Logical description of (weighted) parametric component-based systems with (w)FOEIL

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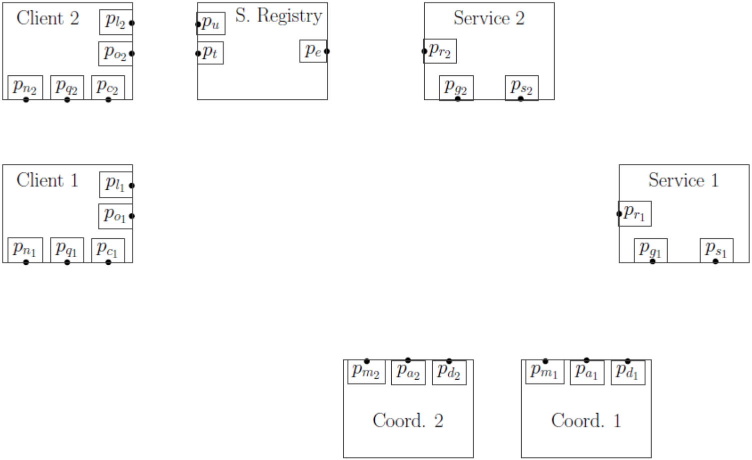
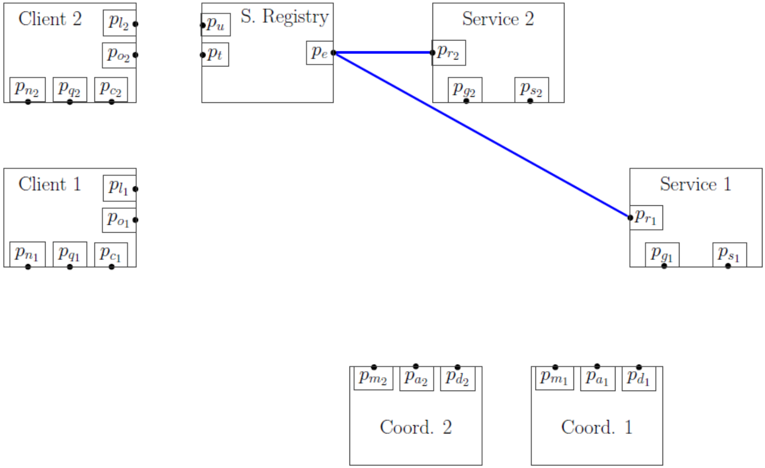
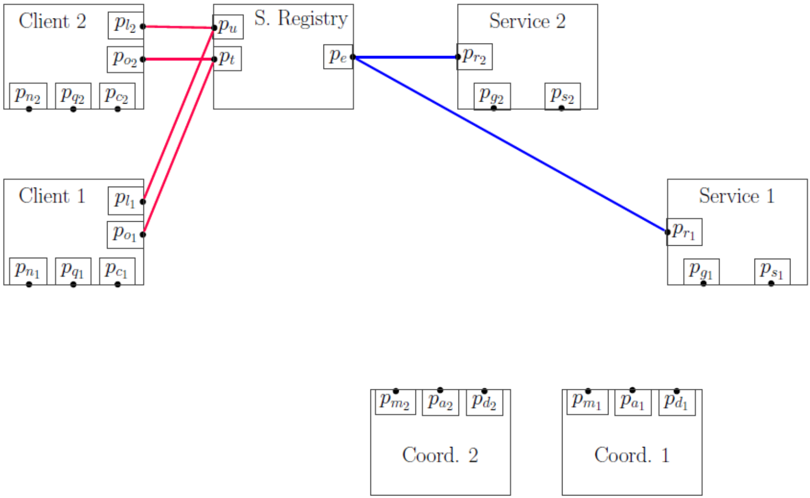
- **Parametric systems:** are constructed by a finite number of component types with an unbounded number of copies (instances) of them.


Client 2
p_{l_2}
p_{o_2}
p_{n_2}
p_{q_2}
p_{c_2}
S. Registry
p_u
p_t
p_e
Service 2
p_{r_2}
p_{g_2}
p_{s_2}
Client 1
p_{l_1}
p_{o_1}
p_{n_1}
p_{q_1}
p_{c_1}
Service 1
p_{r_1}
p_{g_1}
p_{s_1}
p_{m_2}
p_{a_2}
p_{d_2}
Coord. 2
p_{m_1}
p_{a_1}
p_{d_1}
Coord. 1

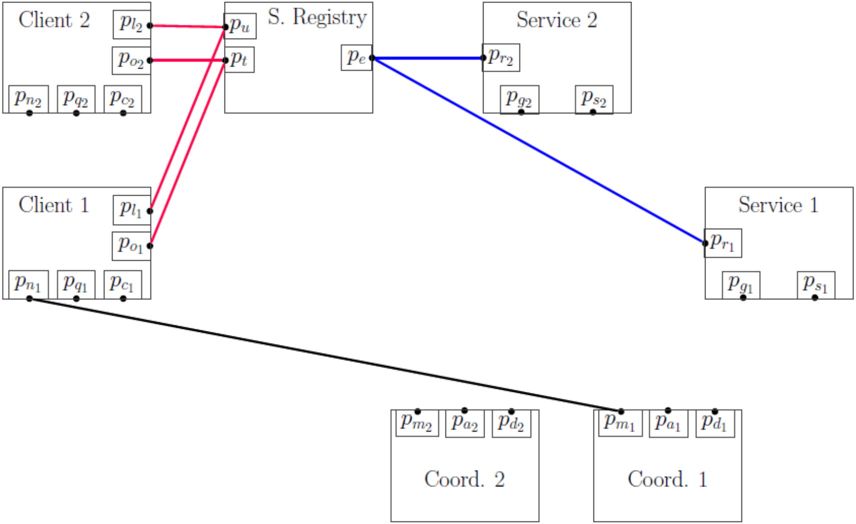
Initially services enroll in registry in any order



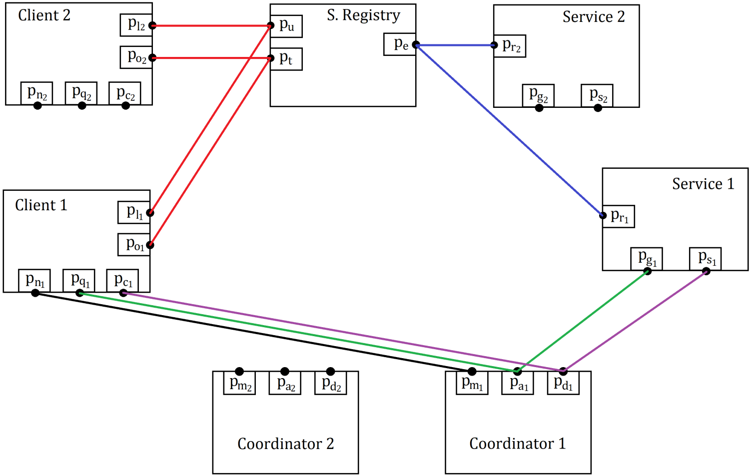
Clients search the registry and obtain a service's address



Client connects to coordinator



Client sends request to service and receives its response (via coordinator)



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$$\zeta ::= \phi \mid \zeta * \zeta \mid \zeta \between \zeta$$
$$\varphi ::= \zeta \mid \neg\zeta \mid \varphi \vee \varphi \mid \varphi \wedge \varphi \mid \varphi * \varphi \mid \varphi \between \varphi \mid \varphi^{+}$$

  where ϕ is a PIL formula over P.

Semantics of PIL

$$a \in I(P)$$

- $a \models_{PIL} true$
  $a \models_{PIL} p$ iff $p \in a$
  $a \models_{PIL} \neg\phi$ iff $a \not\models_{PIL} \phi$
  $a \models_{PIL} \phi_1 \vee \phi_2$ iff $a \models_{PIL} \phi_1$ or $a \models_{PIL} \phi_2$

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Semantics of EPIL

$$w \in I(P)^+$$

- $w \models \phi$ iff $w \models_{PIL} \phi$
  $w \models \zeta_1 * \zeta_2$ iff $w = w_1 w_2$ and $w_1 \models \zeta_1$, $w_2 \models \zeta_2$
  $w \models \zeta_1 \between \zeta_2$ iff $w \in w_1 \between w_2$ and $w_1 \models \zeta_1$, $w_2 \models \zeta_2$
  $w \models \neg\zeta$ iff $w \not\models \zeta$
  $w \models \varphi_1 \vee \varphi_2$ iff $w \models \varphi_1$ or $w \models \varphi_2$
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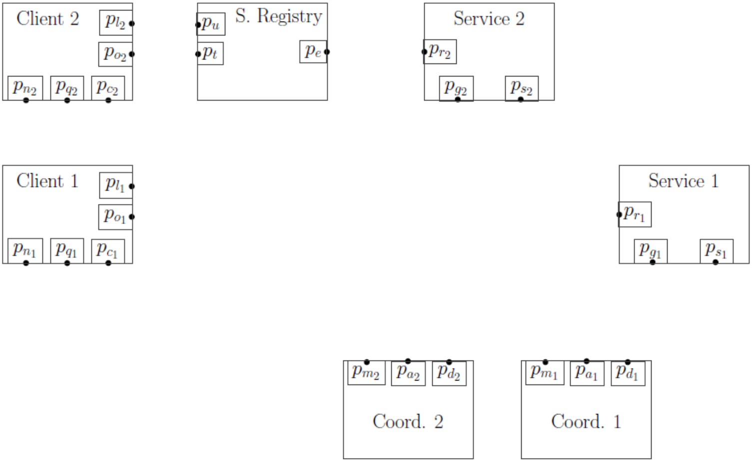
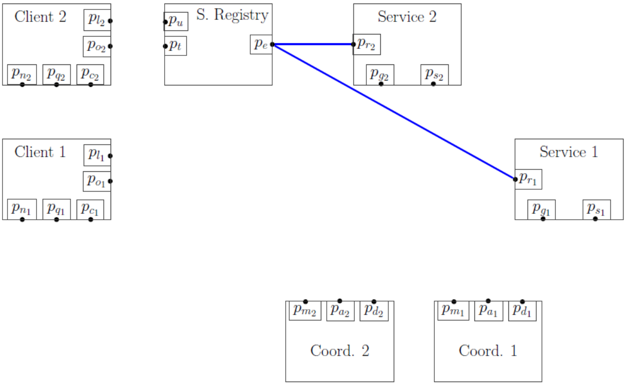
  $w \models \varphi_1 \between \varphi_2$ iff $w \in w_1 \between w_2$ and $w_1 \models \varphi_1$, $w_2 \models \varphi_2$
  $w \models \varphi^+$ iff there exists $n > 0$ such that $w \models \varphi^n$
  where $\varphi^1 = \varphi$ and $\varphi^{n+1} = \varphi^n * \varphi$



Components are labelled transition systems with ports as labels.

Initially services enroll in registry in any order



$$\#(p_e \wedge p_{r_1}) \between \#(p_e \wedge p_{r_2})$$

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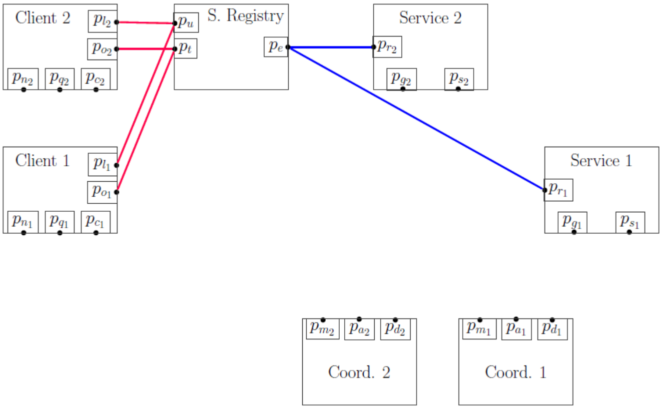
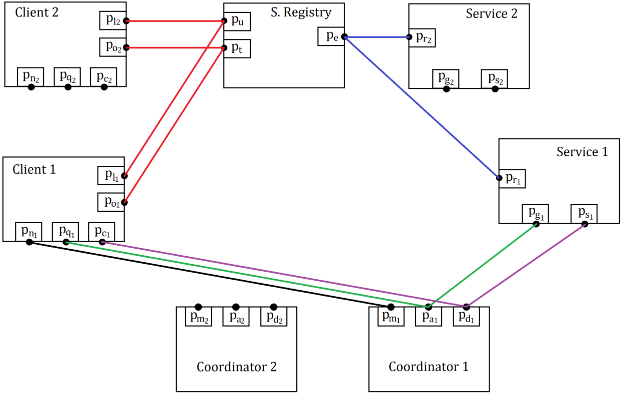
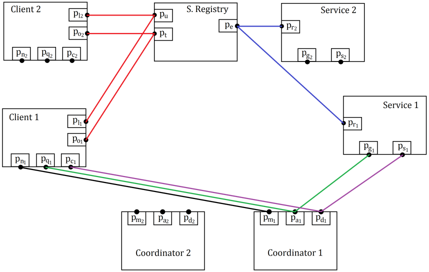


$$(\#(p_e \wedge p_{r_1}) \between \#(p_e \wedge p_{r_2})) * ((\#(p_{l_1} \wedge p_u) * \#(p_{o_1} \wedge p_t)) \between (\#(p_{l_2} \wedge p_u) * \#(p_{o_2} \wedge p_t)))$$

Client sends request to service and receives its response



$$(\#(p_e \wedge p_{r_1}) \between \#(p_e \wedge p_{r_2})) * ((\#(p_{l_1} \wedge p_u) * \#(p_{o_1} \wedge p_t)) \between (\#(p_{l_2} \wedge p_u) * \#(p_{o_2} \wedge p_t))) * (\#(p_{n_1} \wedge p_{m_1}) * \#(p_{q_1} \wedge p_{a_1} \wedge p_{g_1}) * \#(p_{c_1} \wedge p_{d_1} \wedge p_{s_1}))$$



$$\varphi = (\#(p_e \wedge p_{r_1}) \between \#(p_e \wedge p_{r_2})) *$$
$$((\#(p_{l_1} \wedge p_u) * \#(p_{o_1} \wedge p_t)) \between (\#(p_{l_2} \wedge p_u) * \#(p_{o_2} \wedge p_t))) *$$
$$\begin{pmatrix} (\varphi_{11} \vee \varphi_{21} \vee (\varphi_{11} * \varphi_{21}) \vee (\varphi_{21} * \varphi_{11}))^{+} \bigvee \\ (\varphi_{12} \vee \varphi_{22} \vee (\varphi_{12} * \varphi_{22}) \vee (\varphi_{22} * \varphi_{12}))^{+} \bigvee \\ ((\varphi_{11} \vee \varphi_{21} \vee (\varphi_{11} * \varphi_{21}) \vee (\varphi_{21} * \varphi_{11}))^{+} \between \\ (\varphi_{12} \vee \varphi_{22} \vee (\varphi_{12} * \varphi_{22}) \vee (\varphi_{22} * \varphi_{12}))^{+})^{+} \end{pmatrix}^{+}$$

$$\varphi_{ij} = \#(p_{n_i} \wedge p_{m_j}) * \#(p_{q_i} \wedge p_{a_j} \wedge p_{g_j}) * \#(p_{c_i} \wedge p_{d_j} \wedge p_{s_j})$$

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- $P_{p\mathcal{B}(\mathcal{X})} = \{p(x^{(i)}) \mid i \in [n], p \in P(i), x^{(i)} \in \mathcal{X}^{(i)}\}$

- **Syntax** of FOEIL over $p\mathcal{B}$

$$\psi ::= \varphi \mid x^{(i)} = y^{(i)} \mid \neg(x^{(i)} = y^{(i)}) \mid \psi \vee \psi \mid \psi \wedge \psi \mid \psi * \psi \mid \\ \psi \between \psi \mid \psi^{+} \mid \exists x^{(i)}.\psi \mid \forall x^{(i)}.\psi \mid \exists^{*} x^{(i)}.\psi \mid \forall^{*} x^{(i)}.\psi \mid \\ \exists^{\between} x^{(i)}.\psi \mid \forall^{\between} x^{(i)}.\psi$$

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  - φ EPIL formula over $P_{p\mathcal{B}(\mathcal{X})}$,
  - if ψ contains $\exists^{*} x^{(i)}.\psi'$ or $\exists^{\between} x^{(i)}.\psi'$, then negation in ψ' is permitted only in $x^{(i')} = y^{(i')}$ and PIL formulas.

- $r : [n] \rightarrow \mathbb{N}$, $i \in [n]$ $r(i)$ number of instances of $B(i)$,

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- $P_{p\mathcal{B}(r)} = \bigcup_{i \in [n], j \in [r(i)]} P(i,j)$,
- $I_{p\mathcal{B}(r)}$ interactions of $p\mathcal{B}(r)$. At most one port of every instance participates in any interaction.

- **Semantics** of FOEIL over $p\mathcal{B}$

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- $w \in I^{+}_{p\mathcal{B}(r)}$

$$(r, \sigma, w) \models \varphi \text{ iff } w \models \sigma(\varphi)$$

$$(r, \sigma, w) \models x^{(i)} = y^{(i)} \text{ iff } \sigma(x^{(i)}) = \sigma(y^{(i)})$$

$$(r, \sigma, w) \models \exists x^{(i)}.\psi \text{ iff there exists } j \in [r(i)] \text{ such that } (r, \sigma[x^{(i)} \to j], w) \models \psi$$

$$(r, \sigma, w) \models \forall x^{(i)}.\psi \text{ iff } (r, \sigma[x^{(i)} \to j], w) \models \psi \text{ for every } j \in [r(i)]$$

$$(r, \sigma, w) \models \exists^{*} x^{(i)}.\psi \text{ iff } w = w_{l_1} \ldots w_{l_k} \text{ and } (r, \sigma[x^{(i)} \to j], w_j) \models \psi \text{ for every } j = l_1, \ldots, l_k$$

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$$(r, \sigma, w) \models \exists^{\between} x^{(i)}.\psi \text{ iff } w \in w_{l_1} \between \ldots \between w_{l_k} \text{ and } (r, \sigma[x^{(i)} \to j], w_j) \models \psi \text{ for every } j = l_1, \ldots, l_k$$

$$(r, \sigma, w) \models \forall^{\between} x^{(i)}.\psi \text{ iff } w \in w_1 \between \ldots \between w_{r(i)} \text{ and } (r, \sigma[x^{(i)} \to j], w_j) \models \psi \text{ for every } j \in [r(i)]$$

$\mathcal{X}^{(1)}$:registry, $\mathcal{X}^{(2)}$:services, $\mathcal{X}^{(3)}$:clients, $\mathcal{X}^{(4)}$:coordinators

- $$\psi = \left(\exists x^{(1)}. \begin{pmatrix} (\forall^{\between} x^{(2)}.\#(p_e(x^{(1)}) \wedge p_r(x^{(2)})))* \\ (\forall^{\between} x^{(3)}.\#(p_l(x^{(3)}) \wedge p_u(x^{(1)}))* \\ \#(p_o(x^{(3)}) \wedge p_t(x^{(1)}))) \end{pmatrix} \right) * \left(\exists^{\between} y^{(2)} \exists x^{(4)} \exists^{*} y^{(3)}.\xi \wedge \begin{pmatrix} \forall y^{(4)} \forall z^{(3)} \forall z^{(2)}.(\theta \vee \\ (\forall t^{(3)} \forall t^{(2)} (z^{(2)} \neq t^{(2)}).\theta')) \end{pmatrix} \right)^{+}$$

  where

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  $$\left(\exists^{\between} y^{(2)} \exists x^{(4)} \exists^{*} y^{(3)} . \xi \wedge \begin{pmatrix} \forall y^{(4)} \forall z^{(3)} \forall z^{(2)} . (\theta \vee \\ (\forall t^{(3)} \forall t^{(2)} (z^{(2)} \neq t^{(2)}) . \theta')) \end{pmatrix} \right)^{+}$$

  where

  $$\xi = \#(p_n(y^{(3)}) \wedge p_m(x^{(4)}) * \#(p_q(y^{(3)}) \wedge p_a(x^{(4)}) \wedge p_g(y^{(2)})) * \\ \#(p_c(y^{(3)}) \wedge p_d(x^{(4)}) \wedge p_s(y^{(2)}))$$

- $$\theta = \neg(\#(p_q(z^{(3)}) \wedge p_a(y^{(4)}) \wedge p_g(z^{(2)})) \between true)$$
  $$\theta' = (\#(p_q(z^{(3)}) \wedge p_a(y^{(4)}) \wedge p_g(z^{(2)})) \between true) \wedge \\ \neg(\#(p_q(t^{(3)}) \wedge p_a(y^{(4)}) \wedge p_g(t^{(2)})) \between true)$$

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$r : [n] \longrightarrow \mathbb{N}$

- **Results**

$p\mathcal{B} = \{B(i) \mid i \in [n]\}$ set of parametric components

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- **Results**

- The equivance problem for FOEIL sentences over $p\mathcal{B}$ w.r.t. r is decidable in doubly exponential time.

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- **Results**

- The equivance problem for FOEIL sentences over $p\mathcal{B}$ w.r.t. r is decidable in doubly exponential time.

- The satisfiability problem for FOEIL sentences over $p\mathcal{B}$ w.r.t. r is decidable in exponential time.

$p\mathcal{B} = \{B(i) \mid i \in [n]\}$ set of parametric components

$r : [n] \rightarrow \mathbb{N}$

- **Results**

- The equivance problem for FOEIL sentences over $p\mathcal{B}$ w.r.t. r is decidable in doubly exponential time.

- The satisfiability problem for FOEIL sentences over $p\mathcal{B}$ w.r.t. r is decidable in exponential time.

- The validity problem for FOEIL sentences over $p\mathcal{B}$ w.r.t. r is decidable in doubly exponential time.

- $(K, +, \cdot, 0, 1)$ commutative semiring

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- **Syntax** of wFOEIL over $pw\mathcal{B}$ and K

$$\widetilde{\psi} ::= k \mid \psi \mid \widetilde{\psi}_1 \oplus \widetilde{\psi}_2 \mid \widetilde{\psi}_1 \otimes \widetilde{\psi}_2 \mid \widetilde{\psi}_1 \odot \widetilde{\psi}_2 \mid \widetilde{\psi}_1 \varpi \widetilde{\psi}_2 \mid \widetilde{\psi}^{+} \mid \sum x^{(i)}.\widetilde{\psi} \mid \prod x^{(i)}.\widetilde{\psi} \mid \sum\nolimits^{\odot} x^{(i)}.\widetilde{\psi} \mid \prod\nolimits^{\odot} x^{(i)}.\widetilde{\psi} \mid \sum\nolimits^{\varpi} x^{(i)}.\widetilde{\psi} \mid \prod\nolimits^{\varpi} x^{(i)}.\widetilde{\psi}$$

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- $k \in K$,
- ψ FOEIL formula over $p\mathcal{B}$,
- if $\widetilde{\psi}$ contains $\sum^{\odot} x^{(i)}.\widetilde{\psi}'$ or $\sum^{\varpi} x^{(i)}.\widetilde{\psi}'$, and $\widetilde{\psi}'$ contains a FOEIL subformula ψ, then the application of negation in ψ is permitted only on formulas $x^{(i)} = y^{(i)}$ and PIL formulas.

- $r : [n] \rightarrow \mathbb{N}$, $i \in [n]$ $r(i)$ number of instances of $wB(i)$,
- $\mathcal{V} \subset \mathcal{X}$ finite,
- $\sigma : \mathcal{V} \rightarrow \mathbb{N}$, with $\sigma(\mathcal{V} \cap \mathcal{X}^{(i)}) \subseteq [r(i)]$,
- $P_{p\mathcal{B}(r)} = \bigcup_{i\in[n], j\in[r(i)]} P(i,j)$,
- $I_{p\mathcal{B}(r)}$ interactions of $pw\mathcal{B}(r)$. At most one port of every instance participates in any interaction.

Semantics of wFOEIL over $pw\mathcal{B}$ and K

$w \in I^{+}_{p\mathcal{B}(r)}$

$$\|k\|(r,\sigma,w) = k$$

$$\|\psi\|(r,\sigma,w) = \begin{cases} 1 & \text{if } (r,\sigma,w) \models \psi \\ 0 & \text{otherwise} \end{cases}$$

$$\left\|\widetilde{\psi}_1 \oplus \widetilde{\psi}_2\right\|(r,\sigma,w) = \left\|\widetilde{\psi}_1\right\|(r,\sigma,w) + \left\|\widetilde{\psi}_2\right\|(r,\sigma,w)$$

$$\left\|\widetilde{\psi}_1 \otimes \widetilde{\psi}_2\right\|(r,\sigma,w) = \left\|\widetilde{\psi}_1\right\|(r,\sigma,w) \cdot \left\|\widetilde{\psi}_2\right\|(r,\sigma,w)$$

$$\left\|\widetilde{\psi}_1 \odot \widetilde{\psi}_2\right\|(r,\sigma,w) = \sum_{w=w_1w_2}\left(\left\|\widetilde{\psi}_1\right\|(r,\sigma,w_1) \cdot \left\|\widetilde{\psi}_2\right\|(r,\sigma,w_2)\right)$$

$$\left\|\widetilde{\psi}_1 \varpi \widetilde{\psi}_2\right\|(r,\sigma,w) = \sum_{w \in w_1 \between w_2}\left(\left\|\widetilde{\psi}_1\right\|(r,\sigma,w_1) \cdot \left\|\widetilde{\psi}_2\right\|(r,\sigma,w_2)\right)$$

$$\left\|\widetilde{\psi}^{+}\right\|(r,\sigma,w) = \sum_{\nu \geq 1}\left(\left\|\widetilde{\psi}\right\|^{\nu}(r,\sigma,w)\right)$$

Semantics of wFOEIL over $pw\mathcal{B}$ and K

$w \in I^{+}_{p\mathcal{B}(r)}$

$$\left\| \sum x^{(i)}.\widetilde{\psi} \right\| (r, \sigma, w) = \sum_{j \in [r(i)]} \left\| \widetilde{\psi} \right\| (r, \sigma[x^{(i)} \rightarrow j], w)$$

$$\left\| \prod x^{(i)}.\widetilde{\psi} \right\| (r, \sigma, w) = \prod_{j \in [r(i)]} \left\| \widetilde{\psi} \right\| (r, \sigma[x^{(i)} \rightarrow j], w)$$

$$\left\| \sum\nolimits^{\odot} x^{(i)}.\widetilde{\psi} \right\| (r, \sigma, w) = \sum_{w = w_{l_1} \ldots w_{l_t}} \prod_{j = l_1, \ldots, l_t} \left\| \widetilde{\psi} \right\| (r, \sigma[x^{(i)} \rightarrow j], w_j)$$

$$\left\| \prod\nolimits^{\odot} x^{(i)}.\widetilde{\psi} \right\| (r, \sigma, w) = \sum_{w = w_1 \ldots w_{r(i)}} \prod_{1 \leq j \leq r(i)} \left\| \widetilde{\psi} \right\| (r, \sigma[x^{(i)} \rightarrow j], w_j)$$

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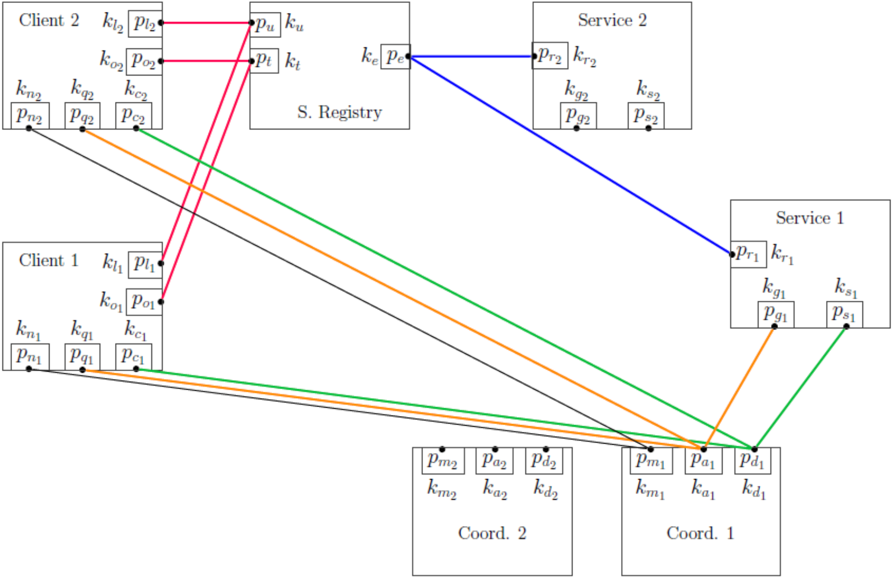
Client 2
k_{l_2} p_{l_2}
k_{o_2} p_{o_2}
k_{n_2} k_{q_2} k_{c_2}
p_{n_2} p_{q_2} p_{c_2}
p_u k_u
p_t k_t
k_e p_e
S. Registry
Service 2
p_{r_2} k_{r_2}
k_{g_2} k_{s_2}
p_{g_2} p_{s_2}
Service 1
p_{r_1} k_{r_1}
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Client 1
k_{l_1} p_{l_1}
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k_{n_1} k_{q_1} k_{c_1}
p_{n_1} p_{q_1} p_{c_1}
p_{m_2} p_{a_2} p_{d_2}
k_{m_2} k_{a_2} k_{d_2}
Coord. 2
p_{m_1} p_{a_1} p_{d_1}
k_{m_1} k_{a_1} k_{d_1}
Coord. 1

$\mathcal{X}^{(1)}$:registry, $\mathcal{X}^{(2)}$:services, $\mathcal{X}^{(3)}$:clients, $\mathcal{X}^{(4)}$:coordinators

$$\widetilde{\psi} = \left(\sum x^{(1)} . \left(\begin{array}{c} (\prod^{\varpi} x^{(2)} . \#_w (p_e(x^{(1)} \otimes p_r(x^{(2)}))) \odot \\ (\prod^{\varpi} x^{(3)} . (\#_w (p_l(x^{(3)}) \otimes p_u(x^{(1)}))) \odot \\ \#_w (p_o(x^{(3)}) \otimes p_t(x^{(1)}))) \end{array} \right) \right) \odot$$

$$\left(\sum^{\varpi} y^{(2)} \sum x^{(4)} \sum^{\odot} y^{(3)} . \widetilde{\xi} \otimes \left(\begin{array}{c} \forall y^{(4)} \forall z^{(3)} \forall z^{(2)} . (\theta \vee \\ (\forall t^{(3)} \forall t^{(2)} (z^{(2)} \neq t^{(2)}) . \theta')) \end{array} \right) \right)^{+}$$

where

$$\widetilde{\xi} = \#_w (p_n(y^{(3)}) \otimes p_m(x^{(4)}) \odot \#_w (p_q(y^{(3)}) \otimes p_a(x^{(4)}) \otimes p_g(y^{(2)})) \odot \\ \#_w (p_c(y^{(3)}) \otimes p_d(x^{(4)}) \otimes p_s(y^{(2)}))$$

$$\theta = \neg(\#(p_q(z^{(3)}) \wedge p_a(y^{(4)}) \wedge p_g(z^{(2)})) \between true)$$

$$\theta' = (\#(p_q(z^{(3)}) \wedge p_a(y^{(4)}) \wedge p_g(z^{(2)})) \between true) \wedge \\ \neg(\#(p_q(t^{(3)}) \wedge p_a(y^{(4)}) \wedge p_g(t^{(2)})) \between true)$$

- K (subsemiring of a) skew field
- $pw\mathcal{B} = \{wB(i) \mid i \in [n]\}$ set of parametric weighted components
- $r : [n] \to \mathbb{N}$
- **Result**

- K (subsemiring of a) skew field
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- **Result**

- The equivance problem for wFOEIL sentences over $p\mathcal{B}$ and K w.r.t. r is decidable in doubly exponential time.

Work in progress

- (Weighted) Second order extended interaction logic.
- Fuzzy EPIL and fuzzy FOEIL

References

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Thank you

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