

Functional Reasoning, Explanation and Analysis: A Collective View and A Proposal

Behrouz HOMAYOUN FAR

**Department of Information and Computer Sciences
Saitama University, Japan**

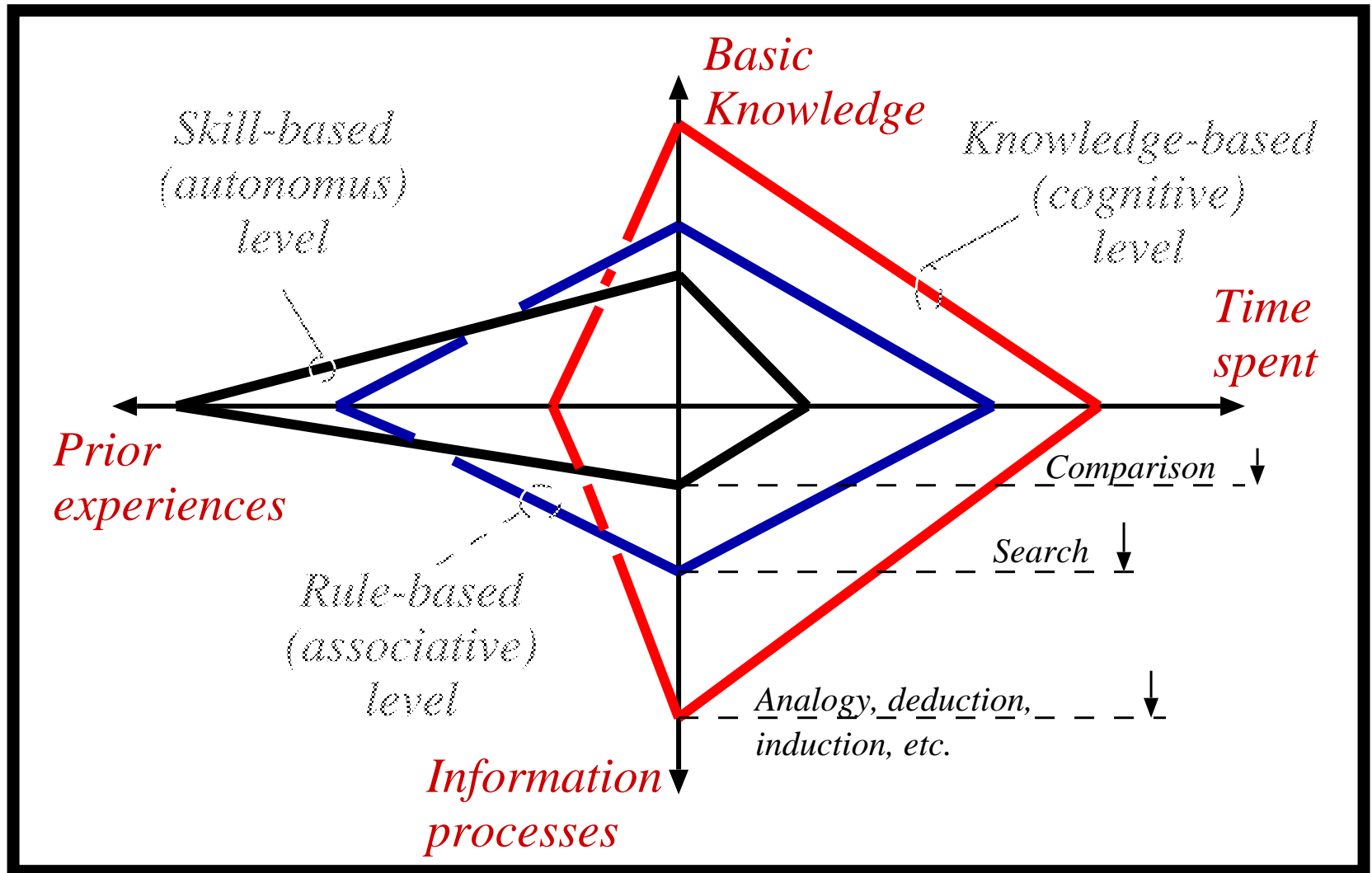
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- 2. Functional reasoning research**
- 3. Qualitative Function Formation (QFF)**
- 4. Functional design using QFF**
- 5. Implementation perspective**
- 6. Discussion & Conclusion**

Chapter 1 :

Introduction

Three levels of human cognitive processes



Factors affecting "cognitive overload" of human designer :

1. Information accessibility

Information for decision making inferred along causal chains;

2. Control directness

Initiating actions whose effects propagate on causal chains to a target variable

3. Counter-intuition

Anticipating system behavior limited by:

- Nonlinearities in device model;*
- Neglecting influence of overlapping procedures;*
- Unanticipated timing and coordination of events;*

Definition:

Function & Functional reasoning

1. Function

- Function is usually mentioned together with "behavior" , "goal" or "purpose".
- Making effort to obtain a certain "result" or "good".
- Tied with intention of humans (in design).

"Function is a relation between the goal of a human user and the behavior of a system. In an assembly, the function of a component relates the behavior of that component to the function of the assembly. "

[BOBROW 84]

2. Functional reasoning:

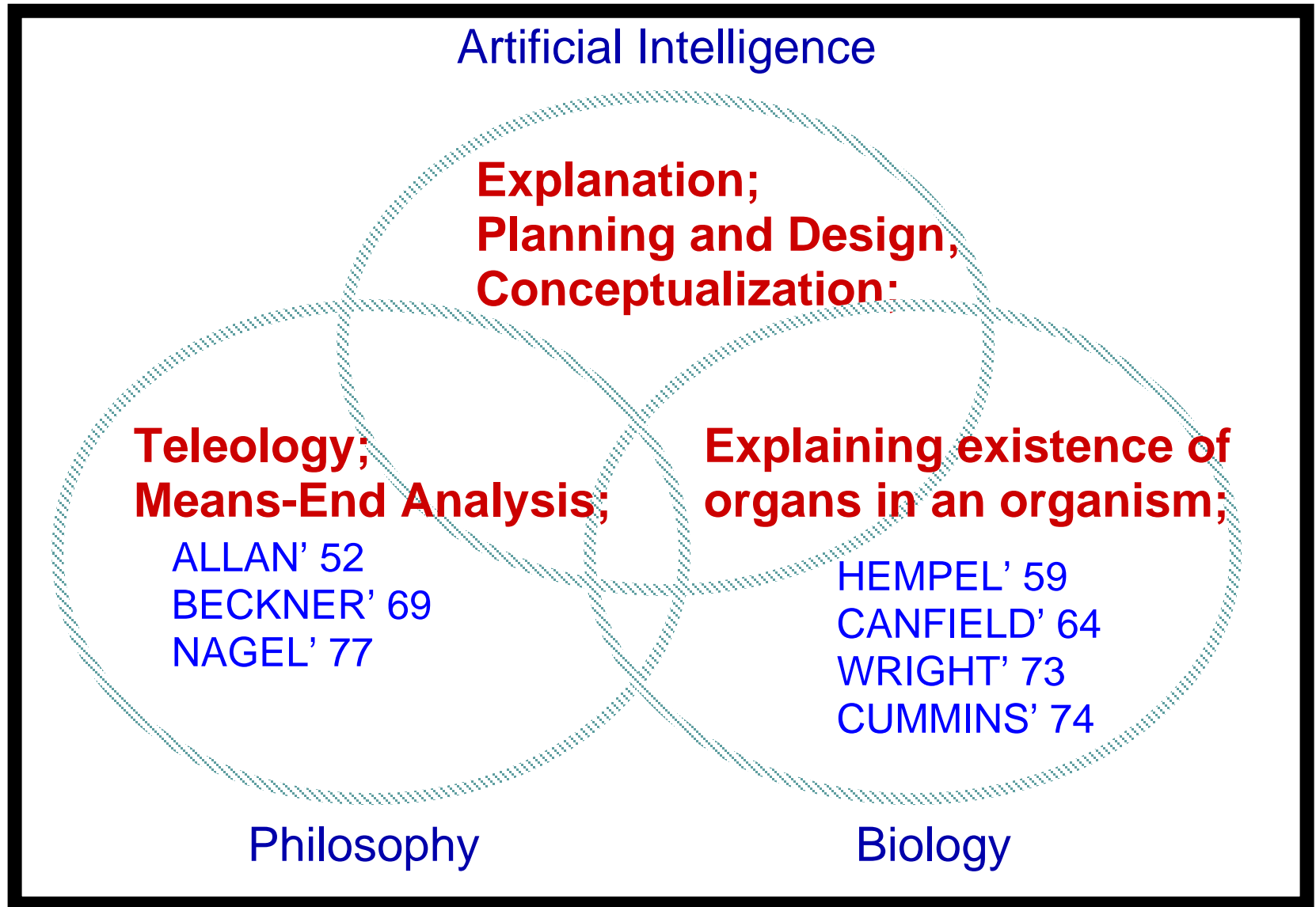
Functional reasoning enables people to reason about :

- Presence and function of objects in a containing system;
- Derive the purpose of the system;
- Explain how it can be achieved;

Chapter 2 :

Functional reasoning research

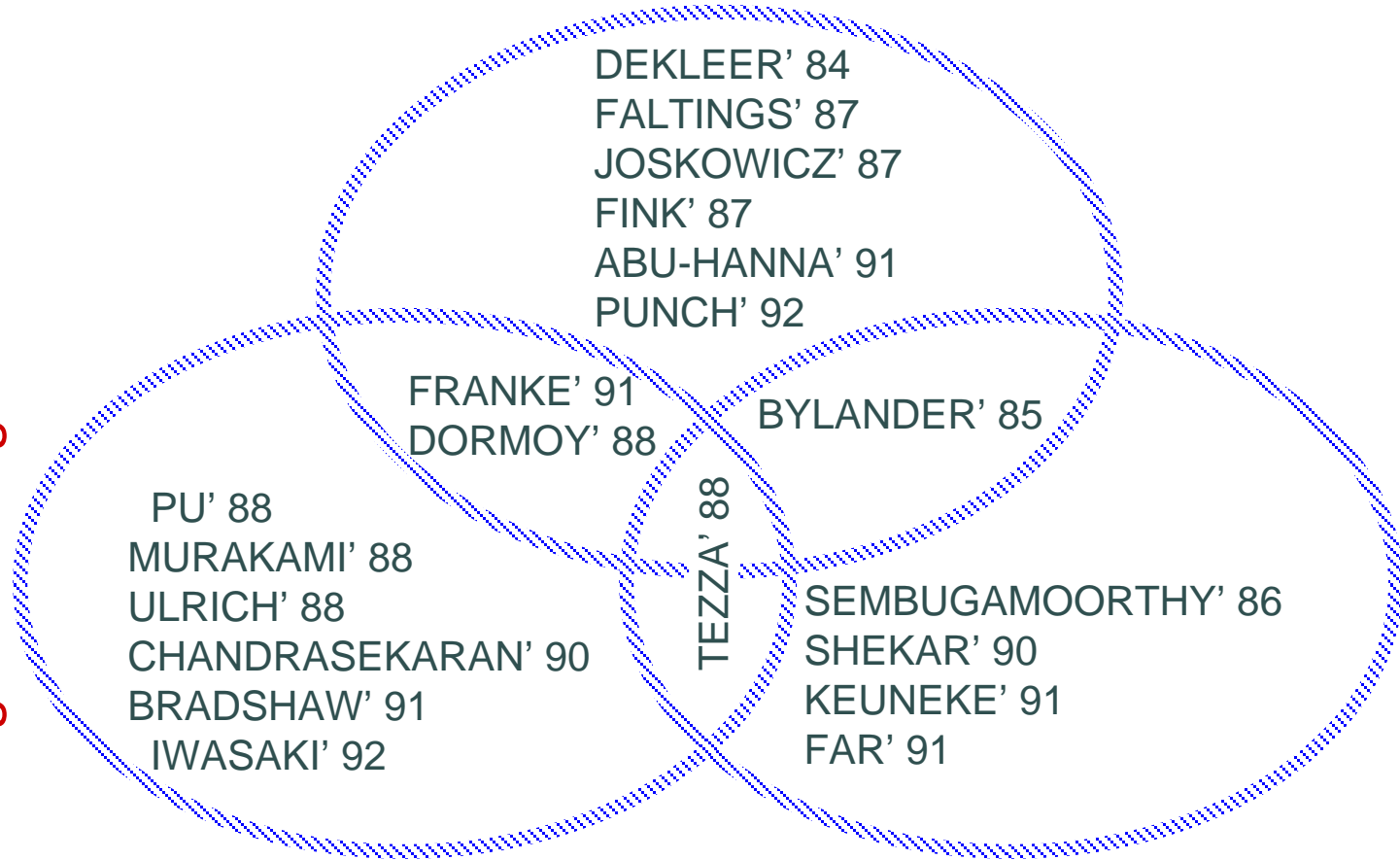
Functional Reasoning Research-1



Functional Reasoning Research-2

Explanation Based Methods

Planning and Design Methods



Conceptualization Methods

Functional Reasoning Problems

1. Identification Problem :

Explaining function of a device using knowledge of structure and behavior of components;

2. Explanation Problem :

Explaining presence of a component in a system in terms of its contribution to function of the system;

3. Selection Problem :

Selecting a set of components that if used together can achieve a desired function;

4. Verification problem :

Verifying whether an object can exhibit a given function in a given situation;

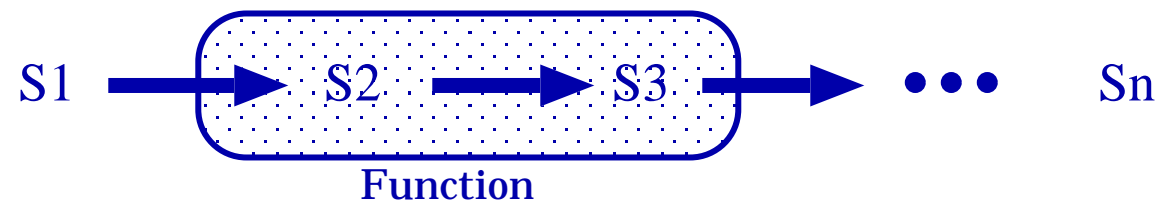
Functional Reasoning Assumptions-1

1. Functionality in State Transition

- A physical phenomena can be explained in terms of 'histories' and 'states' [HAYES 79];
- History that leads to a function displays certain patterns [BIGELOW87];
- A state representation addresses a certain characteristic of its referred object [MATTEN 88];

Therefore :

Function concepts are defined with reference to discovering an order in the state sequence



Functional Reasoning Assumptions-2

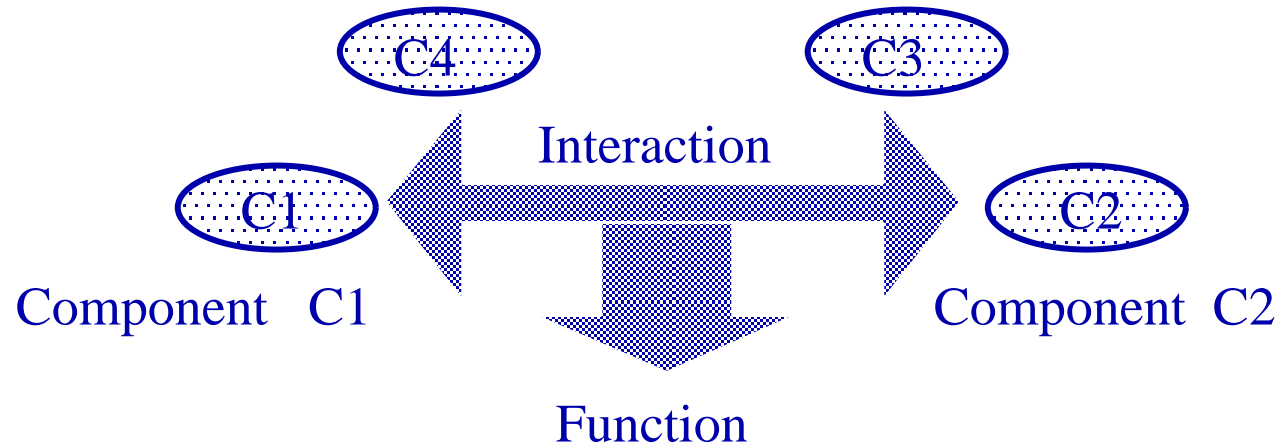
2. Functionality in Component Pair

Defining function concepts in terms of interaction between pairs of components;

Locality of Histories [HAYES 79];

Connectivity Hypothesis [FORBUS 87];

Paiwise Interaction of Parts [FALTINGS 87];



Chapter 3 :

Qualitative Function Formation (QFF) Technique

Qualitative Modeling Concepts

- 1. Qualitative Model**
- 2. Qualitative Flow Graph (QFG)**
- 3. Qualitative Process (QP)**
- 4. Behavioral Fragment (BF)**

Qualitative Function Formation: Qualitative Modeling

The conventional qualitative model is extended to include physical and protocol based interactions.

Qualitative Model (QM) :

$$[Y] = O[X] \text{ 'D' } L_N^i$$

$$[Y] = O[X] \text{ 'D' } O[Z]$$

$$O = \{M^+ , M^- , I^+ , I^- \}$$

$$D = \{ \text{'when' , 'until' , 'default' , 'set' , 'reset' } \}$$

Qualitative Process (QP):

String of connected arcs of the graph representation of QM.

Behavioral Fragment (BF):

Characteristic behavior of the qualitative processes.

Derived by:

- a. Dependency constraint satisfaction;
- b. Landmark value identification;

Repetition Cycle:

Repetitive behavior of the qualitative variables.

Clock and Dependency Constraints

For each qualitative operation "clock" and "dependency" constraints are defined and evaluated to a mod-3 integer.

1. Present ($\neq 1$): Two events occur concurrently;
2. Absent (0) : Two events do not occur concurrently;
3. True (+1): An event has occurred;
4. False (-1): An event has not yet occurred;

QFF expression	Clock constraint	Dependency constraint
$[Y] = O[X] + O[Z]$	$(y^2 = x^2) \text{ or } (y^2 = z^2)$	$y^2 : [X] \rightarrow O \rightarrow [Y]$ $y^2 : [Z] \rightarrow O \rightarrow [Y]$
$[Y] = O[X]$ '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' $O[Z]$	$y^2 = x^2 + z^2 (1 - x^2)$	$x^2 : [X] \rightarrow O \rightarrow [Y]$ $z^2 (1-x^2) : [Z] \rightarrow O \rightarrow [Y]$
$[Y] = O[X]$ 'set' L_N^i	$y^2 = x^2 (-n -n^2)$	$y^2 : [X] \rightarrow O \rightarrow [Y]$
$[Y] = O[X]$ 'reset' L_N^i	$y^2 = x^2 (-n)$	$y^2 : [X] \rightarrow O \rightarrow [Y]$

Qualitative Flow Graph (QFG)

QFG is a digraph represented by 4 sets:

$$\text{QFG} = \{ V, A, O, C \}$$

V : nodes (qualitative variables)

A : arcs (qualitative relations)

$$A : C \dashrightarrow O$$

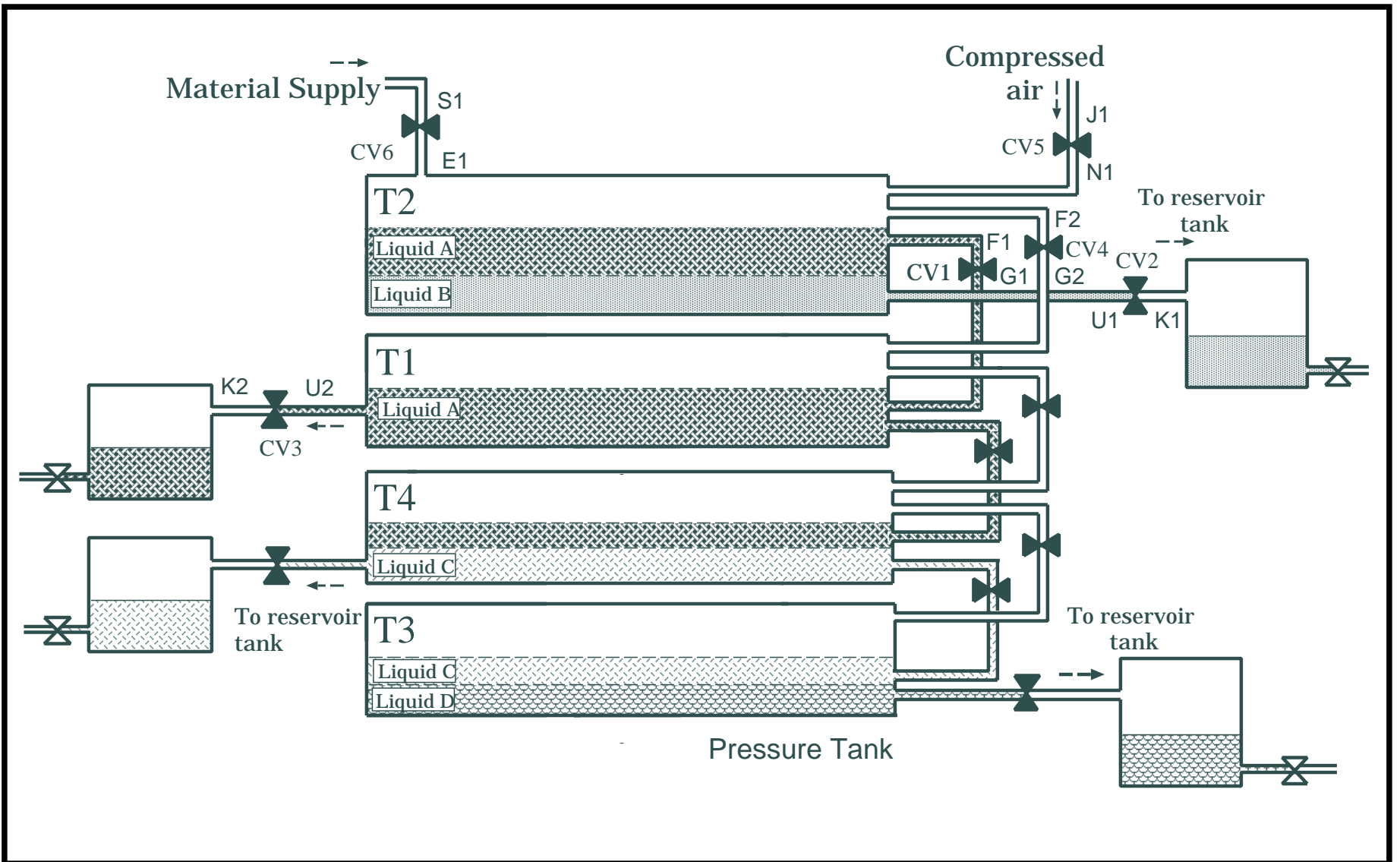
O : ordinary qualitative relations

$$O = \{ M+, M-, I+, I- \}$$

C : dependency constraints for
coordinative qualitative relations

For each A when C is evaluated to either (+1) or (-1) then O is enabled.

EXAMPLE : Pressure Tank System



Qualitative Process (QP)

A qualitative process (QP) is a unidirectional finite sequence of

- Nodes (qualitative variables) of QFG

connected by

- Conditional arcs (qualitative relations)

Qualitative Behavioral Fragment (BF) -1

1. "Behavioral Fragment" is the record of landmark values for qualitative variables of a qualitative process.
2. BF is derived by "Qualitative Simulation" in two steps :
 - a. Dependency constraint satisfaction for the arcs of qualitative process.*
 - b. Landmark value identification of qualitative variables.*

Qualitative Behavioral Fragment (BF) -2

1. The simulator looks for the antecedents of conditional arcs of a qualitative process.
2. Only active qualitative processes can take part in simulation.
3. By clock and dependency analysis the active processes are identified.
4. A conventional qualitative simulation program derives landmark value for the qualitative variables of active processes.

Qualitative Function Concept

1. A "Function" is derived if a repetition cycle or persistence in the sequence of states is detected on "Behavioral Fragment".
2. Function has two attributes:
 - a. Operationality*
 - b. Repetition cycle*

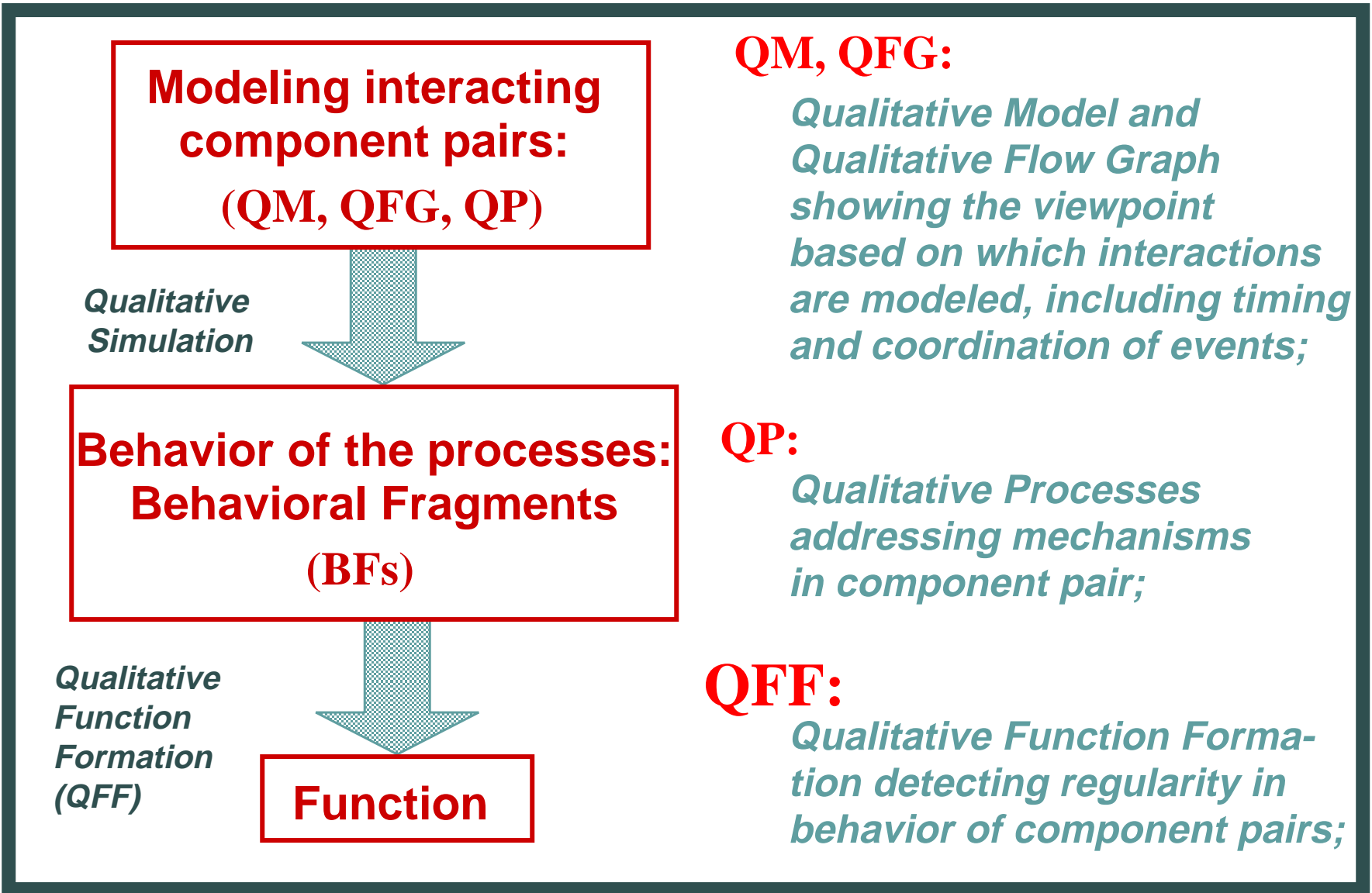
Operationality

Operationality is the sum of enabling conditions for the arcs of qualitative processes whose "Behavioral Fragments" lead to a "Function".

Repetition Cycle in Qualitative Behavior

1. Repetition cycle is defined for the variables of qualitative state vector.
2. Qualitative state vector for a component pair is composed of "Landmark values" of the "Behavioral Fragments" for qualitative variables of active processes.
3. Different repetition cycles can be detected each representing a "function" from a different viewpoint.

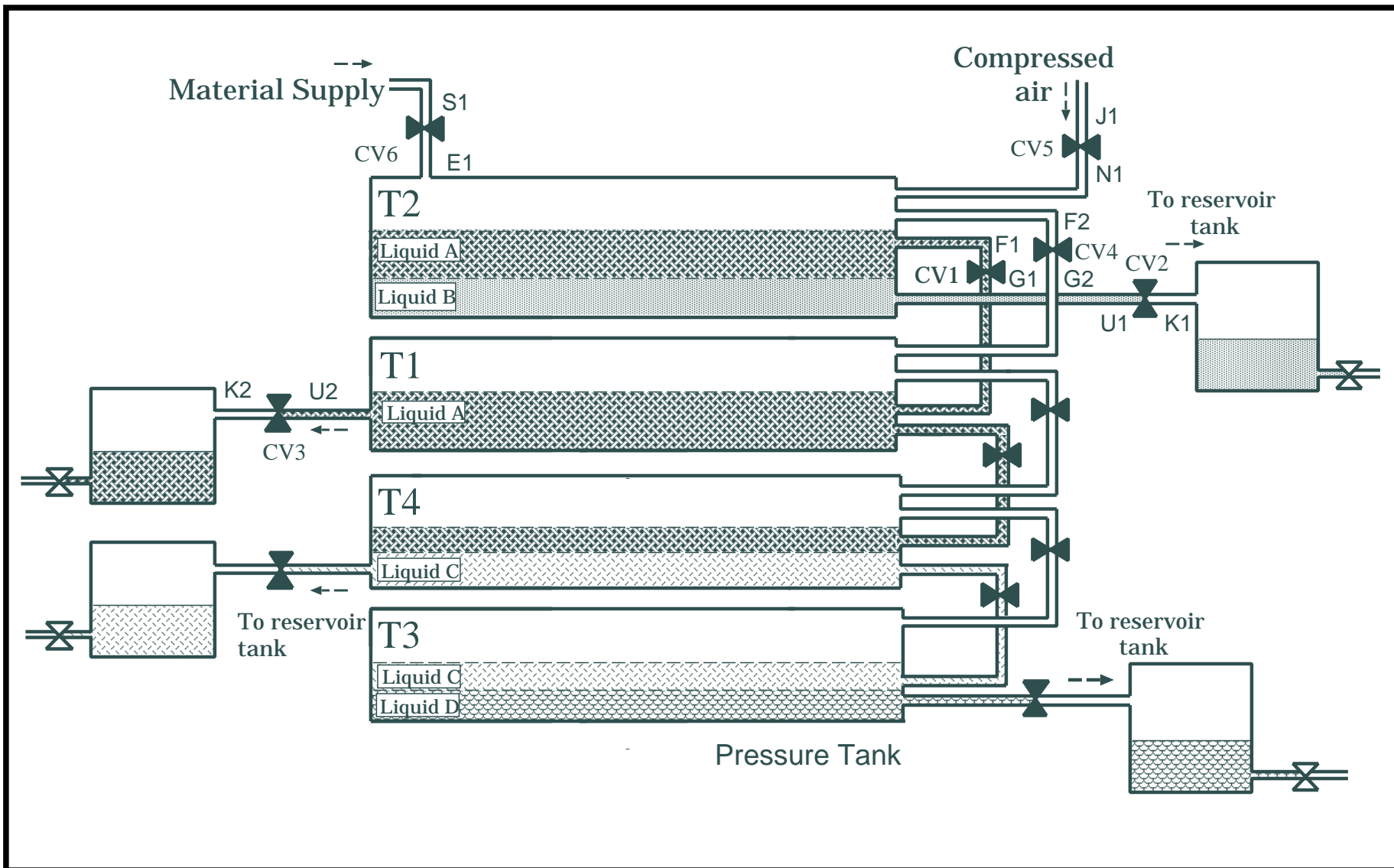
Qualitative Function Formation Technique



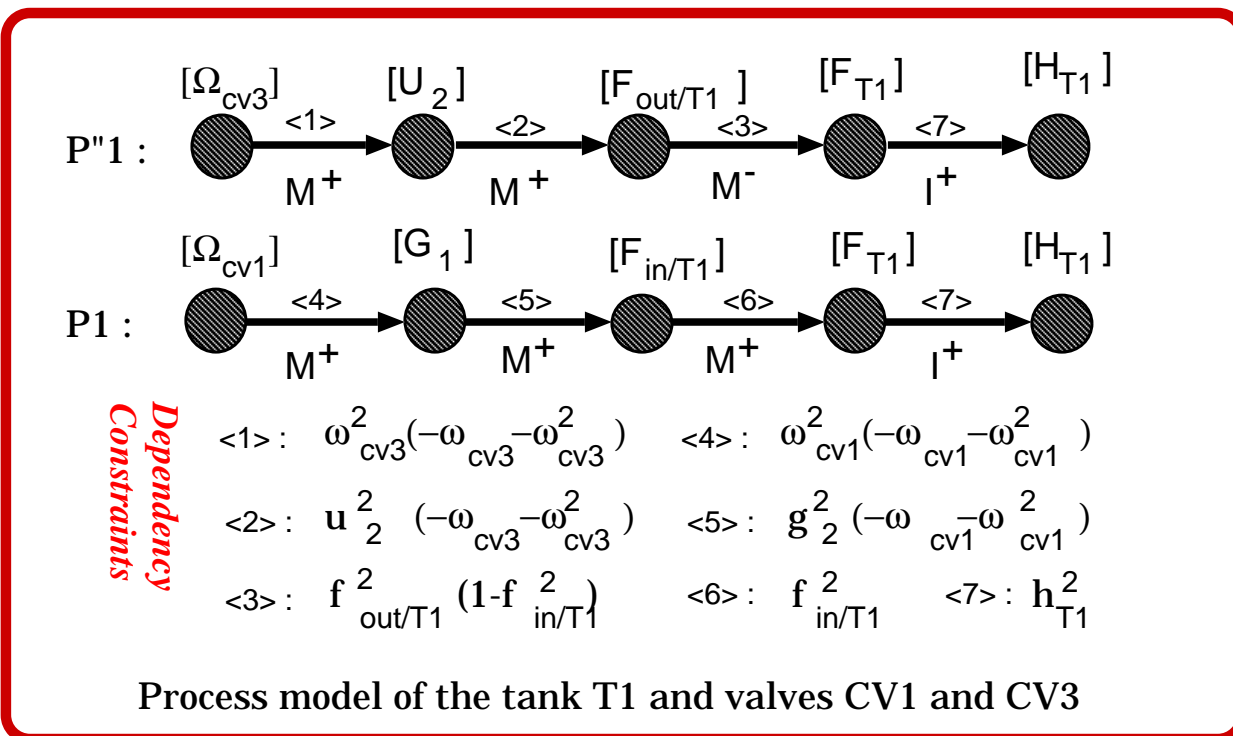
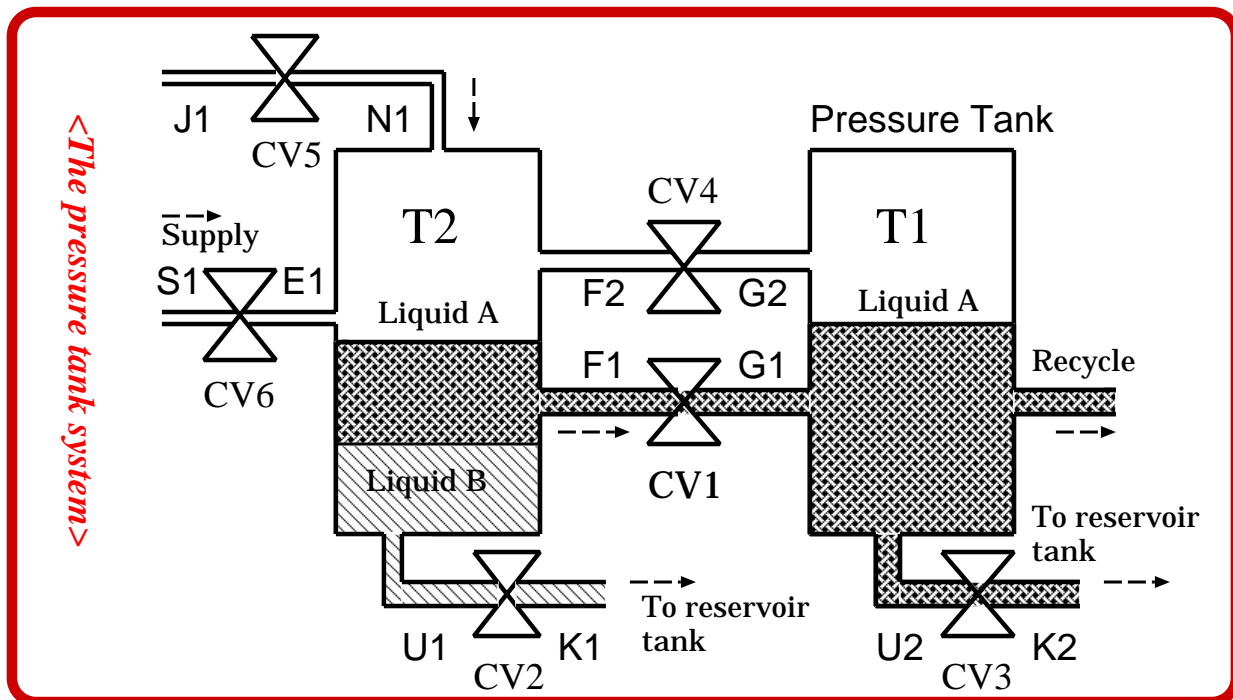
Chapter 4 :

Functional Design Using QFF

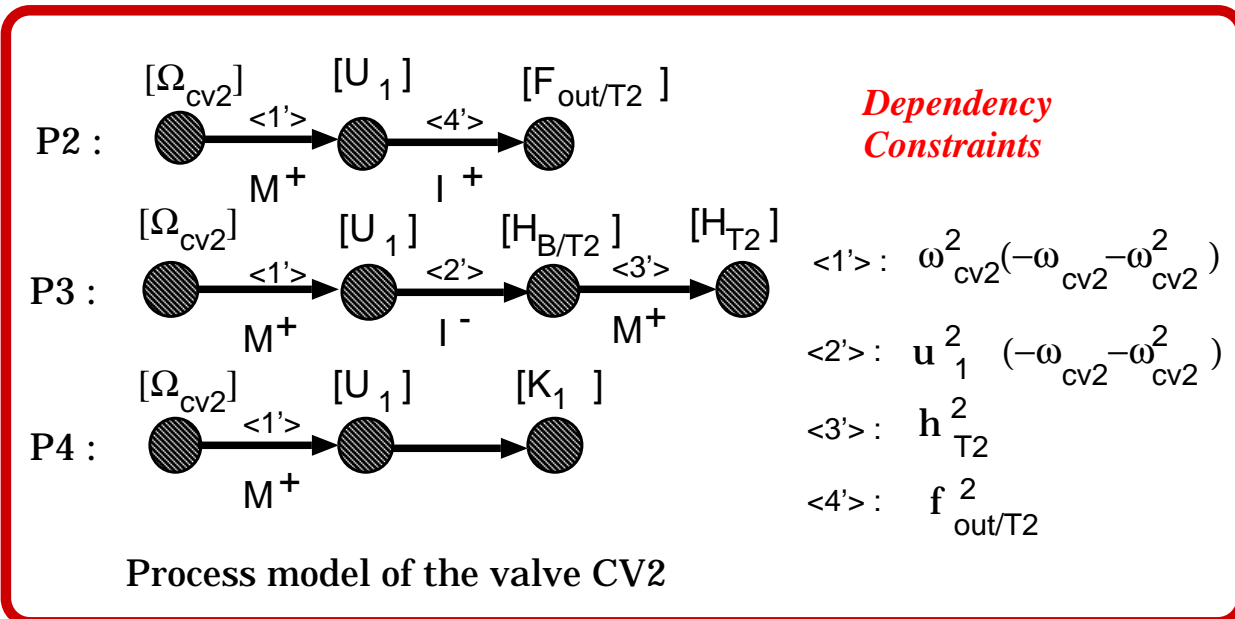
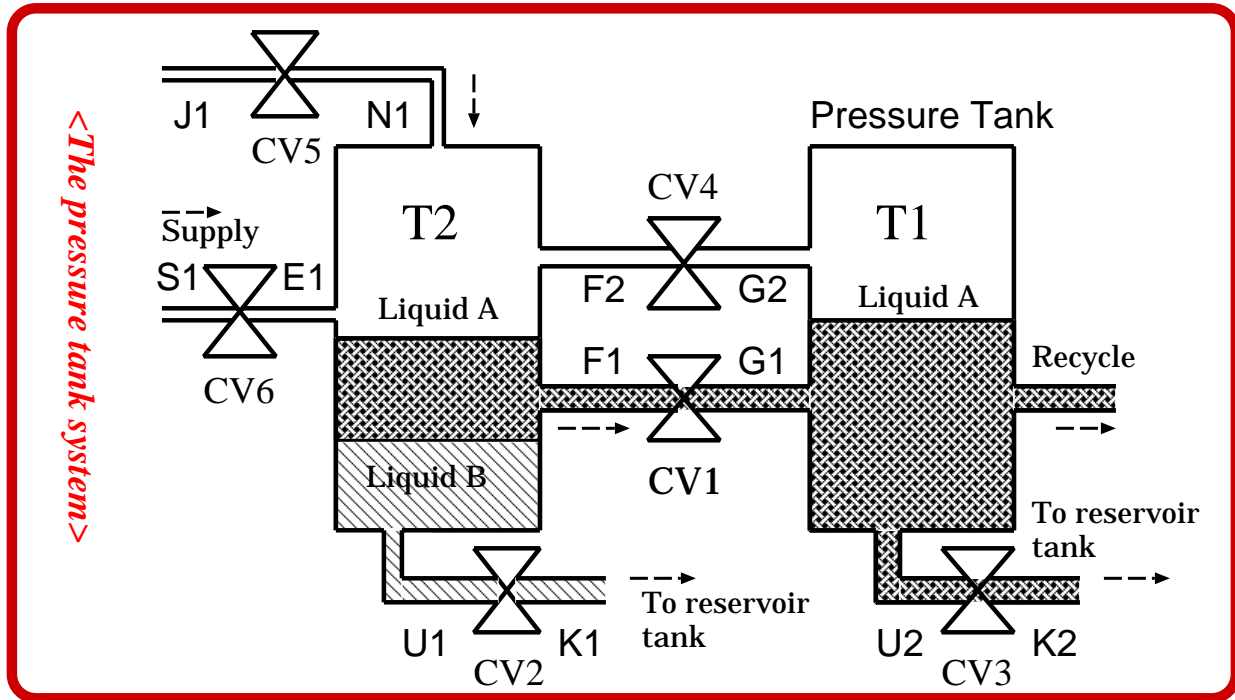
EXAMPLE : Pressure Tank System

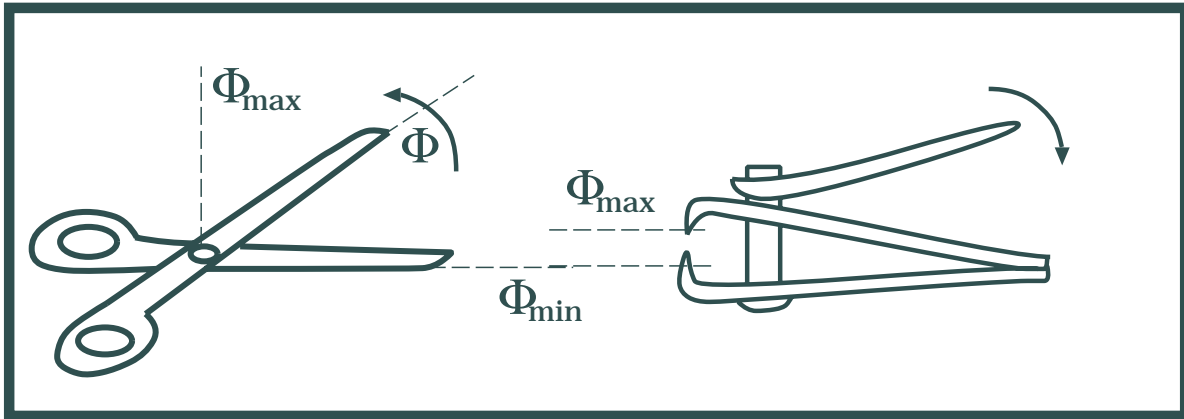


EXAMPLE : Identification of Functions

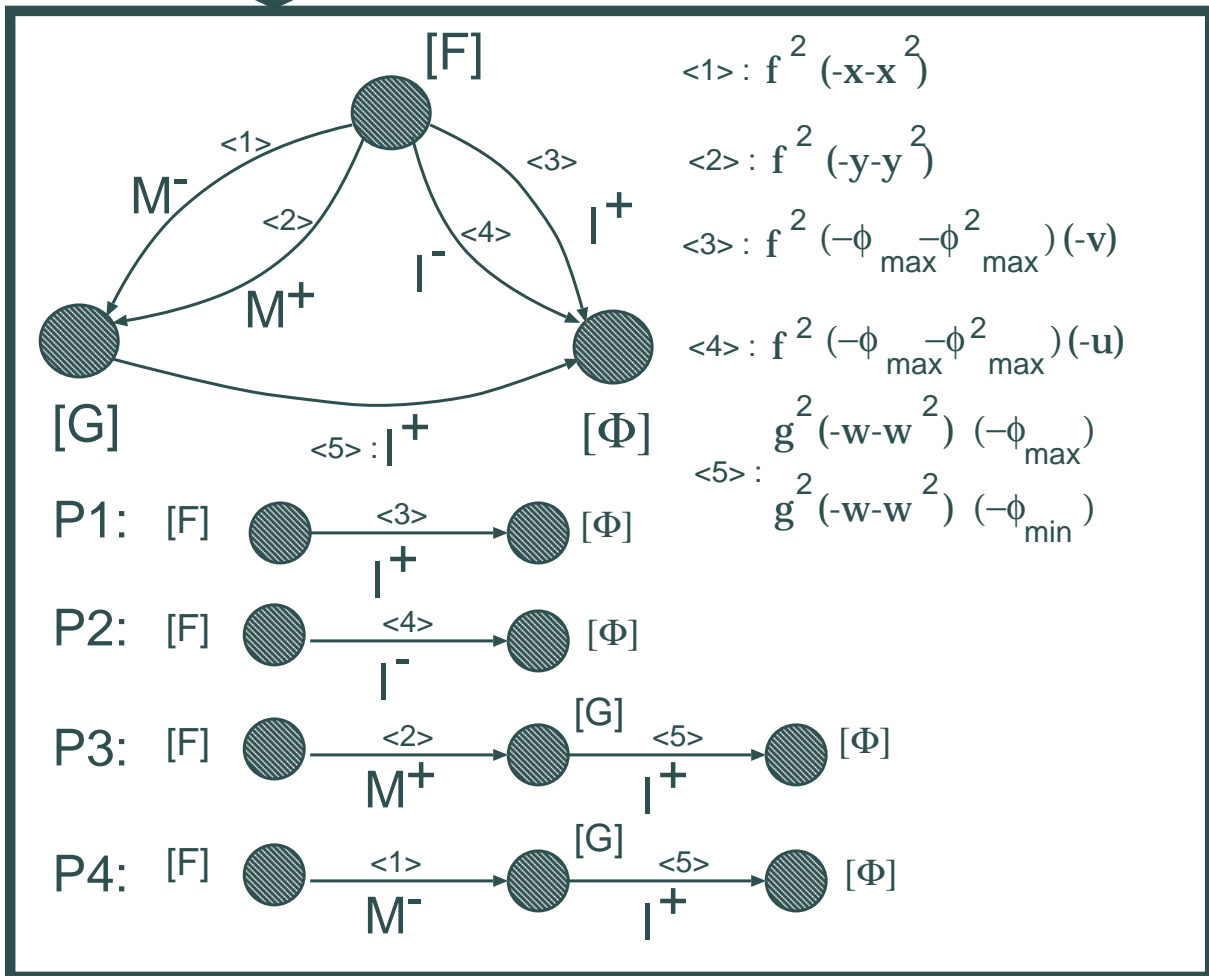


EXAMPLE : Functional Explanation





<Qualitative Model of the devices>



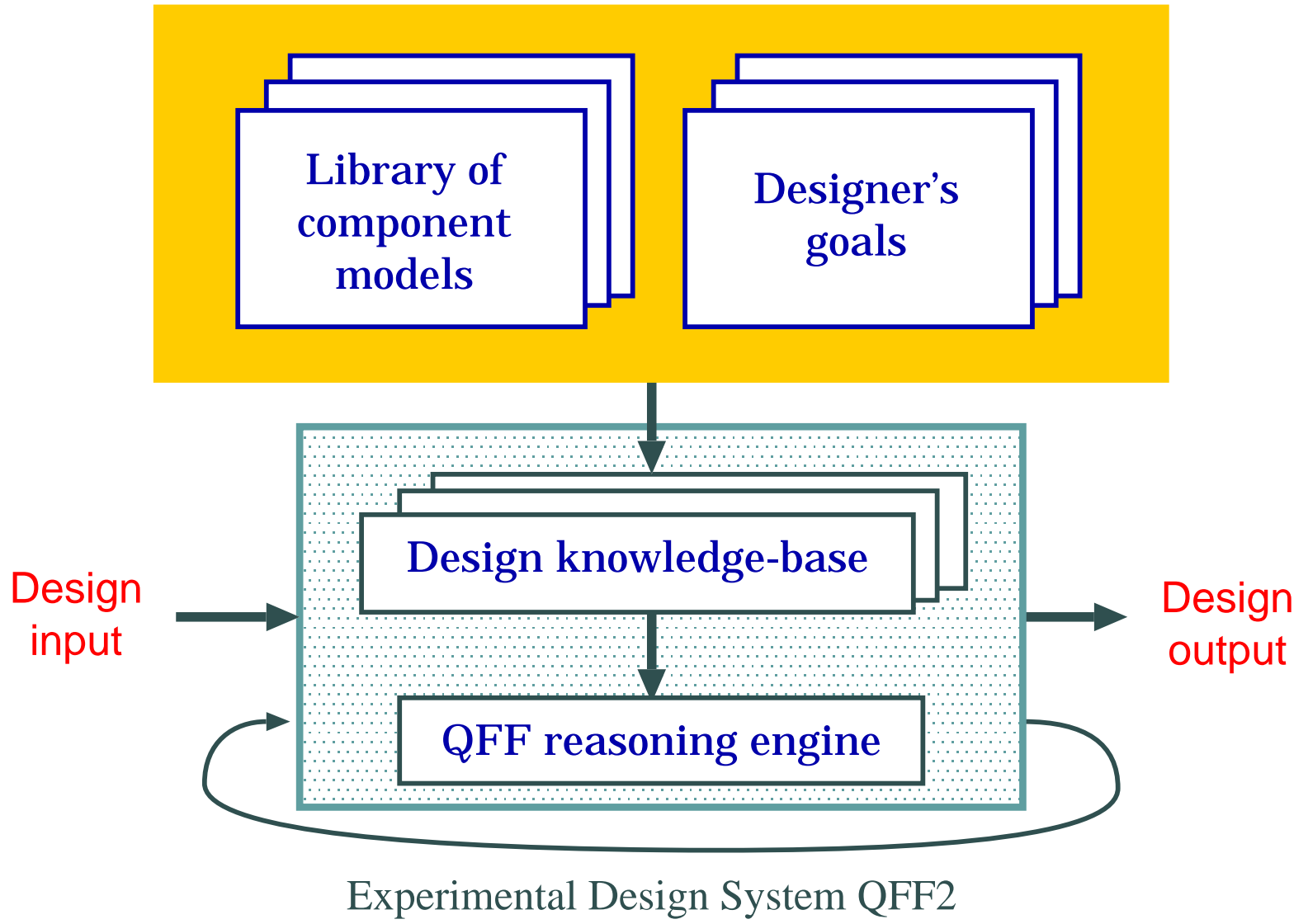
Chapter 5 :

Implementation perspective

Implementation

- 1. Qualitative Function Formation tool**
- 2. Experimental design system QFF2**

Overview of the system



Experimental QFF2

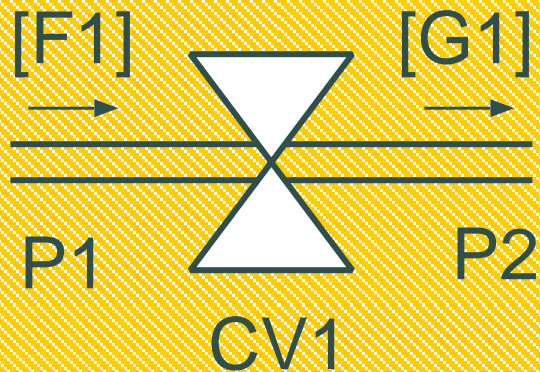
The prototype system contains:

1. Data translator for converting component model to data structure used in the knowledge base;
2. Reasoning (inference) engine + learning module;
3. Qualitative simulator;
4. Window-based user interface;

The knowledge base contains:

1. Frame representation of component model;
2. Frame representation of design goals/functions;
3. Frame representation of component pairs;
4. Frame representation of customized components;

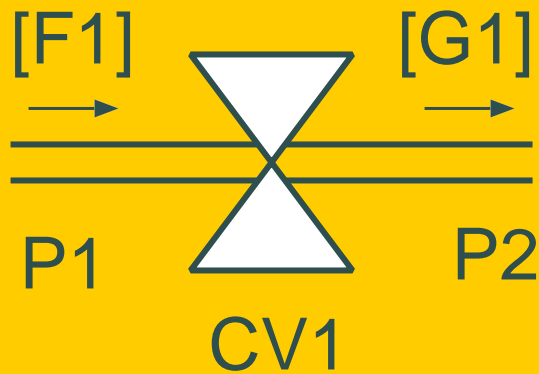
A Simple Component Model



Control Valve
Model

```
11  COMPONENT CV1;  
12      INPUT F1;  
13      CONNECT P1, CV1;  
14      OUTPUT G1;  
15      CONNECT CV1, P2;  
14          STATE S1;                ( $\omega$   $CV1 > 0$ );  
15              CONDITION  
16                  TASK (F1 = G1);  
17          ENDSTATE S1;  
18          NEXTSTATE S2;  
19          STATE S2;                ( $\omega$   $CV1 = 0$ );  
20              CONDITION  
21                  TASK (G1 = 0);  
22          ENDSTATE S2;  
23          STOP;
```

Frame Representation of Component Model



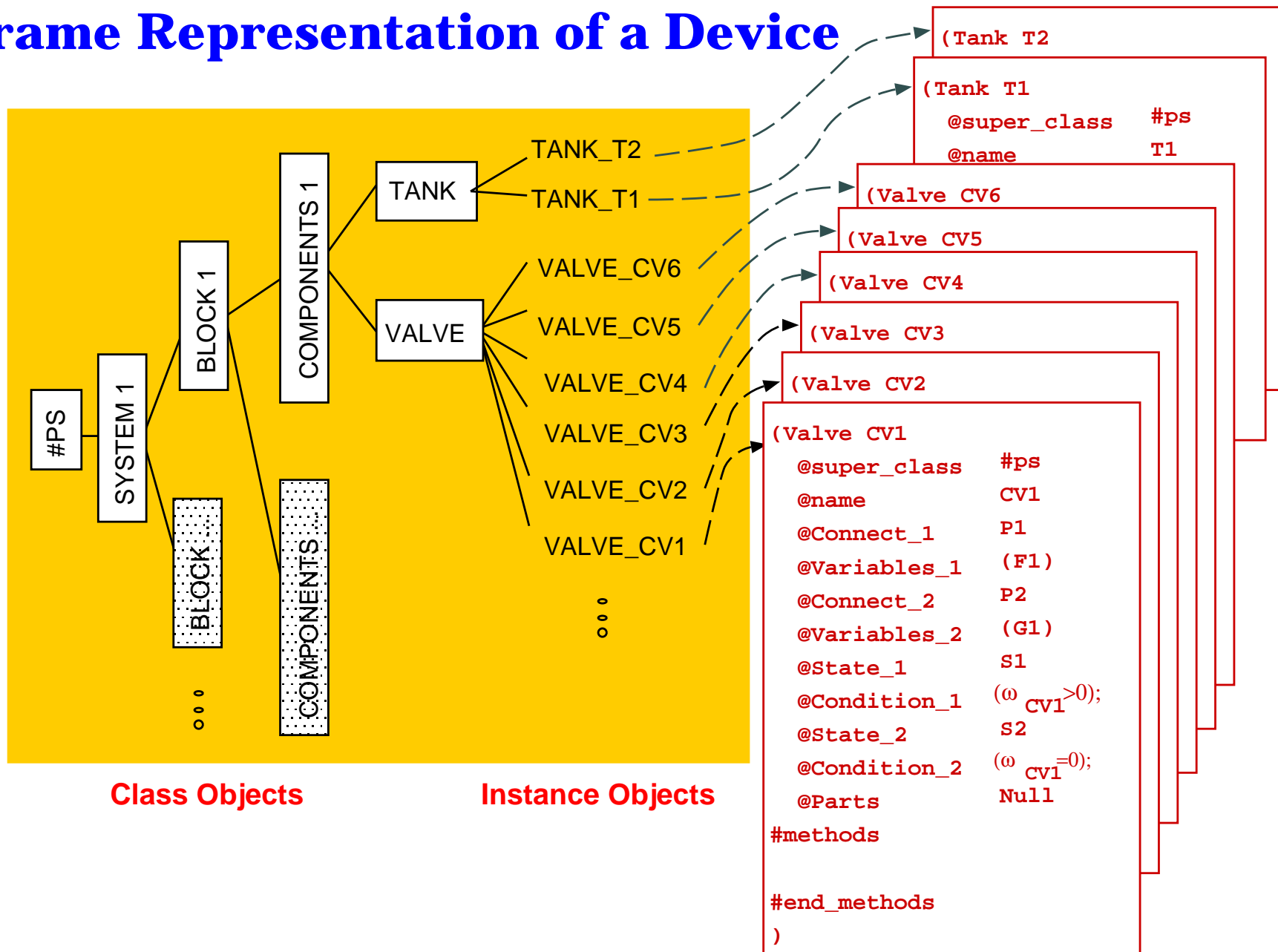
Control Valve
Model

```
(Valve CV1
  @super_class
  @name           #ps
  @Connect_1     CV1
  @Variables_1   P1
  @Connect_2     (F1)
  @Variables_2   P2
  @State_1       (G1)
  @Condition_1   ($1 (ω CV1>0);
  @State_2
  @Condition_2   ($2 (ω CV1=0);
  @Parts
  #methods       Null
  ■
  ■
  ■
  #end_methods
)
```

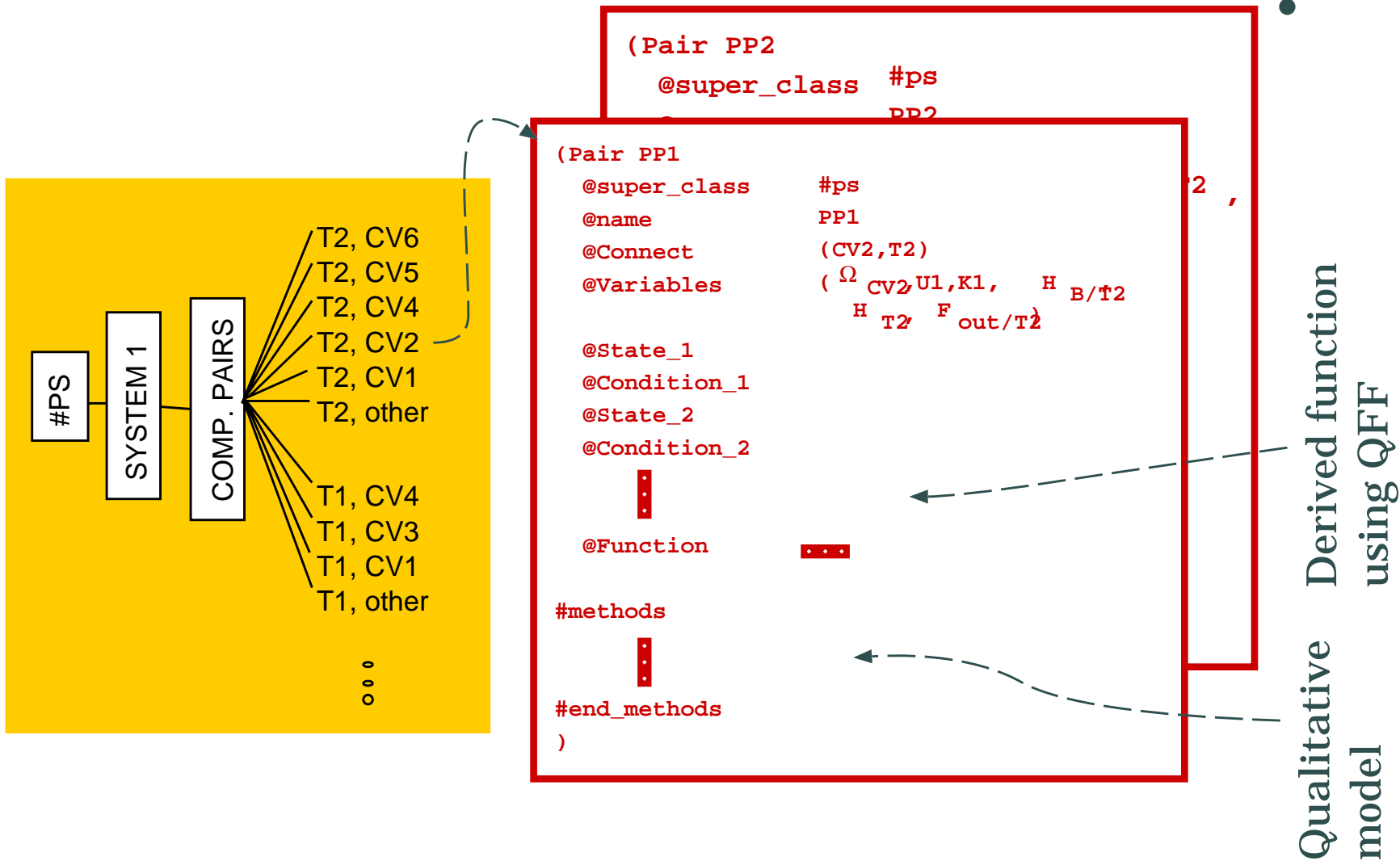
slots

methods

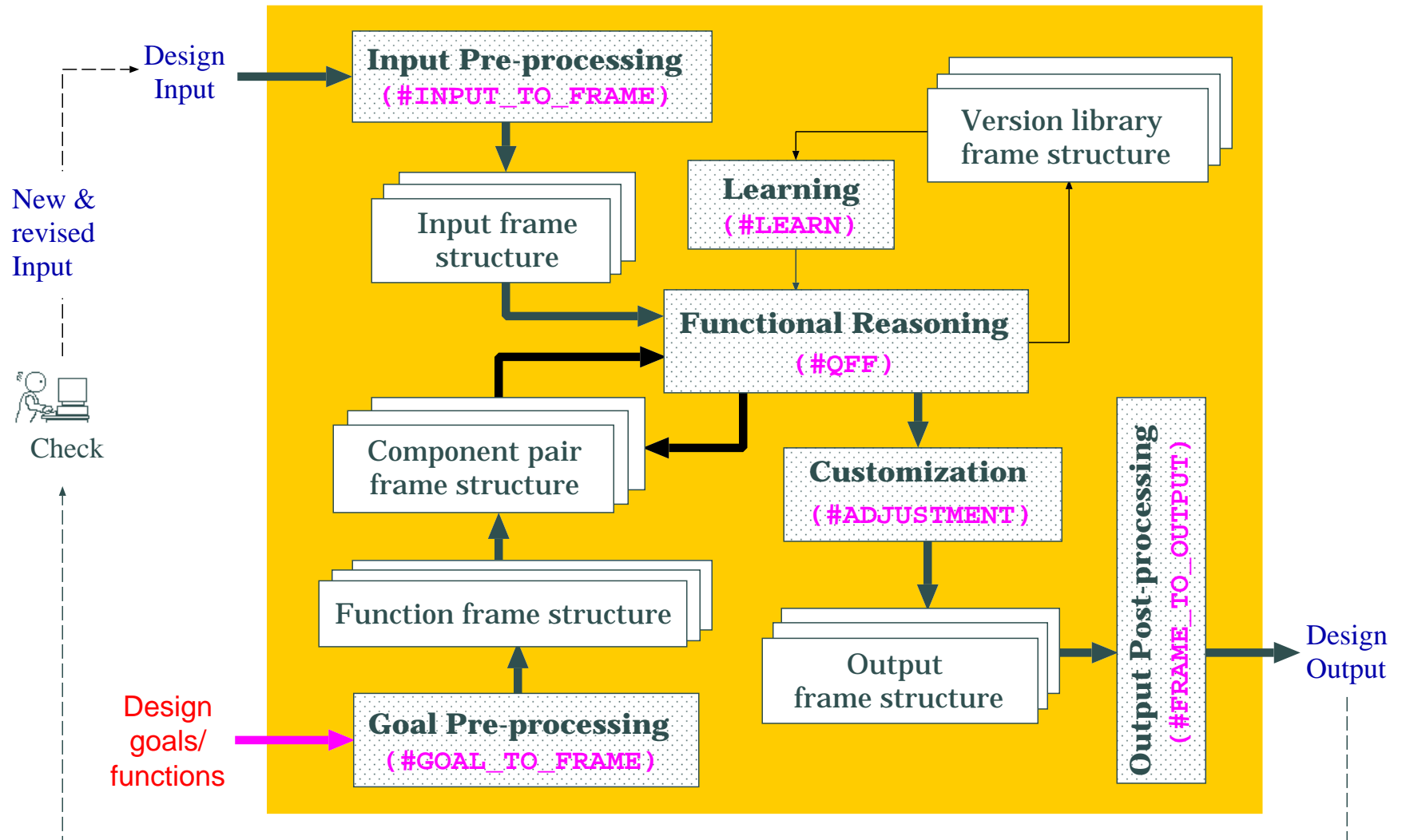
Frame Representation of a Device



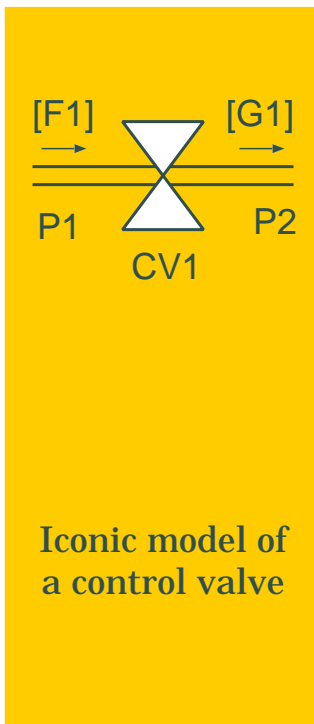
Frame Representation of Component Pairs



Experimental Design System QFF2



A Simple Component Model



```

11 COMPONENT CV1;
12 INPUT F1;
13 CONNECT P1, CV1;
14 OUTPUT G1;
15 CONNECT CV1, P2;
14 STATE S1; (ω CV1>0);
15 CONDITION
16 TASK (F1 = G1);
17 ENDSTATE S1;
18 NEXTSTATE S2;
19 STATE S2; (ω CV1=0);
20 CONDITION
21 TASK (G1 = 0);
22 ENDSTATE S2;
23 STOP;

```

Design input code

```

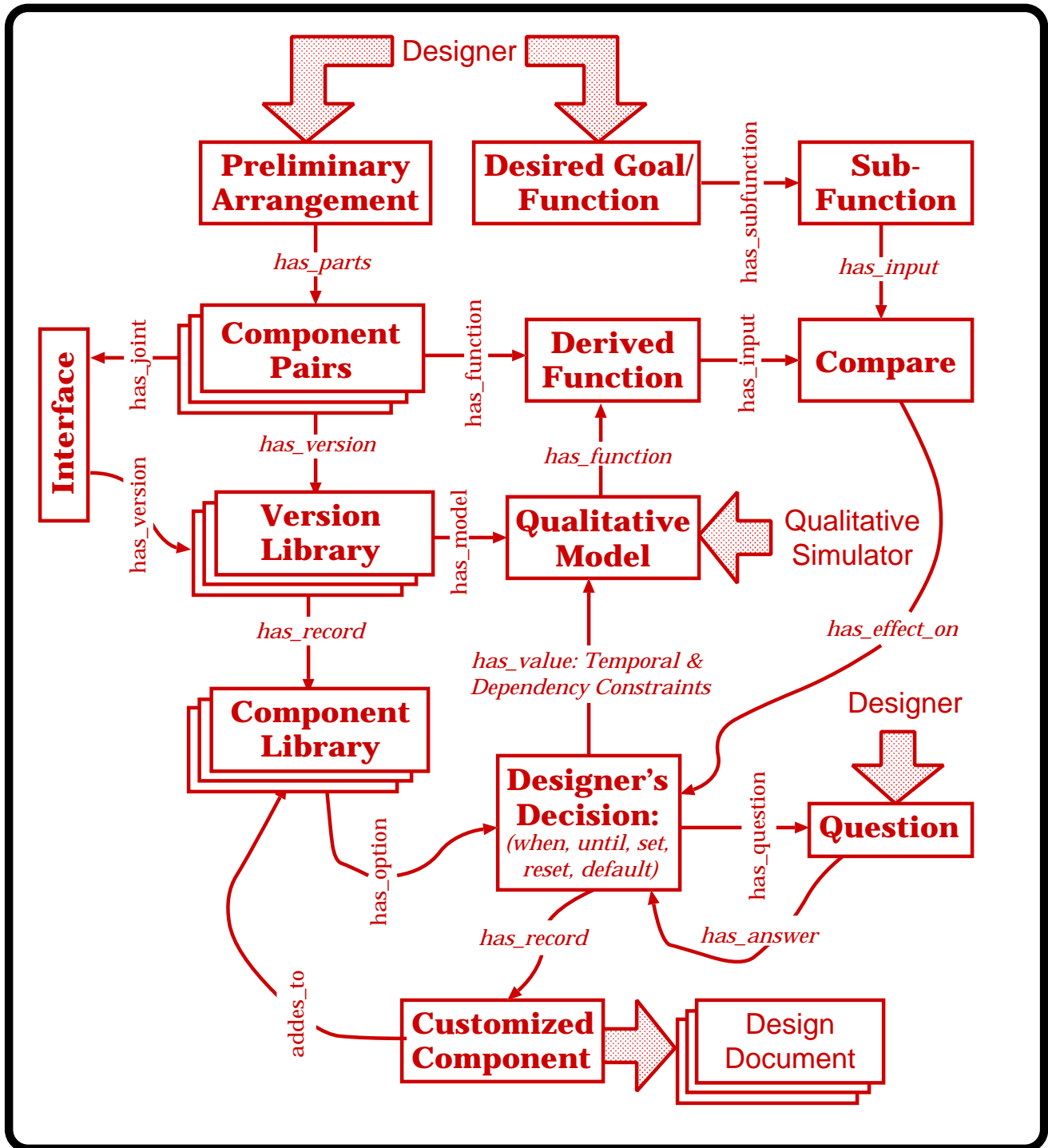
(Valve CV1
  @super_class      #ps
  @name              CV1
  @Connect_1        P1
  @Variables_1      (F1)
  @Connect_2        P2
  @Variables_2      (G1)
  @State_1          S1
  (when_asked M1()) (ω CV1>0)
  @Condition_1
  @State_2          S2
  (when_asked M2()) (ω CV1=0)
  @Condition_2
  @Parts            Null
#methods            ■■■
method M1(          ■■■ )
method M2(          )
#methods_end
)

```

slots

methods

Implementation Perspective



Conclusion

1. Surveying functional reasoning research
2. Function formation technique (QFF):
 - a. Extending common qualitative models to include interactions and timing of events by defining temporal and dependency constraints;
 - b. Defining function concepts as interpretation of a persistence or a cycle in sequence of qualitative states;
3. Implementation :
Implementing QFF in an experimental design tool
4. Future works :
 - a. Formalization of design input/output
 - b. Automatic generation of qualitative model
 - c. Implementing analogical learning
 - d. Application to fault diagnosis and tool utilization