Interface reconciliation in Kahn Process Networks using CSP and SAT

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Kahn process networks (KPNs)

- components are connected by FIFO data channels that transfer self-contained messages (no references or pointers)
- each component contains a set of services. A service is a sequential process that implements some domain-specific algorithm
- the components are developed in a decontextualised manner: a component contains numerous services that represent algorithms compatible with various contexts
- the services are “black boxes”. We assume that services only expose their interfaces
- assumption: the network topology is defined statically (in contrast to actor model or MPI)
- application: web-services in the Cloud (Service-Oriented Architecture)
Web services: state of the art

- Many web services are built using Service-Oriented Architecture (SOA)
- A service contract is specified in Web Service Description Language (WSDL)
- WSDL (XML) is a representational glue for services: responsible for combining and formatting the data
- Lack of flexible representational glue that connects services together
Wheels

Frame factory

Component warehouse

Gears

Customer (Mobile App)

get: wheel(a): {size: int, tread: int}

get: road_frame(b): {size: int, frame_price: int}

get: mtb_frame(~b): {size: int, suspension: int, frame_price: int}

get: gears: {speed: int, material: string}

get: $p

get: $q

get: union($p, $q, {components_price: int})

get(c): {components_price: int | $y}

get(d): front_light: {power: int}

get: $x

get: $y

buy_bicycle(c): union($x, $y, {price: int})

buy_accessories(d): {price: int | $z}

buy_bicycle:
  price: int
  road_frame: {size: int}
  wheel: {size: int, tread: int}
  gears: {speed: int}

return: frame: {id: int}

return:

Boolean variable values:

a: true
b: true
c: true
d: false
e: true
Challenges

• cross-service interaction is essentially local (pairwise)

• processing graph is not taken into account

• cycles make direct constraint resolution impossible
Research problem

• a static mechanism that establishes compatibility of services and works out necessary conditions

• support of structural subtyping in the interfaces is needed

• inheritance that propagates requirements over the processing graph is needed
Contribution

• Designed a Message Definition Language that supports subtyping, inheritance and Boolean flags (MDL can be used instead of XML-based WSDL)

• Developed a mechanism for interface reconciliation based on CSP and SAT

• Designed and implemented a communication protocol for services specified in C++
Message Definition Language

- describes a message format as a term algebra
- the subtyping relation forms two semilattices for term sorts

\[ \text{'nil'} \text{ is equivalent to 'void' type in C} \quad \longleftarrow \quad \text{nil} \quad \rightarrow \quad \ldots \]

\[ \text{symbol} \quad \text{tuple} \quad \text{record} \quad \text{choice} \]

\[ \text{subtype} \]

\[ \ldots \quad \text{none} \quad \leftarrow \quad \text{'none' is a choice without variants} \]

- support of inheritance for

  - records (similar to ‘structs’ in C, but don’t take an order of elements into account)
    intuitively, a record that contains more elements is a subtype
  
  - choices (similar to ‘unions’ in C, but don’t take an order of elements into account)
    intuitively, a choice that contains less elements is a subtype
Constraint Satisfaction Problem

The seniority relation $\sqsubseteq$ represents the subtyping relation on terms. If a term $t'$ describes the input interface of a service, then the service can process any message described by a term $t$, such that $t \sqsubseteq t'$.

**Definition 2 (CSP-KPN).** For each $t \sqsubseteq t' \in C(G)$ find a vector of Boolean values $\vec{b} = (b_1, \ldots, b_i)$, vectors of ground terms $\vec{t}' = (t_1, \ldots, t_m)$, $\vec{t''} = (t'_1, \ldots, t'_n)$ such that

$$t[\vec{f}/\vec{b}, \uparrow \vec{v}/\vec{t}, \downarrow \vec{v}/\vec{t'}] \sqsubseteq t'[\vec{f}/\vec{b}, \uparrow \vec{v}/\vec{t}, \downarrow \vec{v}/\vec{t''}],$$

where $\vec{f} = (f_1, \ldots, f_i)$, $\uparrow \vec{v} = (\uparrow v_1, \ldots, \uparrow v_m)$, $\downarrow \vec{v} = (\downarrow v_1, \ldots, \downarrow v_n)$. The tuple $(\vec{b}, \vec{t}, \vec{t''})$ is called a solution.

Formal proofs are available in the full paper (http://arxiv.org/abs/1503.00622)
Solution algorithm

$B_0 \subseteq B_1 \subseteq \cdots \subseteq B_s$ are sets of Boolean constraints.

$\bar{a}^\uparrow$ and $\bar{a}^\downarrow$ are vectors of semigroup terms called conditional approximations of the solution.

We seek the solution as a fixed point of a series of approximations in the following form:

$$(B_0, \bar{a}_0^\uparrow, \bar{a}_0^\downarrow), \ldots, (B_{s-1}, \bar{a}_{s-1}^\uparrow, \bar{a}_{s-1}^\downarrow), (B_s, \bar{a}_s^\uparrow, \bar{a}_s^\downarrow),$$

(1)

where for every $1 \leq k \leq s$ and a vector of Boolean values $\bar{b}$ that is a solution to SAT($B_k$) (by SAT($B_k$) we mean a set of Boolean vector satisfying $B_k$):

$$\bar{a}_{k-1}^\uparrow[f/\bar{b}] \subseteq \bar{a}_k^\uparrow[f/\bar{b}] \quad \text{and} \quad \bar{a}_k^\downarrow[f/\bar{b}] \subseteq \bar{a}_{k-1}^\downarrow[f/\bar{b}],$$

(2)

where the elements of the vectors are compared pairwise. The starting point is $B_0 = \emptyset$, $\bar{a}_0^\uparrow = (\text{none}, \ldots, \text{none})$, $\bar{a}_0^\downarrow = (\text{nil}, \ldots, \text{nil})$ and the series terminates as soon as SAT($B_s$) = SAT($B_{s-1}$), $\bar{a}_s^\uparrow = \bar{a}_{s-1}^\uparrow$, $\bar{a}_s^\downarrow = \bar{a}_{s-1}^\downarrow$.

Formal proofs are available in the full paper (http://arxiv.org/abs/1503.00622)
Structural subtyping and inheritance

an example for records (messages)

frame factory
\{frame\_price: int, color: int, size: int\}

an interface, which is derived from the service
\{frame\_price: int | $y} \rightarrow \{price: int | $y\}

customer
\{price: int, size: int\}

after specialisation the interface becomes
\{frame\_price: int, size: int\} \rightarrow \{price: int, size: int\}

size is inherited from the input to the output; color is ignored

an example for choices (collections of messages)

warehouse
\{get\_component: ..., rent\_bicycle: ..., replace\_component: ... :\}

an interface, which is derived from the service
\{get\_component: ... | $x :\} \rightarrow \{buy\_bicycle: ... | $x :\}

customer
\{buy\_bicycle: ..., rent\_bicycle: ..., paint\_bicycle: ... :\}

after specialisation the interface becomes
\{get\_component: ..., rent\_bicycle: ... :\} \rightarrow
\{buy\_bicycle: ..., rent\_bicycle: ...:\}

rent\_bicycle is inherited from the output to the input; paint\_bicycle cannot be provided to the customer; present of replace\_component in the interface of the producer would cause an error
Inheritance challenges

• How inheritance should work for services with multiple input and output channels?

• What if the data of various sort needs to be inherited from many channels to one?

• How to inherit data in services with accumulating facility (i.e. a service produces a message in response to a set of messages)?
Implementation

• The CSP solver has been implemented in OCaml
• The solver uses PicoSAT to solve the adjunct SAT problem
• A communication protocol that supports C++ has been implemented. It includes:
  - derivation of interfaces and constraints from the code
  - code specialisation and library generation based on the solution provided by the CSP solver
Summary

• We designed a mechanism that establishes compatibility and specialisation of web-services when they have multiplicity and genericity

• The MDL was introduced to specify flexible service interfaces with support of subtyping, inheritance and Boolean flags

• The problem is represented as a CSP+SAT; the solver has been developed

• Communication protocol for C++ has been developed
Future work

• support of abstract data types (objects)
• performance measurement and optimisation
• improvement of error tracing and reporting
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Thank you!