Interface reconciliation in Kahn Process Networks using CSP and SAT

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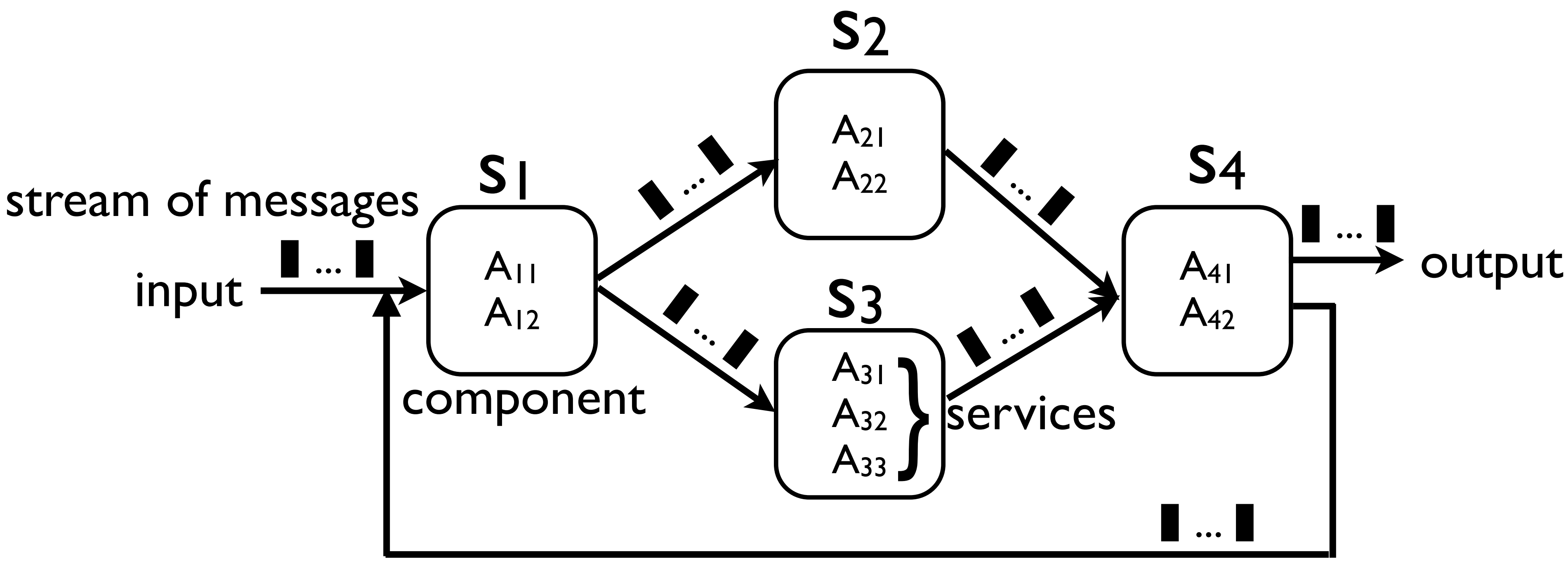
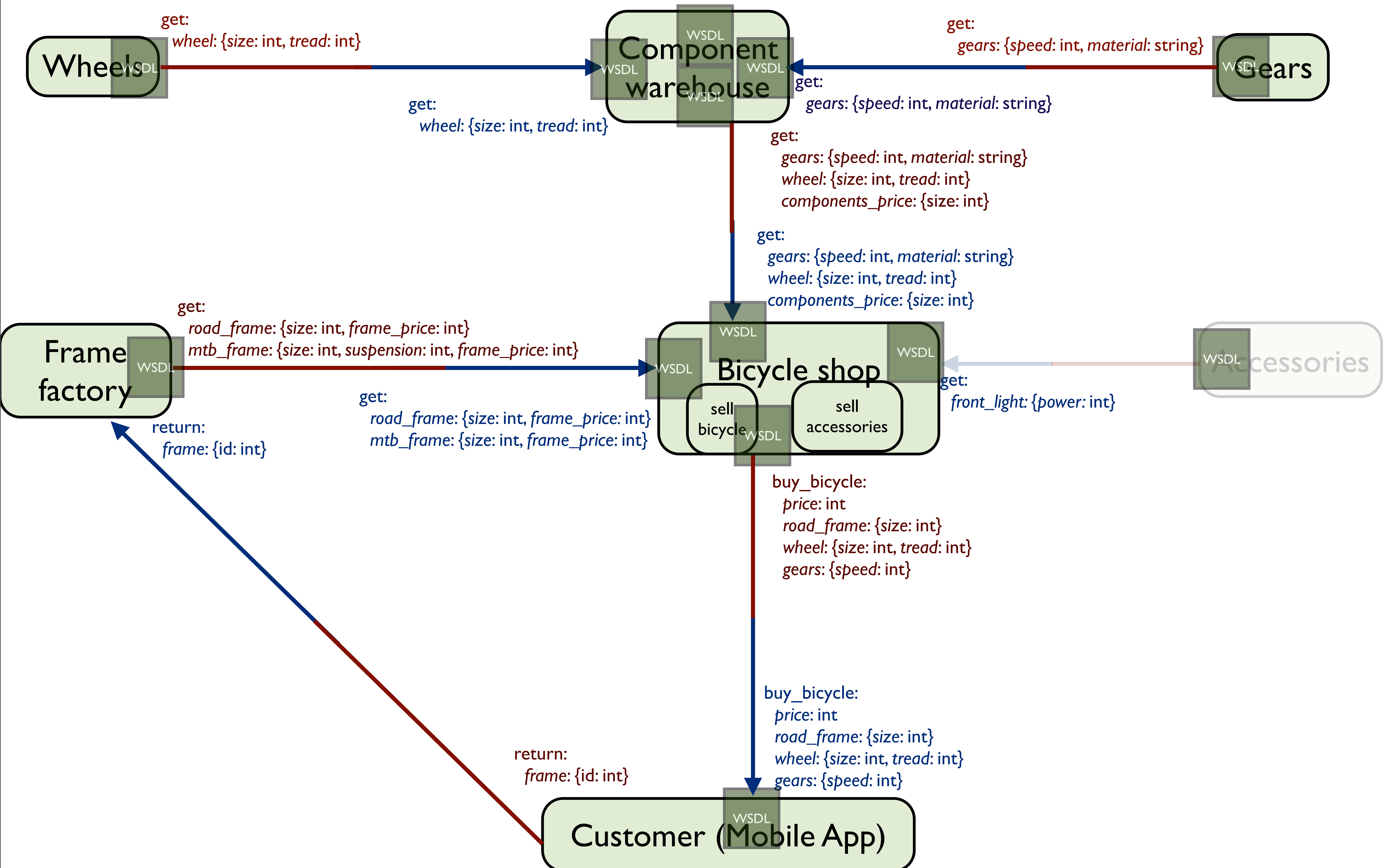
Kahn process networks (KPNs)

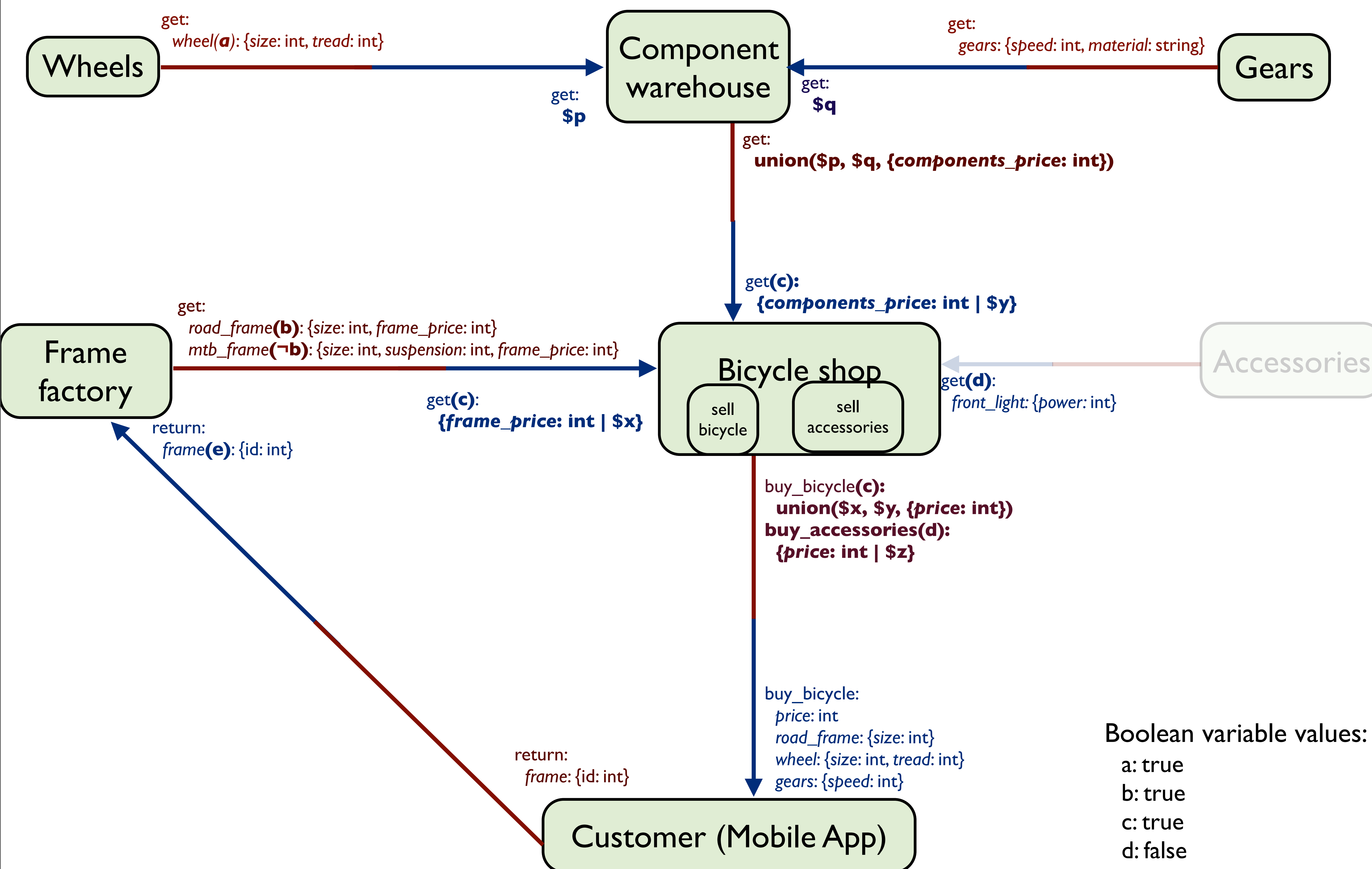


- components are connected by FIFO data channels that transfer self-contained messages (no references or pointers)
- each component contains a set of services. A service is a sequential process that implements some domain-specific algorithm
- the components are developed in a decontextualised manner: 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


get:
wheel: {size: int, tread: int}
Wheels
WSDL
Component warehouse
WSDL
WSDL
WSDL
WSDL
get:
gears: {speed: int, material: string}
Gears
WSDL
get:
wheel: {size: int, tread: int}
get:
gears: {speed: int, material: string}
get:
gears: {speed: int, material: string}
wheel: {size: int, tread: int}
components_price: {size: int}
get:
gears: {speed: int, material: string}
wheel: {size: int, tread: int}
components_price: {size: int}
get:
road_frame: {size: int, frame_price: int}
mtb_frame: {size: int, suspension: int, frame_price: int}
Frame factory
WSDL
Bicycle shop
WSDL
WSDL
WSDL
sell bicycle
WSDL
sell accessories
Accessories
WSDL
get:
front_light: {power: int}
get:
road_frame: {size: int, frame_price: int}
mtb_frame: {size: int, frame_price: int}
return:
frame: {id: int}
buy_bicycle:
price: int
road_frame: {size: int}
wheel: {size: int, tread: int}
gears: {speed: int}
buy_bicycle:
price: int
road_frame: {size: int}
wheel: {size: int, tread: int}
gears: {speed: int}
return:
frame: {id: int}
Customer (Mobile App)
WSDL



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

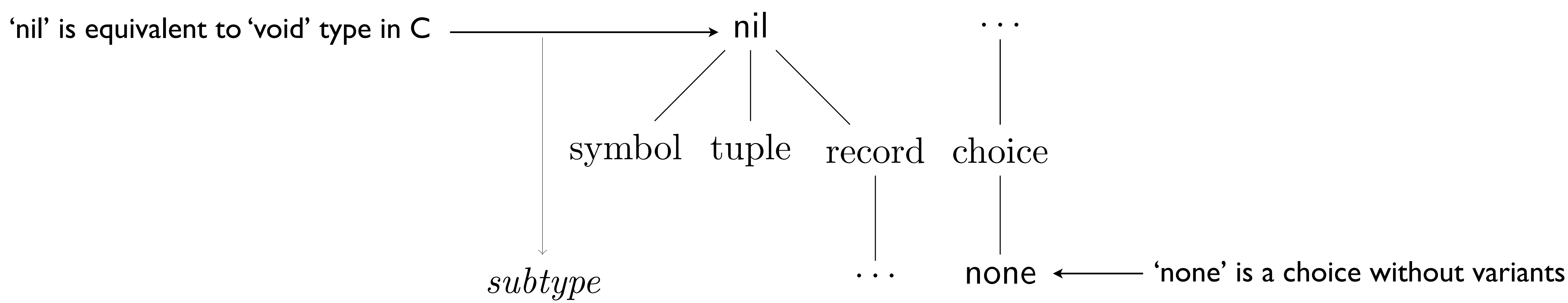
- a static mechanism that establishes compatibility of services and works out necessary conditions
- support of structural subtyping in the interfaces is needed
- inheritance that propagates requirements over the processing graph is needed

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



- 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 $t \sqsubseteq t' \in \mathcal{C}(\mathsf{G})$ find a vector of Boolean values $\vec{b} = (b_1, \ldots, b_l)$, 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 $\vec{f} = (f_1, \ldots, f_l)$, $\uparrow\vec{v} = (\uparrow v_1, \ldots, \uparrow v_m)$, $\downarrow\vec{v} = (\downarrow v_1, \ldots, \downarrow v_n)$. 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.

$\vec{a}^{\uparrow}$ and $\vec{a}^{\downarrow}$ are vectors of semiground terms called *conditional approximations* of the solution.

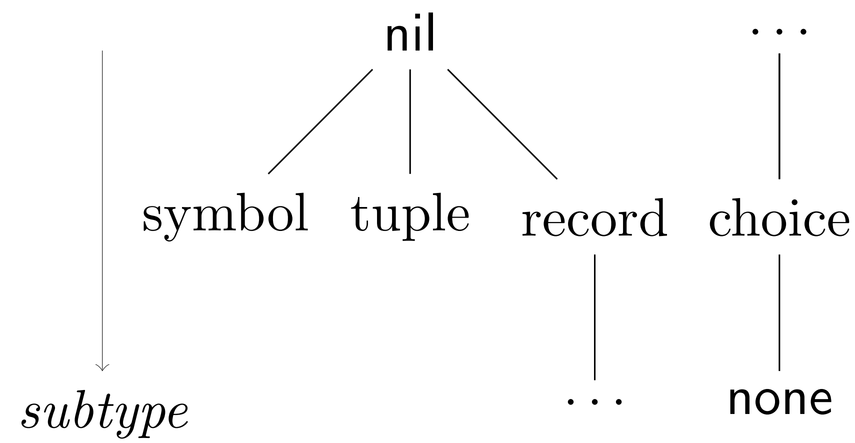
We seek the solution as a fixed point of a series of approximations in the following form:

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

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

$$\vec{a}^{\uparrow}_{k-1}[\vec{f}/\vec{b}] \sqsubseteq \vec{a}^{\uparrow}_k[\vec{f}/\vec{b}] \qquad \text{and} \qquad \vec{a}^{\downarrow}_k[\vec{f}/\vec{b}] \sqsubseteq \vec{a}^{\downarrow}_{k-1}[\vec{f}/\vec{b}], \qquad (2)$$

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



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Structural subtyping and inheritance

an example for records (messages)

an interface, which is derived from the service

frame factory

{frame_price: int,
color: int, *size*: int}

{*frame_price*: int | \$y} → {*price*: int | \$y}

customer

{*price*: int, *size*: int}

after specialisation the interface becomes

{*frame_price*: int, *size*: int} → {*price*: int, *size*: int}

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

an example for choices (collections of messages)

warehouse

an interface, which is derived from the service

customer

(: *get_component*: ...,
rent_bicycle: ...,
~~*replace_component*: ...~~ :)

(: *get_component*: ... | \$x :) → (: *buy_bicycle*: ... | \$x :)

(: *buy_bicycle*: ...,
rent_bicycle: ...,
paint_bicycle: ... :)

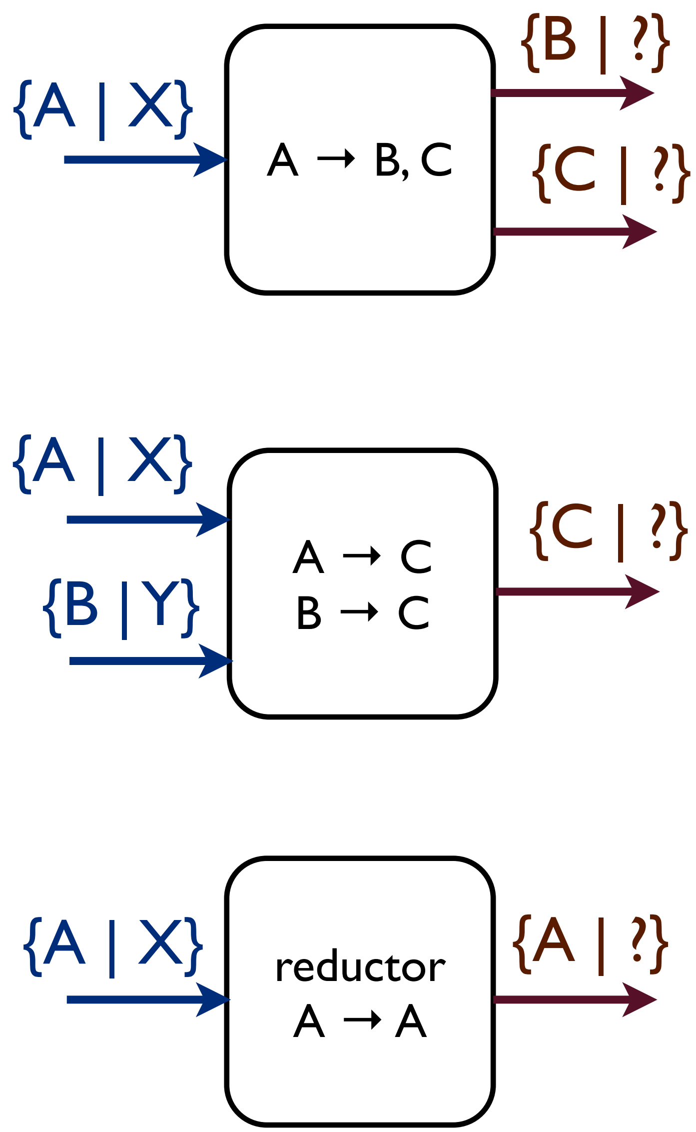
after specialisation the interface becomes

(: *get_component* : ..., *rent_bicycle*: ... :) →
(: *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!