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Model-based Development of Web Services using Design-by-Contract

Lesster

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TFS Colloqium, TU Berlin, 5. 12. 2005

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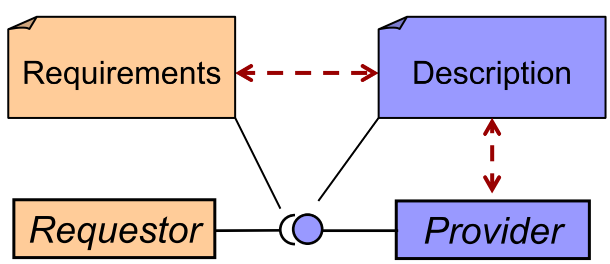
Consistency of Service Composition



1. External: between interface specifications
2. Internal: between interface specification and implementation

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Example: Car Rental Service

<<interface>>
RentalServiceRequired
reservCar(c:Customer, car:Car, ri:RentalInfo)
...

<<interface>>
RentalServiceProvided
makeReserv(c:Customer, car:Car, ri:RentalInfo): EContract
...

Matching *provider* and *requestor* specification within *registry* must ensure compatibility of

- Data types
  - Does Customer have the same meaning for requestor and provider?
- Operation signatures
  - Can provider operation be supplied with suitable parameters from a call of requestor operation?
- Behavior
  - Does provided operation actually carry out what is expected by a requestor?

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Data Types and Signatures

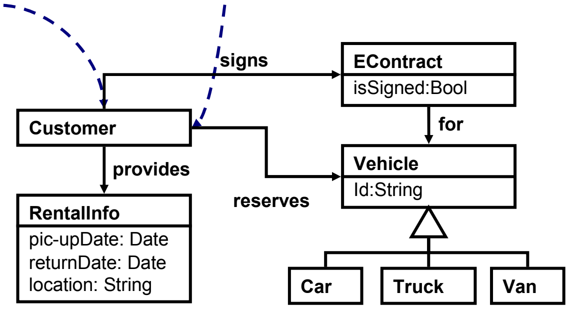
<<interface>>
RentalServiceRequired
reservCar(c:Customer, car:Car, ri:RentalInfo)
...

<<interface>>
RentalServiceProvided
makeReserv(c:Customer, car:Car, ri:RentalInfo): EContract
...

- Reorder and rename pars
- Skip input of requestor
- Ignore output of provider

Data types: parties use common domain model (ontology)

Operation signatures: Zaremski and Wing: *Signature matching: A tool for using software libraries.* TOSEM 1995.



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Behavior: Operation Contracts

Pre-condition:
Customer provides rental info and selects car

Effect:
Car is reserved for customer

Required

- Formal specification (logic, graph transformation, …) for automatic matching
- Integration into mainstream SW development methods (UML) for wider applicability

Outline

- Contracts as graph transformation rules
- Semantics of rules
- Semantic / syntactic compatibility, soundness

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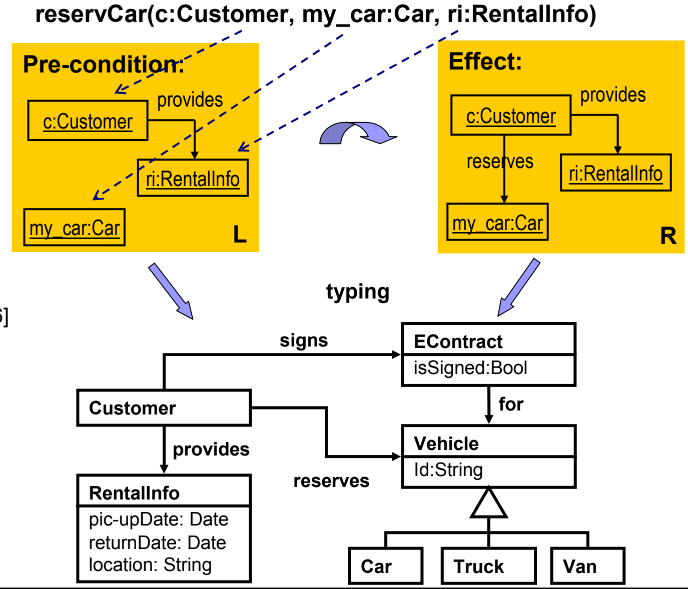
Contracts as Graph Transformation Rules

Signature: **reservCar(c:Customer, my_car:Car, ri:RentalInfo)**

Behavior:
GT rule

Typed DPO
[Corradini et al 96]

Data types:
type graph



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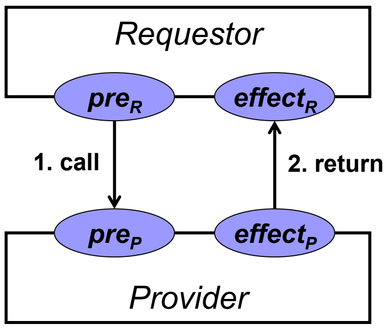
What is the right notion of compatibilty? That depends on …



how services should interact:

1. Requestor guarantees $\boldsymbol{pre_R}$
   → Provider assumes $\boldsymbol{pre_P}$
2. Provider guarantees $\boldsymbol{effect_P}$
   → Requestor assumes $\boldsymbol{effect_R}$

… a *contravariant* relation.

what it should mean, that:

- an *assumption* is correct
- a *guarantee* is fulfilled

… a question about the *semantics of contracts.*

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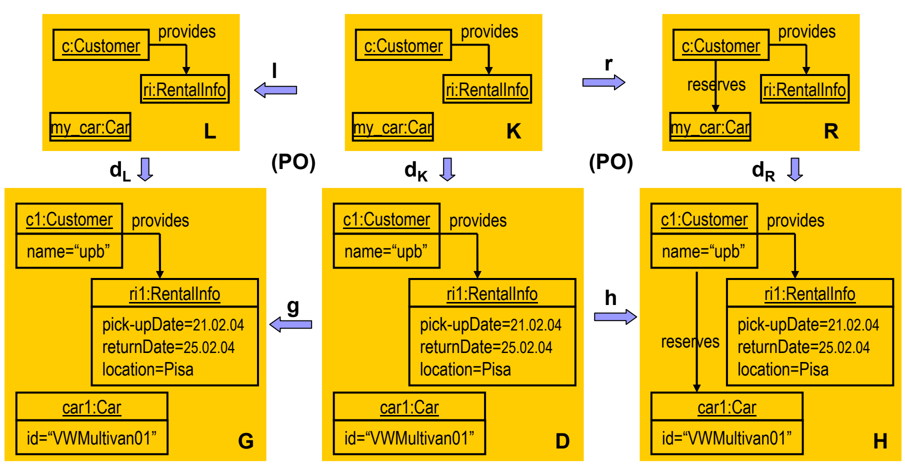
Operational Semantics: The DPO Approach



- *L* is embedded into graph ***G***.
- The elements of ***G*** matched by ***L- l(K)*** are removed.
- The elements matched by ***R - r(K)*** are added to *D*.

The changes to *G* are exactly those specified by the rule

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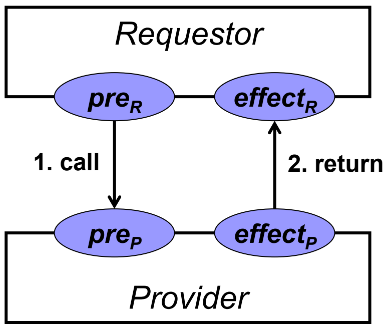
Loose Semantics of Contracts

Requestor has only loose idea of behavior of the other service



Provider has complete info, but may prefer not to publish everything

→ Contracts are incomplete specifications of service behavior

$$\begin{tikzcd} L \arrow[d, "d_L"'] \arrow[dr, phantom, "(PB)"] & K \arrow[l, "l"'] \arrow[r, "r"] \arrow[d, "d_K"] \arrow[dr, phantom, "(PB)"] & R \arrow[d, "d_R"] \\ G & D \arrow[l, "g"] \arrow[r, "h"'] & H \end{tikzcd}$$

Formally: Double-Pullback (DPB), allows unspecified

- Deletion: *at least* elements of G matched by L - l(K) are removed
- Creation: *at least* elements matched by R - r(K) are added to D

(faithful) transition vs. transformation

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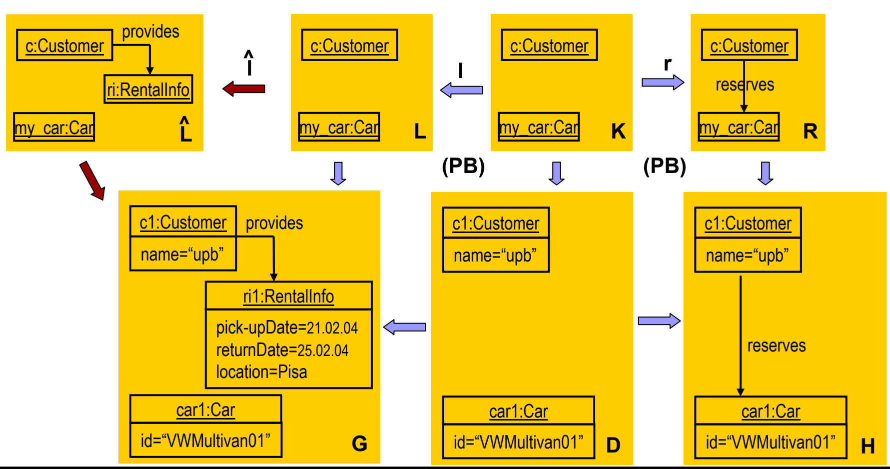
Contracts as Rules, revisited
→ Positive Application Conditions

Precondition: what must be

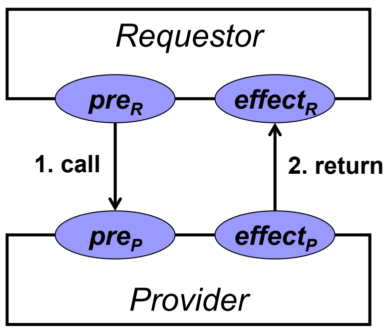
- present before, no matter what happens later

Effect: what must be

- deleted
- preserved
- created



What is the right notion of compatibility? That depends on …



how services should interact:

1. Requestor guarantees ***pre_R***
   → Provider assumes ***pre_P***
2. Provider guarantees ***$effect_P$***
   → Requestor assumes ***$effect_R$***

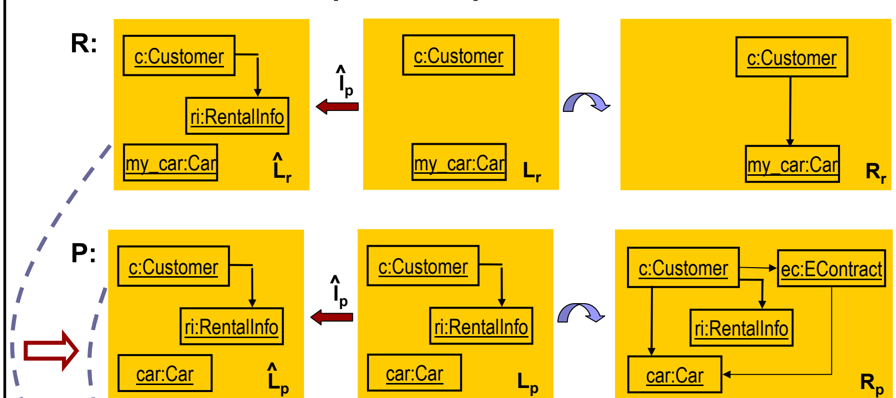
… a *contravariant* relation.

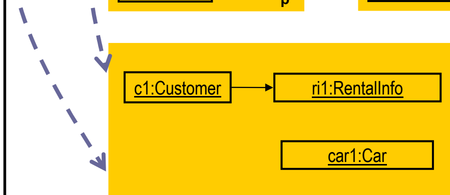
what it should mean, that:

- an *assumption* is correct
- a *guarantee* is fulfilled ✓

… a question about the *semantics of contracts.*

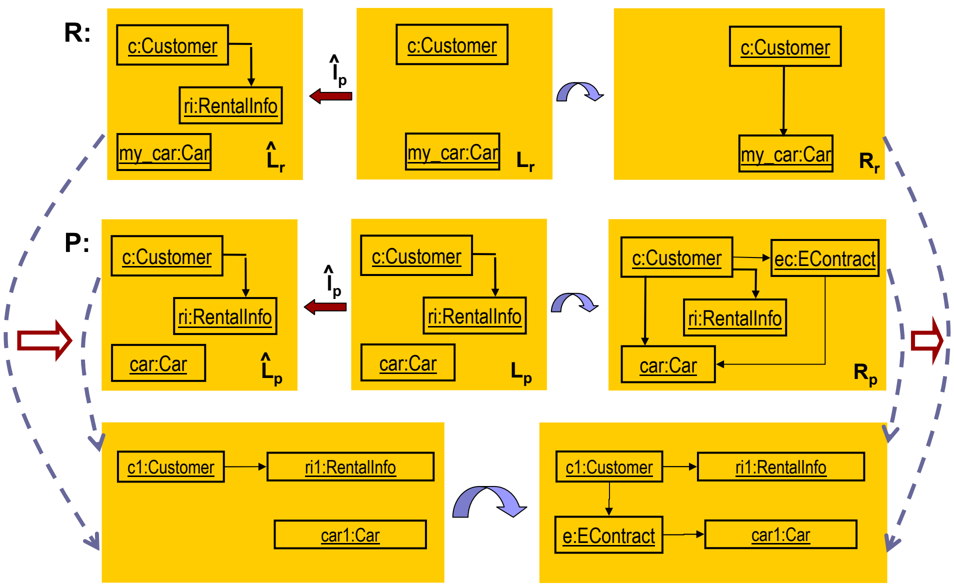
Semantic Compatibility



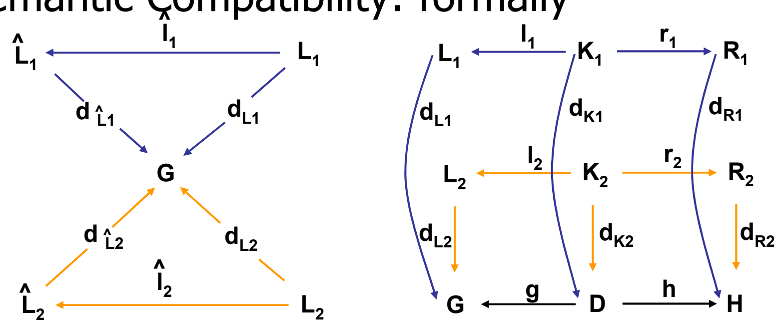


1. ***pre_R → pre_P :*** applicability of requestor rule **implies** applicability of provider rule
2. ***$effect_P$ → $effect_R$:*** transition via provider rule **is also** transition via requestor rule.

Semantic Compatibility



Semantic Compatibility: formally



$(p_1, \hat{L}_1)$ semantically matches $(p_2, \hat{L}_2)$, in symbols $(p_2, \hat{L}_2) \models_{match} (p_1, \hat{L}_1)$, iff:

(i) for all graphs G, if there exists $d_{\hat{L}_1} : \hat{L}_1 \to G$ s.t. $d_{L_1} := d_{\hat{L}_1} \circ \hat{l}_1$ satisfies IC of p_1, then there exists $d_{\hat{L}_2} : \hat{L}_2 \to G$ s.t. $d_{L_2} := d_{\hat{L}_2} \circ \hat{l}_1$ satisfies IC of p_2, and

(ii) for all spans $t : (G \xleftarrow{g} D \xrightarrow{h} H)$, if there exists a transition $G \overset{p_2/d_2}{\rightsquigarrow} H$, then there exists a transition $G \overset{p_1/d_1}{\rightsquigarrow} H$ using the same bottom span t.

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What do we have?

Semantic compatibility relation $|=$

- quantified over all graphs and transitions
- cannot be verified directly

Objective: syntactic matching relation $|--$

- Soundness: p_2 $|--$ p_1 *implies* p_2 $|=$ p_1
- Completeness: p_2 $|=$ p_1 *implies* p_2 $|--$ p_1

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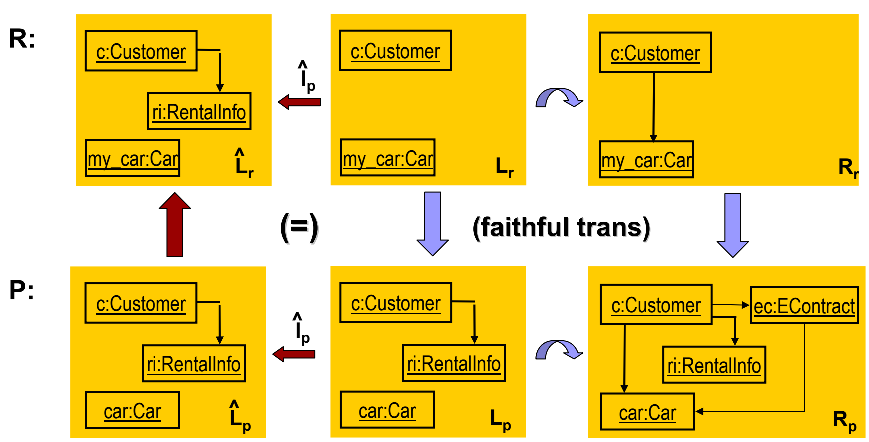
Syntactic Matching Relation



pre$_R$ → pre$_P$: requestor must provide all information necessary for the execution of the provider operation,

effect$_P$ → effect$_R$: effect of the provided operation must include those expected by the requestor.

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Syntactic Matching: formally

$$\begin{tikzcd} \hat{L}_1 & L_1 \arrow[l, "\hat{l}_1"'] \\ \hat{L}_2 \arrow[u, "h_{\hat{L}}"] \arrow[r, phantom, "(=)"] & L_2 \arrow[l, "\hat{l}_2"] \arrow[u, "h_L"'] \end{tikzcd}$$

faithful transition

$$\begin{tikzcd} L_1 \arrow[d, "h_L"'] \arrow[r, phantom, "(PB)"] & K_1 \arrow[l, "l_1"'] \arrow[r, "r_1"] \arrow[d, "h_K"] \arrow[r, phantom, "(PB)"'] & R_1 \arrow[d, "h_R"] \\ L_2 & K_2 \arrow[l, "l_2"'] \arrow[r, "r_2"] & R_2 \\ G & D \arrow[l, "g"'] \arrow[r, "h"] & H \end{tikzcd}$$

$(p_1, \hat{L}_1)$ syntactically matches $(p_2, \hat{L}_2)$, in symbols $(p_2 : s_2, \hat{L}_2) \vdash_{match} (p_1 : s_1, \hat{L}_1)$, iff:

(i) there exists an injective graph homomorphism $h_{\hat{L}} : \hat{L}_2 \to \hat{L}_1$ s.t. $h_{\hat{L}} \circ \hat{l}_2$ satisfies IC of p_2, and

(ii) there exist graph homomorphisms $h_L : L_1 \to L_2$, $h_K : K_1 \to K_2$, and $h_R : R_1 \to R_2$ s.t. the diagrams (a), (b), and the diagram on the left commute, and the diagrams (a) and (b) represent a faithful transition.

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What do we have?

✓ Semantic compatibility: relation |=

✓ Syntactic matching: relation |--

✓ Soundness: ***p*₂ |-- *p*₁** *implies* ***p*₂ |= *p*₁**

✓ Completeness: ***p*₂ |= *p*₁** *implies* ***p*₂ |-- *p*₁**

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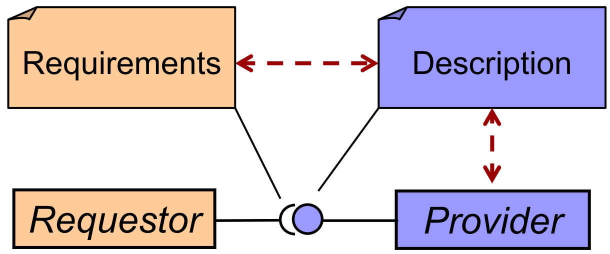
Consistency of Service Composition



- ✓ External: between interface specifications
- 2. Internal: between interface specification and implementation

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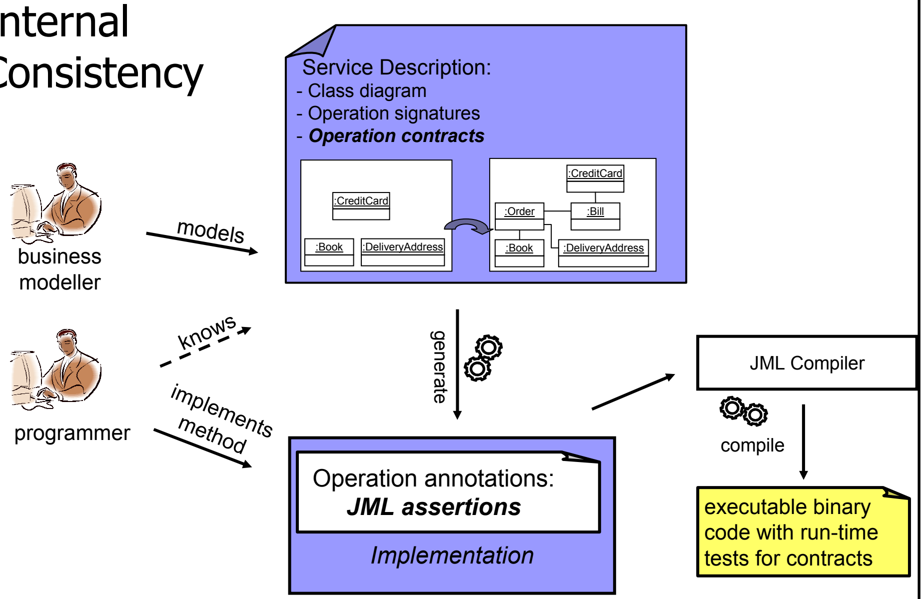
Internal Consistency



JML from Graphical Contracts

Semantic idea: Assume rule ***r*** specifying method ***m*** .

- If ***r*** is applicable to ***G*** , then ***m*** invoked in ***G*** (with appropriate parameters) terminates without exception.
- If invocation yields ***H***, there exists a graph transition from ***G*** to H via ***r***.

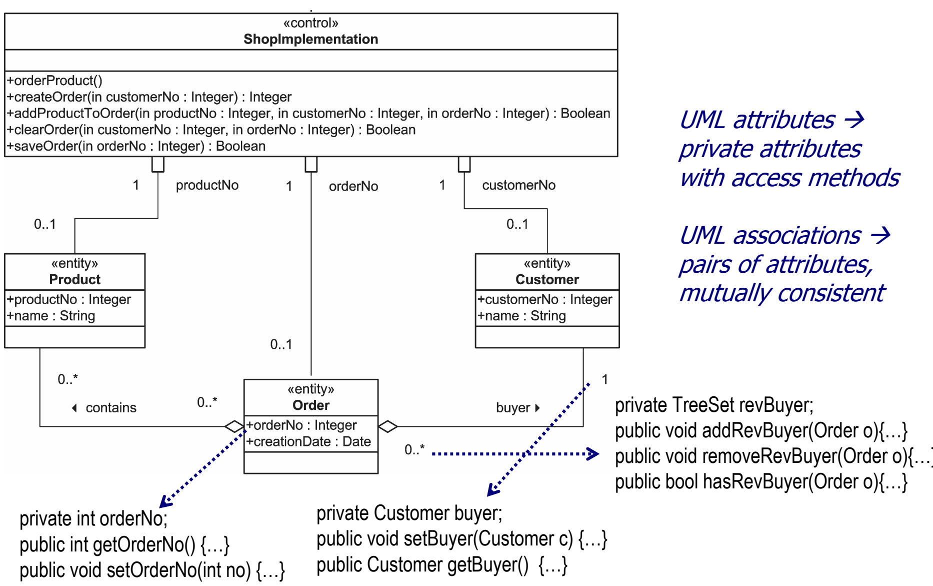
After manually refining the models (business → analysis view), translate

1. class diagram → Java class frames
2. rules → JML
   - patterns
   - rules

Class diagrams → Java class frames

UML attributes → private attributes with access methods

UML associations → pairs of attributes, mutually consistent



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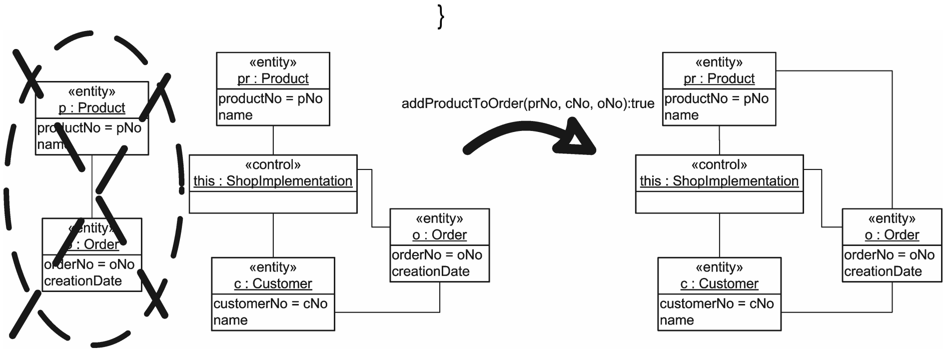
Contracts → JML

```
public class ShopImplementation {
        …
/*          @ public normal_behavior
            @ requires JML-PRE;
            @ ensures JML-POST;
*/
public boolean addProductToOrder(
    int productNo, int customerNo, int orderNo) {…}
        …
}
```



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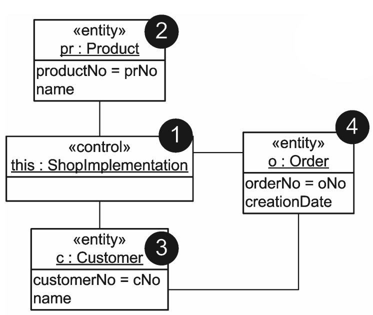
Contracts → JML: Patterns

- starting at *this* navigate to as yet unbound objects, check attributes and links and bind them
- select navigation paths to achieve earliest possible failure




```
@ public normal_behavior
@ requires (\exists Product p;
@           product.contains(p);
@           p.getNo() == productNo);
@           && (\exists Customer c;
@           customer.contains(c);
@           c.getNo() == customerNo
@       && (\exists Order o;
@       order.contains(o);
@       o.getOrderNo() == orderNo
@       && o.getCustomer() == c
@       && o.containsProduct(p) == false)));
```

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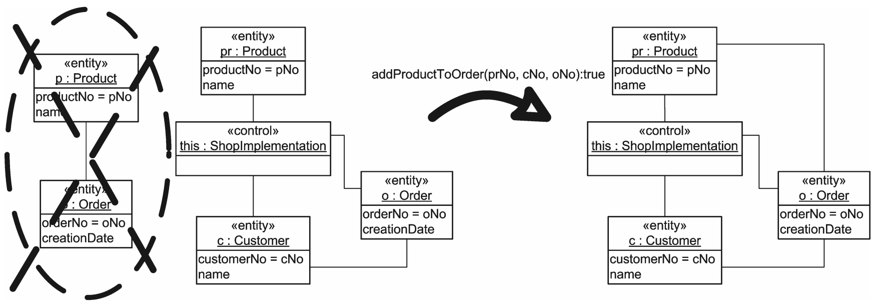
Contracts → JML: Rules



- like let, evaluated in pre state
- works for deterministic matches

```
@ public normal_behavior
@
@ old Product p = getProductByNo(productNo);
@ old Customer c = getCustomerByNo(customerNo);
@ old Order o = c.findOrderByNo(orderNo);
@
@ requires p != null;
@ requires c != null;
@ requires o != null;
@ requires o.getCustomer() == c
@       && o.containsProduct(p) == false;
```

```
@ ensures p != null;
@ ensures c != null;
@ ensures o != null;
@ ensures \not_modified(p, c);
@ ensures o.getCustomer() == c;
@ ensures o.getProducts().contains(p);
```

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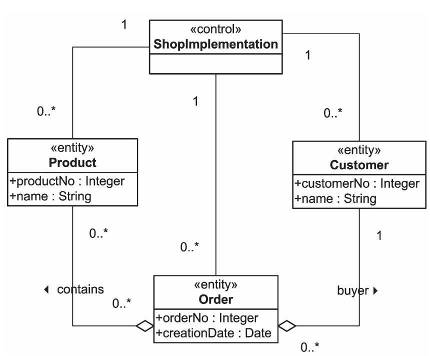
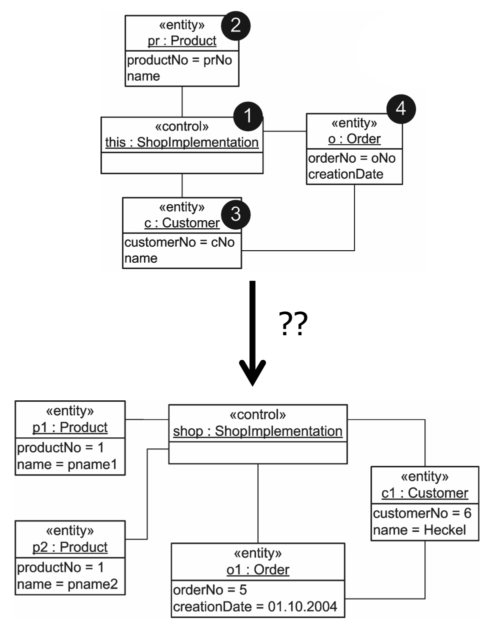
Non-deterministic Matching



alternative class diagram



Solution: store all possible bindings and check that at least on satisfies post-condition

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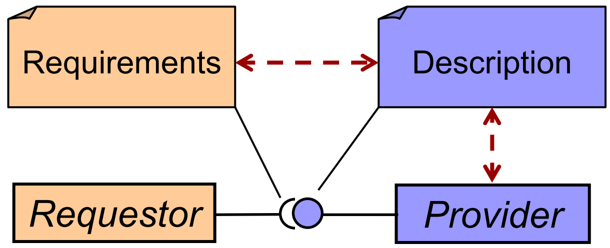
Consistency of Service Composition



Visual representation of contracts based on GT with loose semantics
- External: syntactic characterization of service compatibility
- Internal: mapping of contracts to JML

Open questions
- relation between business-level and analysis-level contracts
- verification of mapping GT → JML
- implementation and evaluation

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Papers

With A. Cherchago, M. Lohmann: *A Formal Approach to Service Specification and Matching based on Conditional Graph Transformation*, ICGT 2004 in Rome

With M. Lohmann: *Model-Driven Development of Reactive Information Systems: From Graph Transformation Rules to JML Contracts, to appear in STTT*