Logic-based description of weighted architecture styles

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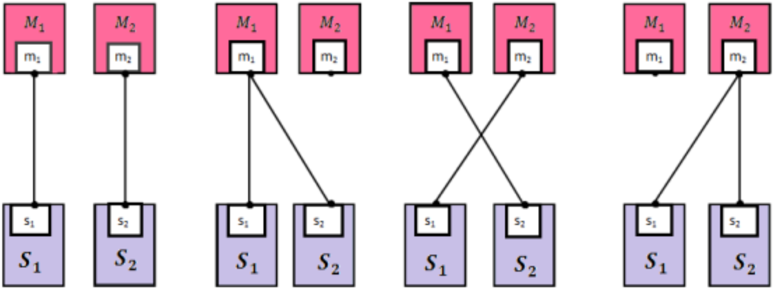
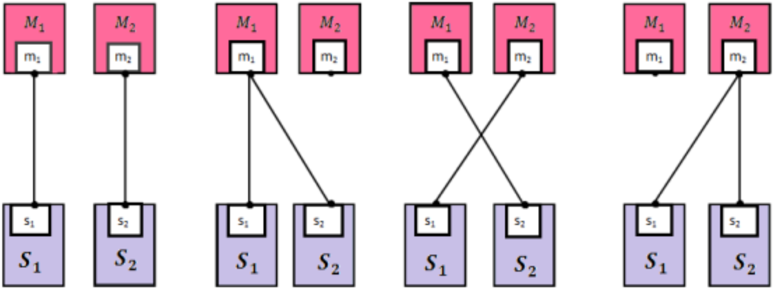
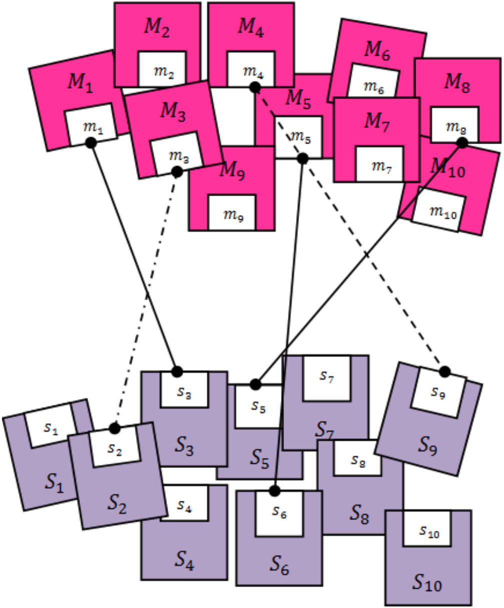
A single Master/Slave architecture



- Does PCL suffice to describe any architecture?
  - **NO**
- We need a way to describe architectures with arbitrarily many **components!**
- Components???
- *M*, *S* are the components of the Master/Slave architecture communicating via ports




M2
m2
M4
m4
M6
m6
M1
m1
M3
m3
M5
m5
M8
m8
M7
m7
M9
m9
M10
m10
s1
S1
s2
S2
s3
S3
s4
S4
s5
S5
s6
S6
s7
S7
s8
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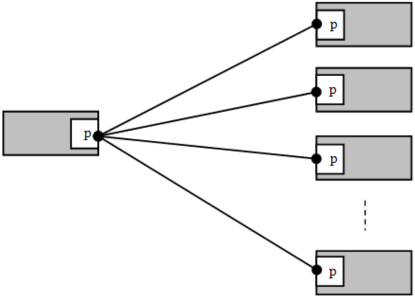
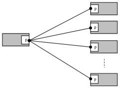
s9
S9
s10
S10

- We need to describe generic architectures
  - For any number of components
  - Satisfying concrete topologies
  - e.g. *Star*

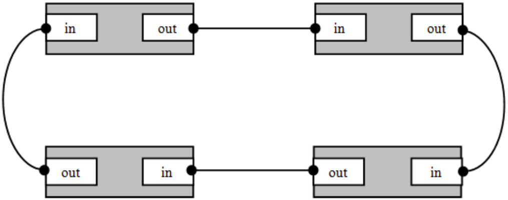


Star

- We need to describe generic architectures
    - For any number of components
    - Satisfying concrete topologies
    - e.g. *Star*, *Ring*

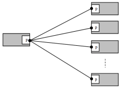


Star

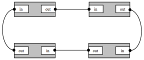


Ring

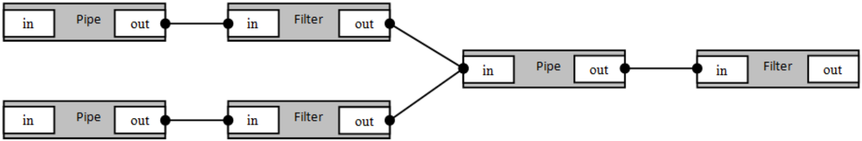
- We need to describe generic architectures
  - For any number of components
  - Satisfying concrete topologies
  - e.g. *Star*, *Ring*, *Pipe Filter*



Star

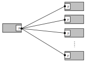


Ring

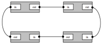


Pipe Filter

- We need to describe generic architectures
  - For any number of components
  - Satisfying concrete topologies
  - e.g. *Star*, *Ring*, *Pipe Filter*, *Grid*

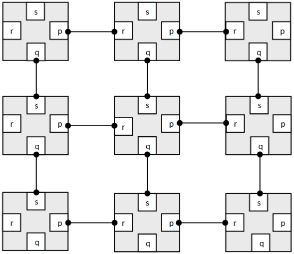


Star



Ring

Pipe Filter



Grid

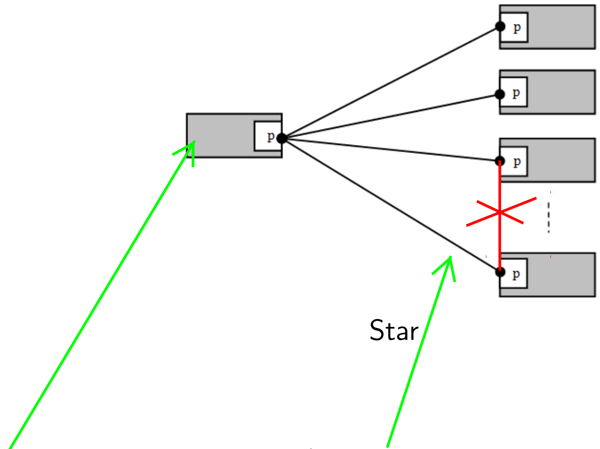
- $T_1, \ldots, T_n$: component types
- $c : T_i$ component c of type T_i
- *First-order configuration logic, Syntax:*

$$F ::= true \mid \phi \mid \neg F \mid F \sqcup F \mid F + F \\ \mid \exists \, (c : T) \, (\Phi(c)).F \mid \textstyle\sum (c : T) \, (\Phi(c)).F$$

- ϕ interaction formula,
- $\Phi(c)$ set-theoretic predicate on c

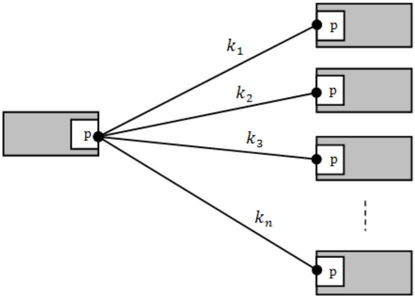
- $T_1, \ldots, T_n$: component types
- $C_{T_i} = \{c : T_i \mid c \text{ component of type } T_i\}$
- P_{T_i}: ports of component type T_i
- $B \subseteq C_{T_1} \cup \ldots \cup C_{T_n}$ set of component instances
- $P_B \subseteq P_{T_1} \cup \ldots \cup P_{T_n}$, $\gamma \in \mathcal{P}(\mathcal{P}(P_B))$

$$
\begin{array}{lll}
(B,\gamma) \models true & & \\
(B,\gamma) \models \phi & \text{iff} & \gamma \models \phi \\
(B,\gamma) \models \neg F & \text{iff} & (B,\gamma) \not\models F \\
(B,\gamma) \models F_1 \sqcup F_2 & \text{iff} & (B,\gamma) \models F_1 \text{ or } (B,\gamma) \models F_2 \\
(B,\gamma) \models F_1 + F_2 & \text{iff} & \gamma = \gamma_1 \cup \gamma_2, (B,\gamma_i) \models F_i, i = 1,2 \\
(B,\gamma) \models \exists (c : T)\, (\Phi(c)).F & \text{iff} & (B,\gamma) \models \bigsqcup_{c' : T \in B \wedge \Phi(c')} F[c'/c] \\
(B,\gamma) \models \sum (c : T)\, (\Phi(c)).F & \text{iff} & (B,\gamma) \models \sum_{c' : T \in B \wedge \Phi(c')} F[c'/c]
\end{array}
$$



$$\exists(s:T).\sum(c:T)\,(c\neq s)\,.\,\big((s.p\wedge c.p)\wedge\forall(c':T)(c'\notin\{s,c\}).\overline{c'.p}\big)$$

How can we represent quantitative features of architectures?



Star with quantitative features

- $(K, \oplus, \otimes, 0, 1)$ commutative semiring
- $T_1, \ldots, T_n$: component types
- $c : T_i$ component c of type T_i
- *Weighted first-order configuration logic, Syntax:*

$$F ::= true \mid \phi \mid \neg F \mid F \sqcup F \mid F + F \mid \exists (c : T)\, (\Phi(c)).F \mid \textstyle\sum (c : T)\, (\Phi(c)).F$$

$$Z ::= k \mid F \mid Z \oplus Z \mid Z \otimes Z \mid Z \uplus Z \mid \bigoplus(c : T)(\Phi(c)).Z \mid \bigotimes(c : T)(\Phi(c)).Z \mid \biguplus(c : T)(\Phi(c)).Z$$

- ϕ interaction formula,
- $\Phi(c)$ set-theoretic predicate on c,
- $k \in K$

- $T_1, \ldots, T_n$: component types, P_{T_i}: ports of component type T_i
- $C_{T_i} = \{c : T_i \mid c \text{ component of type } T_i\}$
- $B \subseteq C_{T_1} \cup \ldots \cup C_{T_n}$, $P_B \subseteq P_{T_1} \cup \ldots \cup P_{T_n}$, $\gamma \in \mathcal{P}(\mathcal{P}(P_B))$

$$\|k\|(B,\gamma) = k$$

$$\|F\|(B,\gamma) = \begin{cases} 1 & \text{if } (B,\gamma) \models F \\ 0 & \text{otherwise} \end{cases}$$

$$\|Z_1 \oplus Z_2\|(B,\gamma) = \|Z_1\|(B,\gamma) \oplus \|Z_2\|(B,\gamma)$$

$$\|Z_1 \otimes Z_2\|(B,\gamma) = \|Z_1\|(B,\gamma) \otimes \|Z_2\|(B,\gamma)$$

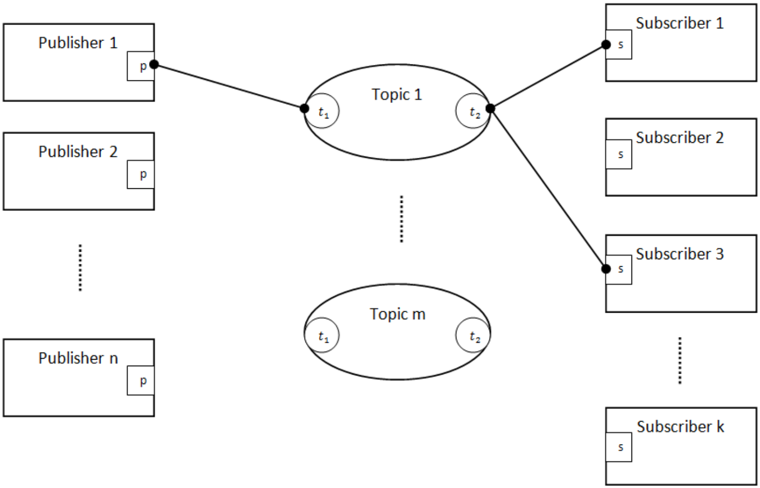
$$\|Z_1 \uplus Z_2\|(B,\gamma) = \bigoplus_{\gamma=\gamma_1\cup\gamma_2} (\|Z_1\|(B,\gamma_1) \otimes \|Z_2\|(B,\gamma_2))$$

$$\left\|\bigoplus(c:T)(\Phi(c)).Z\right\|(B,\gamma) = \bigoplus_{c':T\in B\wedge\Phi(c')} \|Z[c'/c]\|(B,\gamma)$$

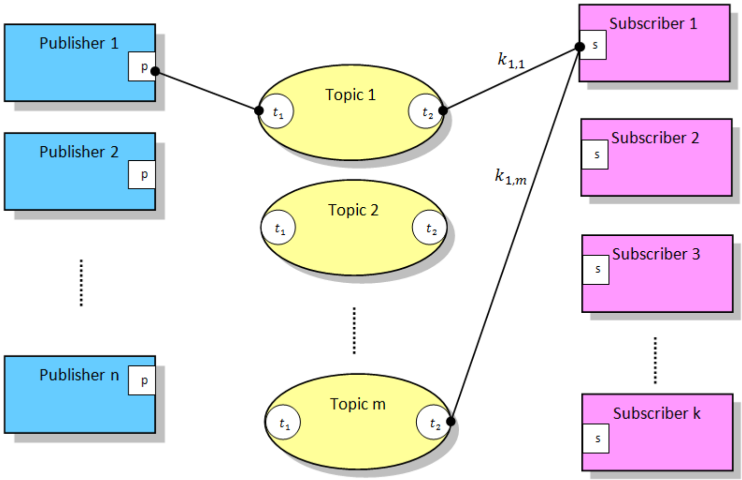
$$\left\|\bigotimes(c:T)(\Phi(c)).Z\right\|(B,\gamma) = \bigotimes_{c':T\in B\wedge\Phi(c')} \|Z[c'/c]\|(B,\gamma)$$

$$\left\|\biguplus(c:T)(\Phi(c)).Z\right\|(B,\gamma) = \bigoplus_{\gamma=\cup\gamma_{c'},c':T\in B\wedge\Phi(c')} \left(\bigotimes_{c':T\in B\wedge\Phi(c')} \|Z[c'/c]\|(B,\gamma_{c'})\right)$$

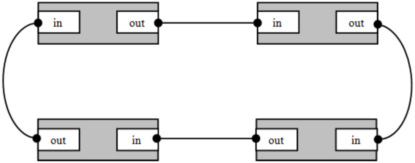
Publish-Subscribe architecture (applications to IoT)



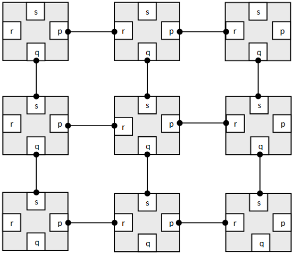
Weighted Publish-Subscribe architecture: assigns to subscribers their priorities for the topics



Does first-order configuration logic always suffice? **NO**



Ring



Grid

- $T_1, \ldots, T_n$: component types
- $c : T_i$ component c of type T_i, $C : T_i$ set of components of type T_i
- *Second-order configuration logic, Syntax:*

$$S ::= true \mid \phi \mid \neg S \mid S \sqcup S \mid S + S \mid \exists (c : T) \, (\Phi(c)).S \mid \\ \textstyle\sum (c : T) \, (\Phi(c)).S \mid \exists (C : T) \, (\Psi(C)).S \mid \textstyle\sum (C : T) \, (\Psi(C)).S$$

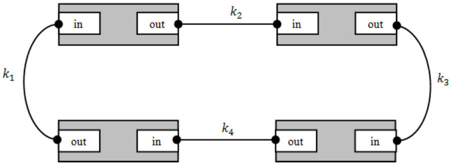
- ϕ interaction formula,
- $\Phi(c)$ set-theoretic predicate on c, $\Psi(C)$ set-theoretic predicate on C

- $T_1, \ldots, T_n$: component types
- $c : T_i$ component c of type T_i, $C : T_i$ set of components of type T_i

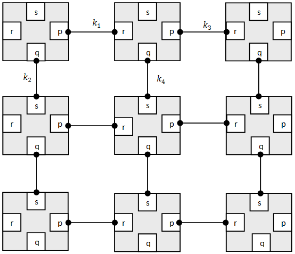
$$S ::= true \mid \phi \mid \neg S \mid S \sqcup S \mid S + S \mid \exists (c : T) \, (\Phi(c)).S \mid \sum (c : T) \, (\Phi(c)).S \mid \exists (C : T) \, (\Psi(C)).S \mid \sum (C : T) \, (\Psi(C)).S$$

$$\Xi ::= k \mid S \mid \Xi \oplus \Xi \mid \Xi \otimes \Xi \mid \Xi \uplus \Xi \mid \bigoplus (c : T) \, (\Phi(c)).\Xi \mid \bigotimes (c : T) \, (\Phi(c)).\Xi \mid \biguplus (c : T) \, (\Phi(c)).\Xi \mid \bigoplus (C : T) \, (\Psi(C)).\Xi \mid \bigotimes (C : T)(\Psi(C)).Z \mid \biguplus (C : T) \, (\Psi(C)).\Xi$$

- $k \in K$,
- S is a second-order configuration logic formula



Weighted ring



Weighted grid

Architectures with quantitative characteristics can be described by weighted second-order configuration logic formulas

$$\|k\|(B,\gamma) = k \qquad \|S\|(B,\gamma) = \begin{cases} 1 & \text{if } (B,\gamma) \models S \\ 0 & \text{otherwise} \end{cases}$$

$$\|\Xi_1 \oplus \Xi_2\|(B,\gamma) = \|\Xi_1\|(B,\gamma) \oplus \|\Xi_2\|(B,\gamma)$$

$$\|\Xi_1 \otimes \Xi_2\|(B,\gamma) = \|\Xi_1\|(B,\gamma) \otimes \|\Xi_2\|(B,\gamma)$$

$$\|\Xi_1 \uplus \Xi_2\|(B,\gamma) = \bigoplus_{\gamma=\gamma_1\cup\gamma_2} (\|\Xi_1\|(B,\gamma_1) \otimes \|\Xi_2\|(B,\gamma_2))$$

$$\|\textstyle\bigoplus(c:T)(\Phi(c)).\Xi\|(B,\gamma) = \bigoplus_{c':T\in B\wedge\Phi(c')} \|\Xi[c'/c]\|(B,\gamma)$$

$$\|\textstyle\bigotimes(c:T)(\Phi(c)).\Xi\|(B,\gamma) = \bigotimes_{c':T\in B\wedge\Phi(c')} \|\Xi[c'/c]\|(B,\gamma)$$

$$\|\textstyle\biguplus(c:T)(\Phi(c)).\Xi\|(B,\gamma) = \bigoplus_{\gamma=\cup\gamma_{c'},c':T\in B\wedge\Phi(c')} \left(\bigotimes_{c':T\in B\wedge\Phi(c')} \|\Xi[c'/c]\|(B,\gamma_{c'})\right)$$

$$\|\textstyle\bigoplus(C:T)(\Psi(c)).\Xi\|(B,\gamma) = \bigoplus_{C':T\subseteq B\wedge\Psi(C')} \|\Xi[C'/C]\|(B,\gamma)$$

$$\|\textstyle\bigotimes(C:T)(\Psi(C)).\Xi\|(B,\gamma) = \bigotimes_{C':T\subseteq B\wedge\Psi(C')} \|\Xi[C'/C]\|(B,\gamma)$$

$$\|\textstyle\biguplus(C:T)(\Psi(C)).\Xi\|(B,\gamma) = \bigoplus_{\gamma=\cup\gamma_{C'},C':T\subseteq B\wedge\Psi(C')} \left(\bigotimes_{C':T\subseteq B\wedge\Psi(C')} \|\Xi[C'/C]\|(B,\gamma_{C'})\right)$$

Open problems under investigation

- Normal form for first-order configuration logic (fragment?)
- Normal form for weighted first-order configuration logic (fragment?)
- Implementation in Maude of weighted first-order configuration logic
- (Weighted) configuration logic with data transfer among components

References

- A. Mavridou, E. Baranov, S. Bliudze, J. Sifakis, Configuration logics: Modelling architecture styles, *J. Log. Algebr. Methods Program.* 86(2016) 2–29. Extended abstract in: *Proceedings of FACS 2015, LNCS* 9539(2015) 256–274.
- P. Paraponiari, G. Rahonis, On weighted configuration logics, in: *Proceedings of FACS 2017, LNCS* 10487(2017) 98–116, and https://arxiv.org/abs/1704.04969v5

Thank you

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