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217 Learning Function of Devices Using Qualitative Function Formation Technique

Behrouz HOMAYOUN FAR
Department of Information and Computer Sciences
Saitama University

ABSTRACT

The goal of this research is developing methods for categorizing and learning function of objects from a formal description of their structure and behavior using Functional Reasoning (FR). A collective view on FR theories and techniques is presented, common assumptions and basic problems are identified. Qualitative Function Formation (QFF) technique is introduced. Some novel points are extending the common qualitative models to include interactions and timing of events, by defining coordinative relations, temporal and dependency constraints, and binding it with the conventional qualitative simulation. A function concept is defined as an interpretation of a persistence or an order in the sequence of qualitative states. Examples of application of QFF in categorization and learning function of objects are given.

Index Terms– Cognitive learning, Categorization, Qualitative modeling, Functional reasoning, Teleology

1 INTRODUCTION

The goal of this research is developing methods for categorizing and learning function of objects from a formal description of their structure and behavior using Functional Reasoning (FR). A main theme in machine learning is devising computational methods and new ways to organize existing knowledge in categories [4]. Category is defined as a common concept for addressing a number of objects considered equivalent. Humans can categorize objects based on perception, iconic images and functions [27]. Categorization by function is mainly based on objects' specific properties in a given situation or by finding analogies between similar features of two objects. FR can contribute to derive the common properties and explain similar features of objects.

Traditionally, FR theories and techniques have appeared in different branches of inquiry. In philosophy, FR has to find answer to a set of problems such as explaining why an organ (e.g. heart) is in an organism (e.g. human's body) in terms of its contribution to the functionality of the whole organism [29, 21, 33, 5, 24]. Also it may be required to derive the 'natural function' of an organ (i.e. heart for pumping blood versus making heart sound, etc.). In engineering, functional reasoning generally has to differentiate between 'means' and 'ends', in order to explain why a component is used in a designed artifact in terms of its contribution to the functionality of the whole system [15, 30, 23, 31, 10].

Generating understandable and sound explanation of function of artifacts with reference to common physical laws is considered as an area of study in qualitative reasoning (QR) [1]. Qualitative reasoning uses models reflecting how the objects interact and behave. The focus of this research is on systematic generation and reasoning with the qualitative models that describe and account for human understanding capabilities. Humans use such models in various level of abstraction that is best defined in the Skill-Rule-Knowledge (S-R-K) perspective [26]. The qualitative models comprising either of levels of the S-R-K correspond to decreasing level of familiarity with the task [26], and account for the trade off between the problem solving task and mental workload. Three stages of learning, corrseponding to the S-R-K levels are identified: *autonomus*, *associative* and *cognitive* [28] (see Figure 1). Autonomous learning is based on identification of certain patterns which have already been recorded. In associative learning one exploits already recorded knowledge in the form of rules or tables and comparison and search techniques are used to derive a certain pattern. Knowledge in this level may include functional concepts and reasoning may have reference to function. Cognitive learning is mainly based on hypothesis generation and test, using various information processes such as deduction, induction, analogy, etc. The model in this level should have no reference to function, i.e. *no function in structure, NFIS* [6]. Distinction among these levels is crucial in explaining behavior and function of objects.

Qualitative Function Formation (QFF) technique is introduced. QFF can contribute to the cognitive level of learning. Basic features of QFF are described in the following sections. Section 2 gives an introduction to the basic concepts, terminology and assumptions. Section 3 introduces the QFF and its modeling and reasoning techniques. In Section 4 an example of application of QFF in categorization and learning is given. Finally, Section 5 summarizes the achievements and presents a handful of some research problems and some ongoing attempts to solve them.

2 BACKGROUND

2.1 Functional Reasoning in AI

Functional Reasoning (FR), in its common sense use, enables people to reason about the presence and function of objects

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[1] Qualitative reasoning concentrates on six tasks: simulation, envisionment, building mental models, diagnosis, verification and deducing functionality [3].

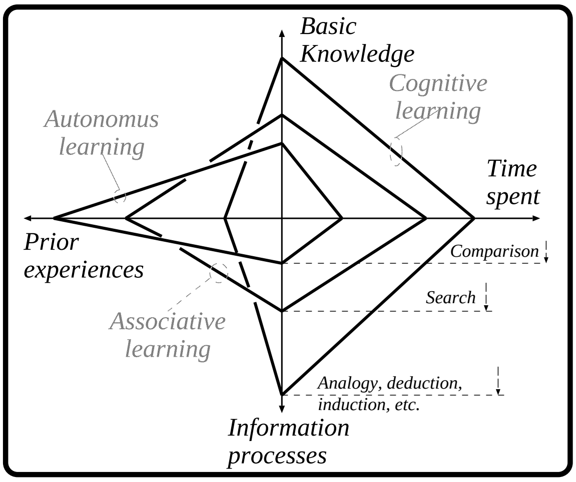

Figure 1: Three levels in concept learning.

in a containing system, derive the purpose of the system and explain how it can be achieved.

The term *function* has a multilateral spectrum of meanings. Function of a system is usually mentioned along with its *behavior*, *goal* and *purpose*. Also it has strong connections with the notion of making efforts to obtain a certain result (mainly in man-made objects), or a certain future event [2]. In AI function of a system is addressed with reference to intention of humans [6, 9, 8, 23, 30, 31, 18, 17]. In such works the choice of a function concept usually depends on preferences rather than rigor algorithms.

Trace of qualitative reasoning in FR can be found along with the three major theories of qualitative physics. The qualitative process theory [12] influenced deriving function of mechanical objects using geometric data (see [9] in which a way of finding description of behavior of mechanical assemblies based on geometry of components is discussed), qualitative confluence theory [7] has influenced explanation of function of electronic circuits using mechanism graphs and teleological analysis (see [6]) and qualitative simulation [20] has led to explaining function of designed artifacts using scenarios and partial states (see [14]).

2.2 Functional Reasoning and Learning

There is an analogy between the explanation based functional reasoning systems and explanation based learning (EBL) techniques. The proposed methods each resemble a kind of EBL using either chunking or generalization [6, 9, 14]. Identifying primitive fragments on the Dekleer's mechanism graph resembles chunking, and teleological analysis seems to be a kind of EBL using qualitative data (derived by qualitative simulation based on confluences) as its input sequence. Similarly, identifying *places* in Faltings works resembles chunking, using metric diagrams as the input sequence. Finally, Franke's partial ordering of states from the simulated behavior is a kind of generalization in EBL using qualitative data (derived by the QSIM method) as its input sequence.

2.3 Functional Reasoning Problems

QFF provides solution to the following FR problems:

1. *Identification Problem*: Given an object, explaining its function using knowledge of structure and behavior of its component and their organization. Typical works: [15, 6, 18, 30, 8, 9, 17].
2. *Explanation Problem*: Explaining presence of a component in a containing system in terms of its contribution to the overall function of the system. Typical works: [21, 33, 5, 24].
3. *Selection Problem*: Given a set of components, selecting the proper components that if used together can achieve a desired function. Typical works: [15, 25].
4. *Verification Problem*: Verifying whether an object can exhibit a required function in a given situation. Typical works: [23, 31].

Categorization and learning are expressed in terms of the FR problems. Categorization is equivalent to identifying function of different objects and generating list of objects having the same functions. Model based learning is the result of identification and explanation of function objects.

2.4 Basic Assumptions

a. Functionality in State Transition

A physical phenomena can be explained in terms of *histories* [16] and *episodes* or *states*. Intuitively, the history that leads to a function should display a certain pattern [2]. A basic feature of state representation is that it assigns a certain characteristic to its referred object [22], therefore it is possible to define function concepts with reference to discovery of an order in the state sequence. The key idea is that a function concept emerges from discovering a persisted state or an ordered pattern in the sequence of states. This is called '*Functionality in State Transition (FST)*'. In biological systems persistence is considered to be the most interesting characteristic and is believed to be governed by natural selection law. In designed artifacts besides persistence other kinds of ordered patterns may also be considered.

b. Functionality in Item Pair

It seems that humans have a data base in which an object is associated with several functionalities. Some of the theories and systems have considered the function as a property of a single object. However there are certain difficulties in both logical formulation (see for instance [33]) and actual implementation (see [30], etc.) of such theories. It is argued that function can be ascribed to a pair of objects instead of one (see [13], etc.). This is called '*Functionality in Item Pair (FIP)*', stating that at least a pair of objects (or a pair of components of an object) are required to interact functionally, and function concepts can be derived from their combined histories[2] .

Without these assumption sit is almost impossible to explain how a single object can have several functions in different situations using the history and states of the object itself.

3 QUALITATIVE FUNCTION FORMATION (QFF)

A qualitative theory of change presumes theories of interactions. Conventional qualitative theories consider physical

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[2] Close ideas are mentioned also by the Locality of Histories [16], Connectivity Hypothesis [13] and Pairwise Interaction of Parts [9].

interactions that are represented by ordinary qualitative relationships between variables, such as monotonic increase, monotonic decrease, etc. [7, 12, 20]. We have extended the qualitative model to embody both physical and protocol based interactions by defining two types of relationships: *ordinary* and *coordinative*.

Extended Qualitative Model (EQM) is composed of a set of expressions involving three primitives: qualitative variables and two types of qualitative relationships. Qualitative variables are counterpart of physical quantities, such as temperature and pressure, representing characteristics of the system's inner environment. Relation between the qualitative variables is defined by qualitative relationships. Ordinary relationships are the conventional monotonic increase (M^+), monotonic decrease (M^-) [20], positive influence (I^+) and negative influence (I^-) [12]. Coordinative relationships model the protocol based relations and timing.

Definition 3.1 (Extended Qualitative Model) *EQM is a set of expressions of either of the following forms:*

$$\begin{array}{rcl} [Y] & = & O[X] \quad 'D' \quad [L_N^i] \\ [Y] & = & O[X] \quad 'D' \quad O[Z] \end{array}$$

$[Y], [X], [Z]$ *and* $[N]$ *are qualitative variables;* L_N^i *is the ith landmark value of* N*;* O *is an ordinary qualitative relationship.* $O \in \mathcal{O}$,
$\mathcal{O} = \{M^+, M^-, I^+, I^-\}$
'D' is a coordinative relationship ('when', 'until' *and* 'default'*),*

1. *'when' relationship:* $[Y] = O[X]$ *'when'* L_N^i*; implying that* $[Y] = O[X]$ *only after* $[N]$ *is evaluated to* L_N^i.
2. *'until' relationship:* $[Y] = O[X]$ *'until'* L_N^i*; implies that* $[Y] = O[X]$ *before* $[N]$ *being evaluated to* L_N^i.
3. *'default' relationship:* $[Y] = O[X]$ *'default'* $O[Z]$*; implying that* $[Y] = O[X]$*, but only in special cases that* $[X]$ *is not present,* $[Y] = O[Z]$.

In special cases $[N]$ can be a logical variable with only two landmark values evaluated to *true* or *false*.

For each coordinative relationship *clock* and *dependency* constraints are defined [1]. Clock and dependency constraints can only be evaluated to one of the followings represented by mod-3 integers, indicating [1]: *present* (± 1) i.e. two events occur concurrently; *absent* (0) i.e. two events do not occur concurrently; *true* ($+1$) i.e. an event has occurred; *false* (-1) i.e. an event has not occurred; Table 3 depicts the clock and dependency constraints.

QDM can be visualized by a digraph whose arcs are qualitative relations and nodes are qualitative variables. QDM embodies Qualitative Processes (QPs) that are finite, connected, unidirectional strings of arcs of the graph. A key point is distinguishing the effects of an input variable on the network of the overlapping processes. Using the conventional notion of process in qualitative reasoning (see such as [32] and [12]), for each process a number of possible behaviors can be generated and removing the ambiguity is not trivial. In QFF processes are extracted from the QDM by decomposition, i.e. the merging variables and the succeeding shared variables and arcs between two processes are assigned to both. This is a requirement in QFF because the direct consequences of a certain process and its effect on the behavior of the whole system should be distinguished first, and then combined behavior of the cooperative processes derived. This is where QFF departs from the main stream of the other qualitative techniques.

QPs compete and cooperate to realize the system's overall function. Each process relates a characteristic feature of a component pair to the effects it has on the system. Such effects are described by Behavioral Fragments (BFs). A BF is the characteristic behavior of a process and is defined as the record of landmark values for the qualitative variables belonging to that process.

Definition 3.2 (Behavioral Fragment) *Behavioral fragment* BF_{P_j} *of a process* P_j*, is a finite sequence of landmark values* (L_V^k)*, of the form:*

$$BF_{P_j} = \{\forall V \in P_j \mid \quad (L_V^0, L_V^1, \ldots, L_V^n)\} \tag{1}$$

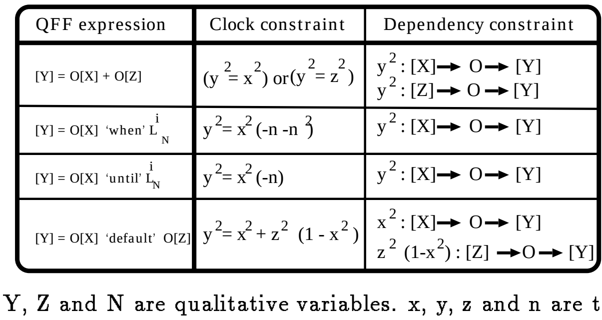
$$BF_{P_j} = \{\forall v \in P_j \mid \quad \biguplus_{k=0}^{n} (L_V^k)\} \tag{2}$$

L_V^k *is the kth landmark value of the qualitative variable V; and* $\biguplus$ *is a symbol for abbreviating (1) to (2).*

BFs are derived by qualitative simulation in two steps: (a) Dependency constraint satisfaction on the arcs of the processes. (b) Landmark value identification of the qualitative variables. First, the simulator looks for the antecedents of the conditional arcs that can satisfy the given situation. Through clock and dependency analysis one can verify which of the arcs of the processes are activated and can take part in simulation. Then processes whose enabling conditions of their arcs are not yet satisfied are deleted and a conventional simulation program derives landmark values for each variable of the remaining processes.

The behavior of the system is the record of BFs. A function concept can be expressed in terms of: *Operationality* [19], i.e. activated processes and their enabling conditions, and *repetition cycle* denoting a persistence or an order in the trace of the BFs. The repetition cycle or persistence is derived for each of the variables. Note that different cycles can possibly be detected and each cycle may represent a functional concept from a different viewpoint. Figure 4 shows an overview of QFF.

Some other works, such as aggregation theory, show more interest in *eventuality* of a certain process [32]. We are interested in finding the eventual outcome for a number of cooperating and competing processes. The constraints on the way processes can cooperate or compete has a strong influence on the final outcome.



QFF expression	Clock constraint	Dependency constraint
$[Y] = O[X] + O[Z]$	$(y^2 = x^2)$ or $(y^2 = z^2)$	$y^2 : [X] \rightarrow O \rightarrow [Y]$ $y^2 : [Z] \rightarrow O \rightarrow [Y]$
$[Y] = O[X]$ 'when' L_N^i	$y^2 = x^2 (-n - n^2)$	$y^2 : [X] \rightarrow O \rightarrow [Y]$
$[Y] = O[X]$ 'until' L_N^i	$y^2 = x^2 (-n)$	$y^2 : [X] \rightarrow O \rightarrow [Y]$
$[Y] = O[X]$ 'default' $O[Z]$	$y^2 = x^2 + z^2 \; (1 - x^2)$	$x^2 : [X] \rightarrow O \rightarrow [Y]$ $z^2 \, (1 - x^2) : [Z] \rightarrow O \rightarrow [Y]$

X, Y, Z and N are qualitative variables. x, y, z and n are their mod-3 values $(-1, 0, +1)$, respectively. L_N^i is the ith landmark value of the variable N.

Table 1: Clock and dependency constraints

4 EXAMPLES

Qualitative simulation and QFF can be used to learn function of objects, i.e. identifying function and explaining why a component is exploited in the designed object. These are explained through an example of a pressure tank system shown in Figure 4. In this system, there is a uniform supply of material to T_2 through CV_6. The pressure in T_2 is controlled by the settings of CV_4 and CV_5. The overall amount of the two phase material (material A and B) in T_2 is controlled by CV_1 and CV_2. The pressure in T_1 is controlled by CV_4. The level of material in T_1 is controlled by CV_1 and CV_3.

a. Identification of functions

In function identification each component pair of the system is modeled and the function of each pair as well as the function of the whole system is derived from their model. Let's consider a portion of the pressure tank system, composed of two valves CV_1 and CV_3 and the tank T_1. There are three object pairs: $(CV_1, T1)$, (CV_3, T_1) and (CV_1, CV_3). The relation between (CV_1, T_1) as well as (CV_3, T_1) is constrained by rules of flow and conservation,

$$
\begin{array}{lcllc}
[F_1] = [G_1] & = & M^+[\Omega_{CV_1}] & 'when' & (\Omega_{CV_1} > 0) \\
[F_{in/T_1}] & = & M^+[G_1] & 'when' & (\Omega_{CV_1} > 0) \\
[U_2] = [K_2] & = & M^+[\Omega_{CV_3}] & 'when' & (\Omega_{CV_3} > 0) \\
[F_{out/T_1}] & = & M^+[U_2] & 'when' & (\Omega_{CV_3} > 0) \\
[F_{T_1}] & = & M^+[F_{in/T_1}] & + & M^-[F_{out/T_1}] \\
[H_{T_1}] & = & I^+[F_{T_1}] & &
\end{array}
\tag{3}
$$

$[F_1]$, $[G_1]$, $[U_2]$ and $[K_2]$ stand for the flow-in and flow-out for the valves CV_1 and CV_3; $[F_{in/T_1}]$ and $[F_{out/T_1}]$ are material flow-in and flow-out for T_1; $[F_{T_1}]$ is the net flow and $[H_{T_1}]$ is the level of material in T_1; The clock constraints are given below and dependency constraints are shown in Figure 4.

$$
\begin{array}{lcl}
f_1^2 = g_1^2 & = & \omega_{CV_1}^2(-\omega_{CV_1} - \omega_{CV_1}^2) \\
u_2^2 = k_2^2 & = & \omega_{CV_3}^2(-\omega_{CV_3} - \omega_{CV_3}^2) \\
f_{in/T_1}^2 & = & g_1^2(-\omega_{CV_1} - \omega_{CV_1}^2) \\
f_{out/T_1}^2 & = & u_2^2(-\omega_{CV_3} - \omega_{CV_3}^2) \\
(f_{T_1}^2 & = & f_{in/T_1}^2) or \\
(f_{T_1}^2 & = & f_{out/T_1}^2) \\
h_{T_1}^2 & = & f_{T_1}^2
\end{array}
$$

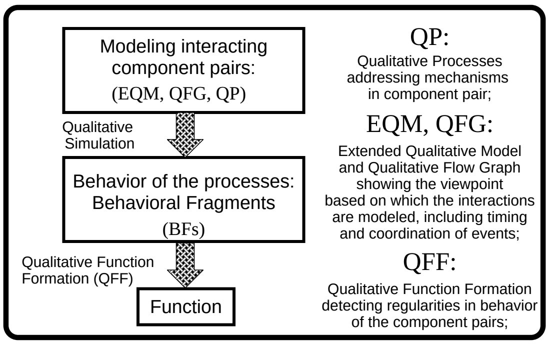


Figure 2: Overview of QFF technique.

The qualitative processes for this system are shown in Figure 4. Behavior of the component pairs can be derived, for a given initial setting. For the pair (CV_1, T_1), assuming that $(\Omega_{CV_1} > 0)$ and $(\Omega_{CV_3} = 0)$, from the clock constraints one can derive that.

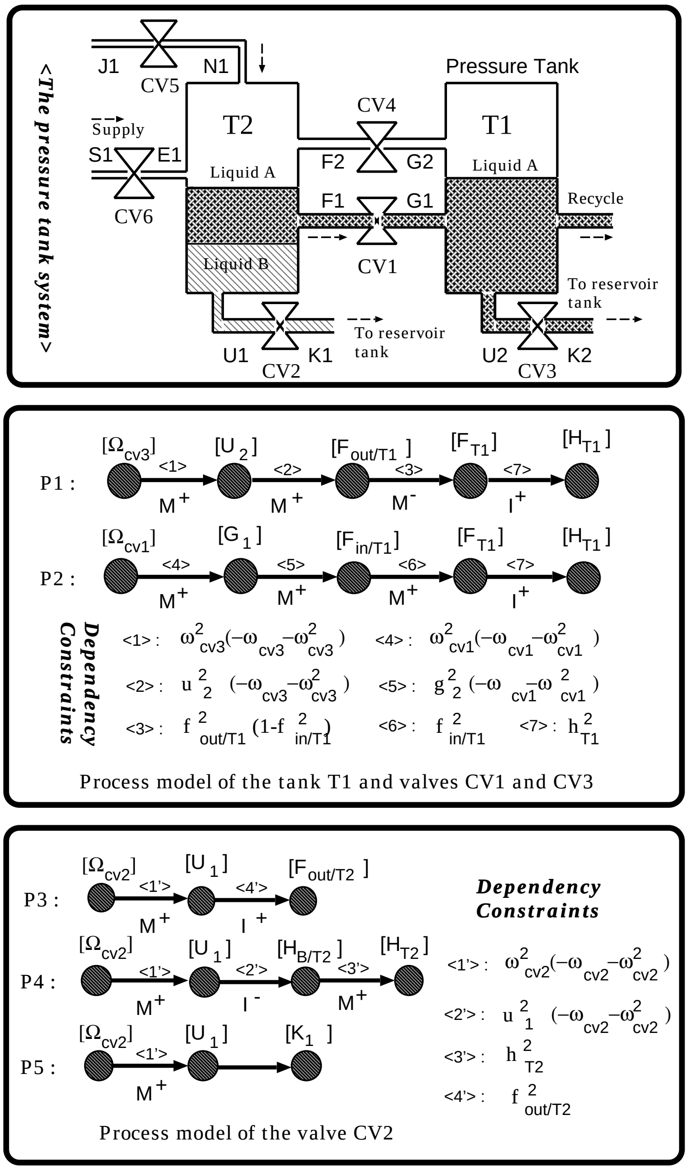


Figure 3: Qualitative process models for the tank system.

$$h_{T_1}^2 = f_{T_1}^2 = f_{in/T_1}^2 = f_1^2 = g_1^2 = 1$$

$$f_{out/T_1}^2 = u_2^2 = k_2^2 = 0$$

The only active process is P_2 with the following BF:

$$
\begin{array}{ll}
BF_{P_2}: & \{\ (\Omega_{CV_1} > 0) \rightarrow (F_{T_1} > 0) \rightarrow \\
& (H_{T_1}^o < H_{T_1} \leq H_{(T_1)max}) \rightarrow (H_{T_1} = H_{(T_1)max})\ \}
\end{array}
$$

This implies that the level of material in the tank will increase up to the maximum allowable level. The function of the pair (CV_1, T_1) can be derived using the cycle detection algorithm. Clearly the persistence in the level of material in the tank is detectable, therefore, the function of this pair is to maintain the level at the $H_{(T_1)max}$, that may be called $FULL$. Note that the term $FULL$ is just a reference term, whose functionally relevant meaning is described by the landmark value $H_{(T_1)max}$ for the pair.

$$FULL: \qquad H_{T_1} = H_{(T_1)max}$$

Similarly for the pair (CV_3, T_1) assuming that $(\Omega_{CV_3} > 0)$ and $(\Omega_{CV_1} = 0)$, one can get to $(h_{T_1}^2 = f_{T_1}^2 = f_{out/T_1}^2 = u_2^2 =$

$k_2^2 = 1$) and ($f_{in/T_1}^2 = f_1^2 = g_1^2 = 0$) for the clock constraints and the active process is P_1 with the BF,

$$\begin{aligned} BF_{P_1}: \quad & \{ \ (\Omega_{CV_3} > 0) \rightarrow (F_{T_1} < 0) \rightarrow \\ & (H_{(T_1)min} \leq H_{T_1} < H_{T_1}^o) \rightarrow (H_{T_1} = H_{(T_1)min}) \ \} \end{aligned}$$

Implying that the level of material in the tank will decreases till the minimum level and the function of this pair is to make the tank $EMPTY$, described by,

$$EMPTY: \quad H_{T_1} = H_{(T_1)min}$$

When two processes can simultaneously cause the state transition to different states, in order to determine which one may happen first, some additional timing constraints must be included in the model. When deriving the function of the overall system with both valves opened, i.e., ($\Omega_{CV_3} > 0$) and ($\Omega_{CV_1} > 0$), it is visible that the variable H_{T_1} can possibly have any value within the whole range of variation ($H_{(T_1)min} \leq H_{T_1} \leq H_{(T_1)max}$) without necessarily sticking to either and the overall function of the system is ambiguous. The reason is that the interactions between some of the component pairs, such as (CV_1, CV_3), is not constrained in the model. Imposing constraints on such pairs, using coordinative expressions may lead to a definite function. Those constraints are mostly considered as design preferences, fulfilling a goal of the designer. A design preference may be considering the system to respond to some possible faults, such as CV_1 clogged. The qualitative model is similar to (3), with an additional default expression:

$$[F_{T_1}] = \quad M^+[F_{in/T_1}] \quad 'default' \quad M^-[F_{out/T_1}]$$

Additional clock and dependency constraints are:

$$f_{T_1}^2 \quad = \quad f_{in/T_1}^2 + f_{out/T_1}^2(1 - f_{in/T_1}^2)$$

$$\begin{array}{lcllcl} f_{in/T_1}^2 & : & [F_{in/T_1}] & \rightarrow M^+ \rightarrow & [F_{T_1}] \\ f_{out/T_1}^2(1 - f_{in/T_1}^2) & : & [F_{out/T_1}] & \rightarrow M^- \rightarrow & [F_{T_1}] \end{array}$$

Let's consider the case that CV_1 is opened ($\Omega_{CV_1} > 0$). In clock constraint terms it means that ($\omega_{CV_1} = 1$). Using clock constraints, one can derive that ($f_{in/T_1}^2 = 1$) and ($h_{T_1}^2 = f_{in/T_1}^2$). Active arcs of the QDM due to dependency constraints are those of P_2 and simulation generates the BF_{P_2}. It follows that the function of the whole system is to make the tank FULL, finally.

If $[F_{in/T_1}]$ is not present (due to a fault making CV_1 clogged), then ($f_{in/T_1} = 0$) and ($h_{T_1}^2 = f_{out/T_1}^2$). On QDM, the arc ($[F_{in/T_1}] \rightarrow M^+ \rightarrow [F_{T_1}]$) is not active any more, but ($[F_{out/T_1}] \rightarrow M^- \rightarrow [F_{T_1}]$) becomes active, instead. Now the process P_1 is responsible for the behavior and simulation generates the BF_{P_1}. Similar argument shows that the system functions as making the tank become EMPTY.

b. Explanation of functions

The reason for a component being selected to be a part of the designed system is explained in terms of its contribution to the functionality of the system. In explanation, the effects of individual components on the system should be identified. Qualitative processes and BFs are found useful. The simulated behavior of the processes exhibits the way the components contribute to the functionality of the system.

Let's consider the system of Figure 4 and explain the why a given control valve, such as CV_2, is exploited in this design. The model embodying the valve CV_2 is:

$$\begin{array}{lcllll} [U_1] & = & M^+[\Omega_{CV_2}] & 'when' & (\Omega_{CV_2} > 0) \\ [F_{out/T_2}] & = & I^-[U_1] & + & I^+[F_1] \\ [H_{B/T_2}] & = & I^-[U_1] & 'when' & (\Omega_{CV_2} > 0) \\ [H_{T_2}] & = & M^+[H_{B/T_2}] \\ [K_1] & = & [U_1] \end{array}$$

$[U_1]$ and $[K_1]$ stand for the flow–in and flow–out for the valves CV_2; $[H_{T_2}]$ is the level of material in T_2; and $[H_{B/T_2}]$ is the level of B material in T_2; The clock constraints are:

$$\begin{array}{lcl} u_1^2 & = & \omega_{CV_2}^2(-\omega_{CV_2} - \omega_{CV}^2) \\ (f_{out/T_2}^2 & = & u_1^2) or \\ (f_{T_1}^2 & = & f_1^2) \\ h_{B/T_2}^2 & = & u_1^2(-\omega_{CV_2} - \omega_{CV_2}^2) \\ h_{T_2}^2 & = & h_{B/T_2}^2 \\ u_1^2 & = & k_1^2 \end{array}$$

CV_2 appears in three processes P_3, P_4 and P_5 and the dependency constraints in this case are given in Figure 4. Their behaviors are:

$$\begin{aligned} BF_{P_3} = \quad & \{ \ (\Omega_{CV_2} > 0) \rightarrow (U_1 > 0) \rightarrow \\ & (0 < F_{out/T_2} \leq F_{(out/T_2)max}) \rightarrow \\ & (F_{out/T_2} = F_{(out/T_2)max}) \ \} \\ BF_{P_4} = \quad & \{ \ (\Omega_{CV_2} > 0) \rightarrow (U_1 > 0) \rightarrow \\ & (H_{(T_2)min} \leq H_{T_2} < H_{T_2}^o) \rightarrow \\ & (H_{(T_2)min} = H_{T_2}) \ \} \\ BF_{P_5} = \quad & \{ \ (\Omega_{CV_2} > 0) \rightarrow (U_1 > 0) \rightarrow (K_1 > 0) \ \} \end{aligned}$$

$[U_1]$ and $[K_1]$ are the flow–in and flow–out for CV_2 whose state variable is $[\Omega_{CV_2}]$; $[H_{T_2}]$ is the overall level of material in T_2; and $[F_{out/T_2}]$ is the flow of material from T_2 and T_1; When CV_2 is opened, BF_{P_3} indicates that the flow of material out of $T_2(F_{out/T_2})$ can increase and BF_{P_4} indicates that level of material in T_2 decreases. BF_{P_5} indicates that it helps material transfer to the reservoir tank. In qualitative terms, the effects of CV_2 in the system are:

$$\begin{aligned} CV_2: \quad & (F_{out/T_2} = F_{(out/T_2)max}) \wedge \\ & (H_{(T_2)min} = H_{T_2}) \wedge (K_1 > 0) \end{aligned}$$

The reason for exploiting CV_2 can be explained in terms of these three landmark values. An explanation may include either one or all of them: *CV_2 can ease the flow of material out of T_2, reduce the level of material in this tank and transfer material to the reservoir tank.*

5 CONCLUSION

A method for categorizing and learning function of objects from a description of their structure and behavior using Qualitative Function Formation (QFF) technique is proposed that can derive function concepts similar to cognitive learning behavior of humans. Some original contributions of this work are:

- Identification of the role of qualitative modeling and reasoning in cognitive learning of function of objects and categorization of functional concepts.

- Extending the common qualitative models to include interactions and timing of events by defining temporal and dependency constraints, and binding it with the conventional qualitative simulation.
- Defining function concepts as interpretations of either a persistence or an order in the sequence of states, using behavioral fragments derived by qualitative simulation on the extended qualitative model.
- Providing solution to some of the functional reasoning problems.

Extending the method to account for the associative learning of functions, operationalization and clustering of function concepts [19], learning function by analogy and induction are other problems to be tackled. Application of QFF in functional design [10] and fault diagnosis [11] is currently under investigation [10].

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