A Model-based Approach for the Specification of a Virtual Power Plant Operating in Open Context

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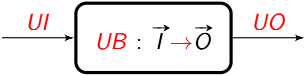
Introduction

- Open Context Systems (OCS)
  - Dynamic system boundary
  - Dynamic context awareness
- Smart Cars, Smart Grids, Smart Homes, etc...
- Virtual Power Plant (VPP)[1]
  - Challenges
  - Limitations
- OCS involve Uncertainty
- Uncertainty is an umbrella over terms (Accuracy, Precision, Ambiguity, Vagueness, Predictability...)
- Where is uncertainty located in a component?
- Uncertain input, output, behavior



[1] Applying formal software engineering techniques to smart grids, SE4SG-2012

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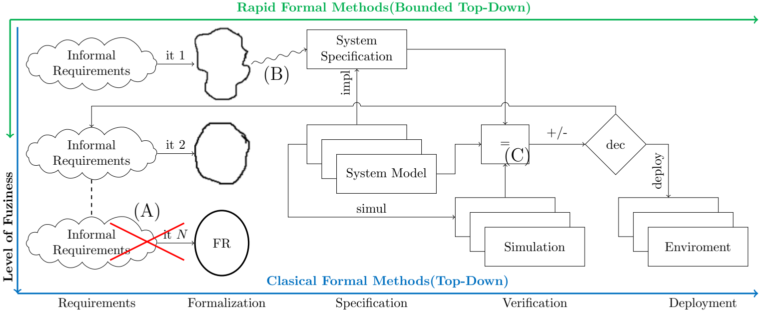
Research Problem



- PS1: Formalism for fuzzy specifications to model explicitly uncertainty in component interactions
- Equivalence model for quantitative reasoning
- PS2: Formalism for qualitative specifications for approximating component behaviors
- Dynamic adaption to systems context

Focus Theory

- A formal theory for interactive systems
- System structure: static hierarchy of components
- Syntactic Interface: $I \triangleright O$
- Component interactions through message exchange
- Streams: finite (M^*) or infinite (M^∞)
- Semantic Interface : $B : \vec{I} \to \wp(\vec{O})$
- Composition of subsystems: $B_1 \otimes B_2$

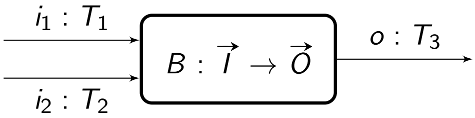


Figure: Focus Component

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Virtual Power Plant

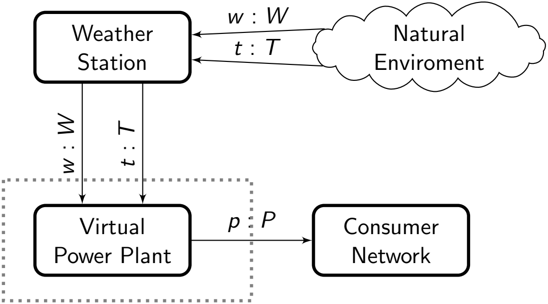

Figure: Virtual Power Plant and its Context

- Context-dependency
- Time-Dependency

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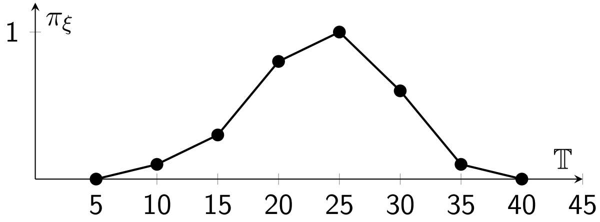
Fuzzy Property

Definition (Fuzzy Property)

A fuzzy property $\widetilde{p}$ is a three-tuple $\langle X, \xi, \pi_\xi \rangle$, where X is the universe of discourse which can be referenced by $\widetilde{p}$, ξ is a linguistic term which characterizes the property and $\pi_\xi : X \rightarrow [0, 1] \cup \{\perp\}$ is the membership function.

	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9
x	0	5	10	15	20	25	30	35	40
$\mu_{Troom}(x)$	0	0	0.1	0.3	0.8	1	0.6	0.1	0



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Fuzzy Port - Bindings

Definition (Fuzzy Port)

A fuzzy port Θ_T over a type T is a set of fuzzy properties $\Theta_T = \{\widetilde{p} \in \mathcal{P}\}$, which satisfies the following two conditions:

- Each property type is a subset of T, formally:

$$\forall \widetilde{p} \in \Theta_T \rightarrow \widetilde{p}.X \subseteq T \tag{c1}$$

- Each property is uniquely characterized by its linguistic term, formally:

$$\forall \widetilde{p}_1, \widetilde{p}_2 \in \Theta_T \ : \ \widetilde{p}_1 \neq \widetilde{p}_2 \rightarrow \widetilde{p}_1.\xi \neq \widetilde{p}_2.\xi \tag{c2}$$

Definition (Binding)

A binding B between a typed channel $c : C$ and a fuzzy port Θ_T is a 2-tuple $B = \langle c, \Theta_T \rangle$ which satisfies following connectivity property:

- $C \subseteq T$

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Syntactic Interface

Syntactic Interface ($I_S \blacktriangleright O_S$) = I/O channels + fuzzy IP/OP ports + I/O bindings

Example (Syntactic Interface of the VPP)

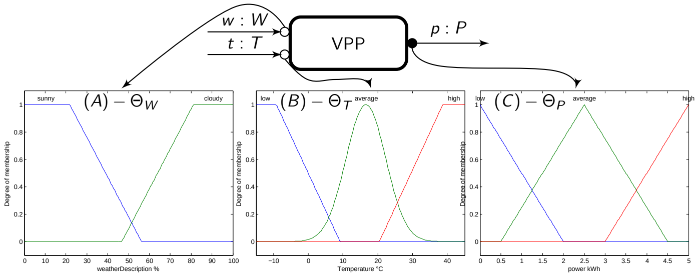

Figure: Syntactic Interface Specification for the VPP

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Rule Base Specification

Given: $I_S \blacktriangleright O_S$ and $\mu = \langle i_1@t, ..., i_n@t \rangle \in I_1 \times ... \times I_n$, the semantics are determined by a rule base of the form:

$$R_r^o\text{: } \textbf{if } i_1@t \text{ is } \xi_{1,r}^{(1)} \text{ .. } \textbf{and} \text{ ... } i_n@t \text{ is } \xi_{n,r}^{(n)}$$

$$\textbf{then } o@(t+1) \textbf{ is } \xi_r,\ r = 1, .., k$$

In case of multiple output channels: $R_S = \{R^{O_1}, ..., R^{O_m}\}$

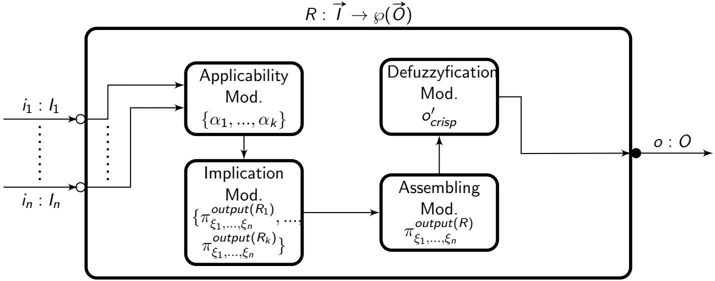

Figure: Behavior interpretation of a rule based specification

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Mapping Strategies

Definition (Mapping Strategy)

A mapping strategy for a given property $\widetilde{p} = \langle X, \xi, \pi_\xi \rangle$(total or partial) is a high order function over a stream to a membership function for that property, formally:

$$mapstr_\xi : Stream\ X, \mathbb{N} \cup \{\infty\} \rightarrow (\pi_\xi : X \rightarrow [0,1])$$

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Composition

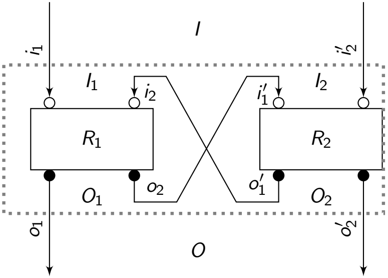

Figure: Parallel Composition with Feedback

Given two subsystems S_1 and S_2 with $I_1 \cap I_2 = \emptyset$ and behavior functions $R_1 : \overrightarrow{I_1} \to \wp(\overrightarrow{O_1})$ and $R_2 : \overrightarrow{I_2} \to \wp(\overrightarrow{O_2})$, the parallel composition is given by:

$$R_1 \otimes R_2 : \overrightarrow{I} \to \wp(\overrightarrow{O})$$

where, $I = I_1 \cup I_2$, $IP_S = IP_{S_1} \cup IP_{S_2}$, $O = O_1 \cup O_2$, and $OP_S = OP_{S_1} \cup OP_{S_2}$.

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VPP Specification

SPECIFICATION VPP

PORTS

in $\Theta_W : \langle W_{CLOUDY}, W_{SUNNY} \rangle$

in $\Theta_T : \langle T_{LOW}, T_{AVERGAE}, T_{HIGH} \rangle$

out $\Theta_P : \langle P_{LOW}, P_{AVERGAE}, P_{HIGH} \rangle$

I/O

in $w : W,\ t : T$

out $p : P$

RULE BASE

R1: if w is SUNNY and t is HIGH then p is HIGH
R2: if w is CLOUDY and t is LOW then p is LOW
R3: if w is SUNNY and t is LOW then p is AVERAGE
R4: if w is CLOUDY and t is HIGH then p is AVERAGE
R5: if w is SUNNY and t is AVERAGE then p is AVERAGE
R6: if w is CLOUDY and t is AVERAGE then p is AVERAGE

MAPPING STRATEGY

local $w' = w_{\downarrow}n \mid t' = t_{\downarrow}n \mid p' = p_{\downarrow}n$

$M_{W_{SUNNY}} = trapezodian(min.w', min.w', \frac{max.w'}{2}, max.w')$

$M_{W_{CLOUDY}} = trapezodian(\frac{max.w'}{2}, \frac{2 \cdot max.w'}{3}, max.w', max.w')$

$M_{T_{AVERAGE}} = gaussmf(min.t' + \frac{2 \cdot max.t'}{3}, max.t' - \frac{2 \cdot max.t'}{3})$

....

....

Figure: Virtual Power Plant Specification

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Conclusion & Future Work

- Formalism for qualitative specifications within Focus
- Framework for Uncertainty based on fuzzy logic
- Limitations
- Tooling
- Case studies to evaluate the expressiveness and effectiveness of the overall approach

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Thank you for your attention!

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