) with X ⊆ O is called extension, Y ⊆ A is called intension, and X = extent (Y) and Y=intent (X). The set of all concepts B (K) forms a complete lattice. Concept lattice L= (B(K), ≤) can be obtained by all formal concepts of a context K with the sub-concept- 1superconcept relation defined by (O_1,A_1) ≤ (O_2,A_2) if and only if $O_1 ⊆ O_2$ (if and only if $A_2 ⊆ A_1$). Its graphical representation is line (or Hasse) diagram. Figure 3 presents the conceptual lattice of a cross table shown in Tab. 1. The set of objects is O ={1, …, 10} with n= *Achieved* (g_n), n=1, …, 10 and the set of all attributes is A ={g_1, …, G_{13}} (see the list of all goals presented above). Table 1 shows the context table, the elements on the left side are objects, the elements at the top are attributes, and the relation between them is represented by the cross mark.

Table 1. Cross table of the formal context.

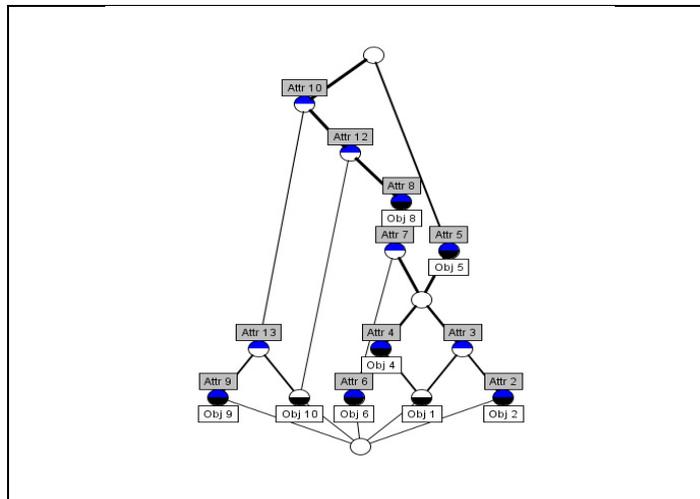| R	g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11	g12	g13
1	x		x	x	x		x	x		x	x	x	
2		x	x		x		x	x		x	x	x	
3			x		x		x	x		x	x	x	
4				x	x		x	x		x	x	x	
5					x						x		
6						x	x	x		x		x	
7							x	x		x		x	
8								x		x		x	
9									x	x			x
10										x		x	x

Fig. 3. Concept lattice of a given context.

Then, the concept lattice is transformed in a partial order by some elementary rules. First, for each node the concept labelled with the intent of the lattice node. In a second step, overlaps are highlighted and the previous ordering is reduced based on simplifications rules [5]. Finally, the bottom element is removed. The resulting goal system is presented in Fig. 4.
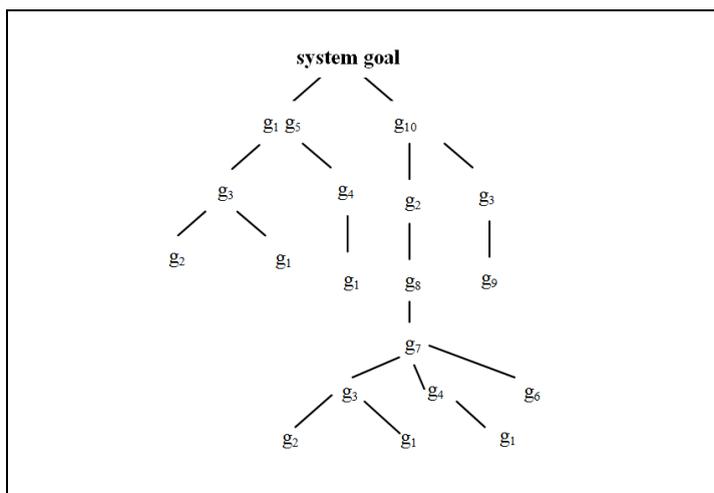

Fig. 4. The goal system with the hierarchy.

Acknowledgements

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