Expressions: Standard library (2)

- **Finite quantification**
  - *c*`->forAll(`*i* : *T* | *e*`)` = *c*`->iterate(`*i* : *T*; *a* : `Boolean` = `true` | *a* **and** *e*`)`
  - *c*`->exists(`*i* : *T* | *e*`)` = *c*`->iterate(`*i* : *T*; *a* : `Boolean` = `false` | *a* **or** *e*`)`
- Selecting values
  - *c*`->any(`*i* : *T* | *e*`)` — some element of *c* satisfying *e*
  - *c*`->select(`*i* : *T* | *e*`)` — all elements of *c* satisfying *e*
- Collecting values
  - *c*`->collect(`*i* : *T* | *e*`)` — collection of elements with *e* applied to each element of *c*
  - *c*`.`*p* — collection of elements *v*.*p* for each *v* in *c* (short-hand for `collect`)

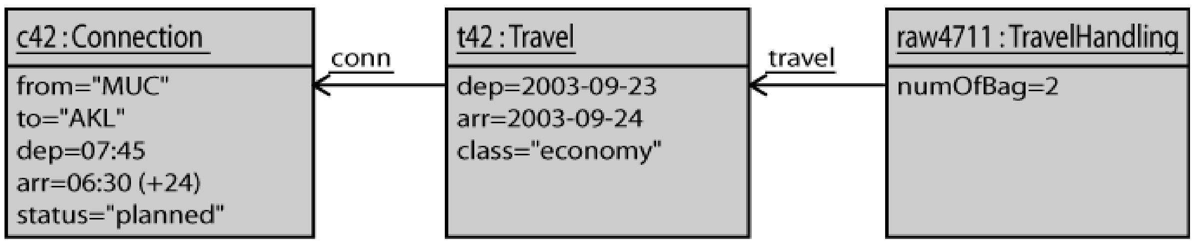
C`.allInstances()`	all current instances of classifier *C*
o`.oclIsInState(`*s*`)`	is *o* currently in state machine state *s*?
v`.oclIsUndefined()`	is value *v* null or invalid?
v`.oclIsInvalid()`	is value *v* invalid?

Evaluation

- Strict evaluation with some exceptions
  - `(if (1/0 = 0) then 0.0 else 0.0 endif).oclIsInvalid() = true`
  - `(1/0).oclIsInvalid() = true`
- Short-cut evaluation for **and**, **or**, **implies**
  - `(1/0 = 0.0) and false = false`
  - `true or (1/0 = 0.0) = true`
  - `false implies (1/0 = 0.0) = true`
  - `(1/0 = 0.0) implies true = true`
  - `if (0 = 0) then 0.0 else 1/0 endif = 0.0`

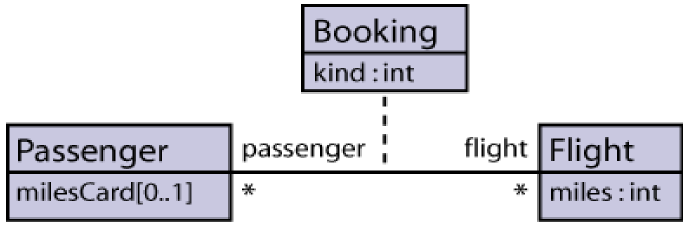
- In general, OCL expressions are evaluated over a system state.

e.g., represented
by an object diagram



Connection to UML

- Import of classifiers and enumerations as types
- Properties accessible in OCL
  - Attributes
    - p.milesCard (with p : Passenger)
  - Association ends
    - p.flight, p.booking, p.booking[flight]
  - { query } operations
  - Access to stereotypes via v.stereotype



- **Representation of multiplicities**

a[1] : T	a : T
a[0..1] : T	a : Set(T) or T
a[m..n] : T	a : Set(T)
a[*] : T { unordered }	a : Set(T)
a[*] : T { ordered }	a : OrderedSet(T)
a[*] : T { bag }	a : Bag(T)

Invariants

context classifier

boolean expression

```
context Passenger
inv: ma.statusMiles > 10000 implies
     status = Status::Albatros
```

Notational variants

explicit `self` (refers to instance of discourse)

```
context Passenger
inv statusLimit: self.ma.statusMiles > 10000 implies
                 self.status = Status::Albatros
```

optional name

```
context p : Passenger
inv statusLimit: p.ma.statusMiles > 10000 implies
                 p.status = Status::Albatros
```

replacement for `self`

Semantics of invariants

- Restriction of valid states of classifier instances
  - when observed from outside
- Invariants (as all constraints) are inherited via generalizations
  - but how they are combined is not predefined
- One possibility: Combination of several invariants by **conjunction**

context C
inv: I_1

context C
inv: I_2

$\rightsquigarrow$

context C
inv: I_1 **and** I_2

Pre-/post-conditions

- In UML models, pre- and post-conditions are defined separately
  - not necessarily as pairs
  - «precondition» and «postcondition» as constraint stereotypes

```
context Passenger::consumeMiles(b : Booking) : Boolean
pre: ma->notEmpty() and
     ma.flightMiles >= b.flight.miles

context Passenger::consumeMiles(b : Booking) : Boolean
post: ma.flightMiles = ma.flightMiles@pre-b.flight.miles and
      result = true
```

- Some constructs only available in post-conditions
  - values at pre-condition time — *p*`@pre`
  - result of operation call — `result`
  - whether an object has been newly created — *o*`.oclIsNew()`
  - messages sent — *o*`^`*op*`()`, *o*`^^`*op*`()`

Semantics of pre-/post-conditions

- Standard interpretation
  - A pre-/post-condition pair (P, Q) defines a relation R on system states such that (σ, σ') $\in R$, if $\sigma \models P$ and (σ, σ') $\models Q$.
    - system state σ on operation invocation
    - system state σ' on operation termination (Q may refer to σ by `@pre`).
  - Thus (P, Q) equivalent to (`true`, P`@pre` **and** Q).

- **Meyer's contract view**
  - A pre-/post-condition pair (P, Q) induces benefits and obligations.
  - benefits and obligations differ for implementer and user

	obligation	**benefit**
user	satisfy P	Q established
implementer	if P satisfied, establish Q	P established

Combining pre-/post-conditions

- Standard interpretation
  - joining pre- and post-conditions conjunctively

context C::op()
pre: P_1 **post:** Q_1

context C::op()
pre: P_2 **post:** Q_2

$\leadsto$

context C::op()
pre: P_1 **and** P_2
post: Q_1 **and** Q_2

- Alternative interpretation
  - **case distinction** (like in protocol state machines)
  - only useful for pre-/post-condition pairs

context C::op()
pre: P_1 **post:** Q_1

context C::op()
pre: P_2 **post:** Q_2

$\leadsto$

context C::op()
pre: P_1 **or** P_2
post: (P_1@pre **implies** Q_1)
and (P_2@pre **implies** Q_2)

Messages

```
context Subject::hasChanged()
post: observer^update(self)
```

---- in calls on hasChanged, some update message with argument `self` will have been sent to observer

```
context Subject::hasChanged()
post: observer^update(? : Subject)
```

---- the actual argument does not matter

```
context Subject::hasChanged()
post: let messages : Set(OclMessage) =
            observer^^update(? : Subject)
      in messages->notEmpty() and
         messages->forAll(m |
            m.result().oclIsUndefined() and
            m.hasReturned() and
            m.subject = self)
```

- `observer^^update(? : Subject)` ---- all those messages
- result of message call ---- `m.result()`
- whether it has finished ---- `m.hasReturned()`
- its actual parameter value ---- `m.subject`

Initial values and derived properties

- Initial values
  - fix the initial value of a property of a classifier

```
package Booking                          -- which package
  context Passenger::status              -- which property
  init: Status::Swallow                  -- initial value
endpackage
```

- { derived } properties
  - define how the value of a property is derived from other information

```
context Passenger::currentFlights : Sequence(Flight)
derive: self->collect(booking)
              ->select(date = today()).flight->asSequence()
```

Query bodies and model features

- Bodies of { query } operations
  - define the value returned by a query operation
  - can be combined with a precondition

```
context TravelHandling::delay() : Minutes
body: tsh.delay->sum()
```

- Definition of additional model features
  - defined for the context classifier

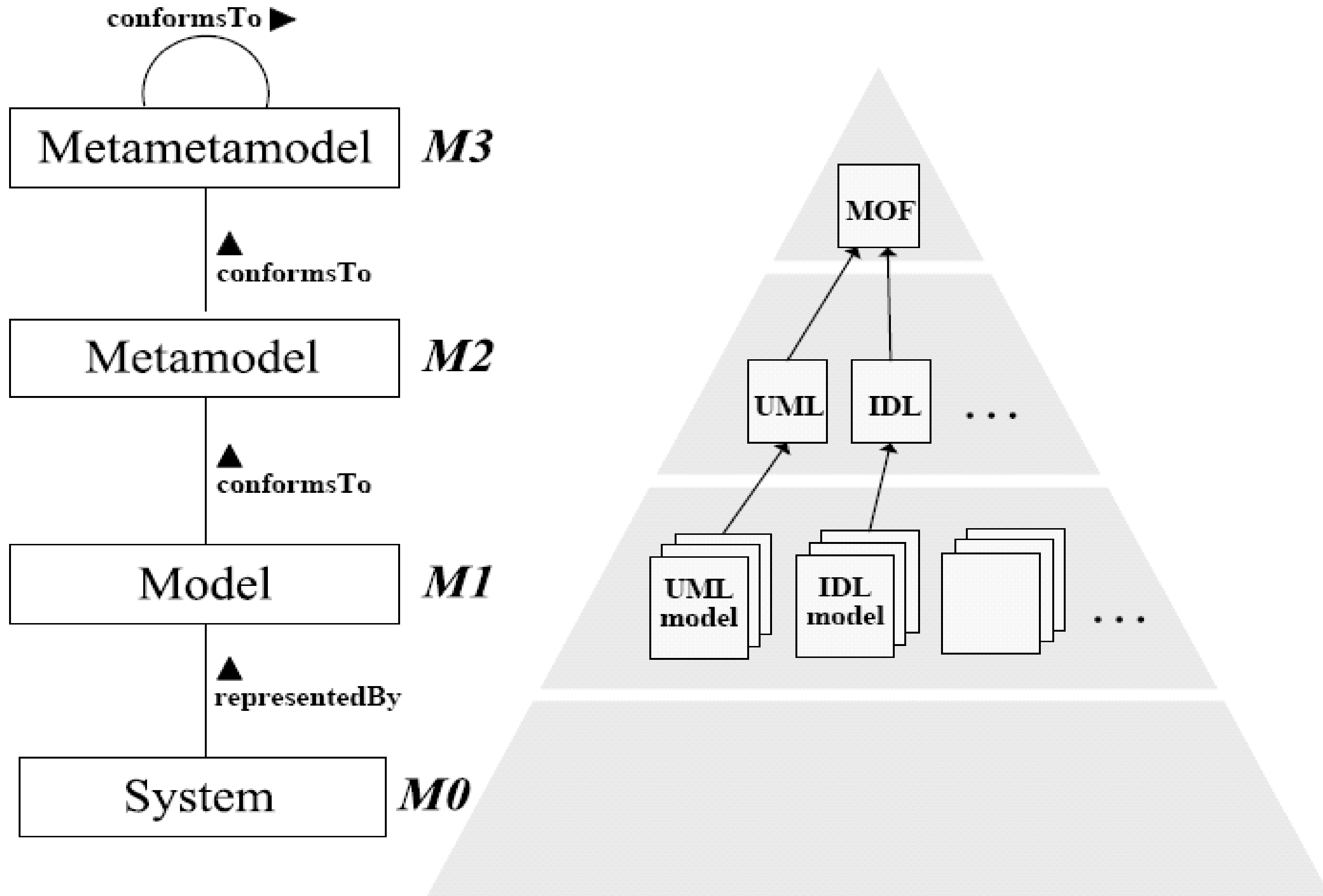
```
context TravelStageHandling
def: isEarly() : Boolean = self.delay < 0

context TravelHandling
def: someEarly() : Boolean = tsh->exists(isEarly())
```

Wrap up

- Formal language for specifying
  - invariants — **context** C **inv**: I
  - pre-/post-conditions — **context** C::op() : T **pre**: P **post**: Q
  - query operation bodies — **context** C::op() : T **body**: e
  - initial values — **context** C::p : T **init**: e
  - derived attributes — **context** C::p : T **derive**: e
  - modelling attributes and operations — **context** C **def**: p : T = e
- Side-effect free
- Typed language
- OCL specifications provide
  - verification conditions
  - assertions for implementations

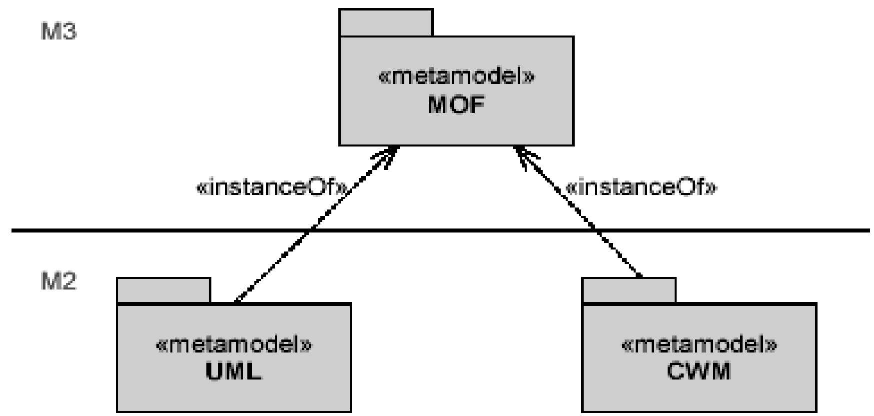
Meta-Object Facility 2

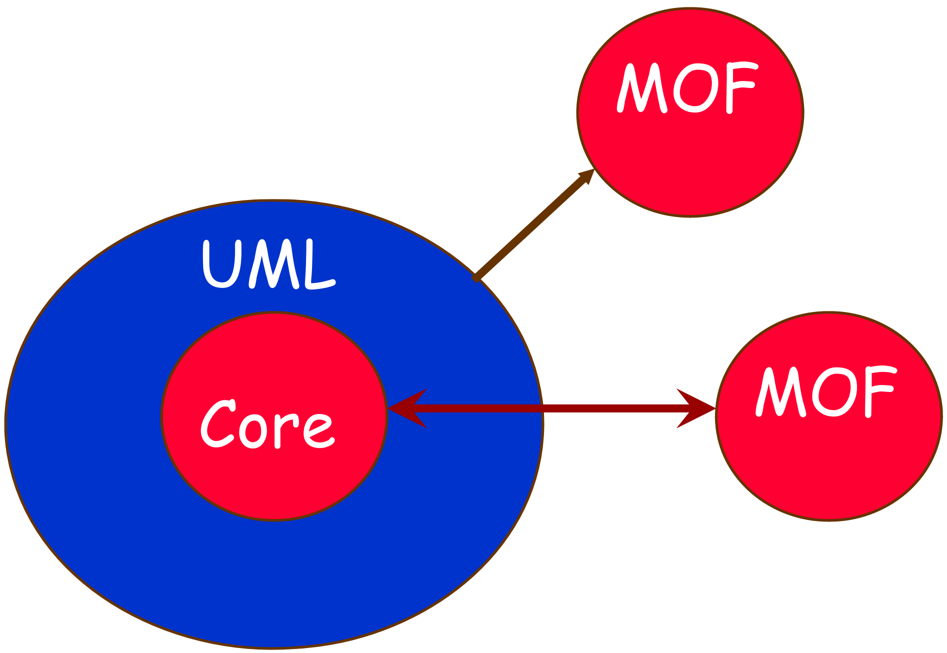
OMG's standards UML and MOF



Relations between UML 2 and MOF 2

- MOF meta-meta-model of UML 2
- MOF is (based on) the core of UML 2
- UML 2 is a drawing tool of the MOF 2
- Definition synchronization





Meta-Object Facility (MOF)

- A **meta-data management framework**
- A language to be used for defining languages
  - i.e., it is an OMG-standard meta-modelling language.
  - The UML metamodel is defined in MOF.
- **MOF 2.0 shares a common core with UML 2.0**
  - Simpler rules for modelling metadata
  - Easier to map from/to MOF
  - Broader tool support for metamodeling (i.e., any UML 2.0 tool can be used)

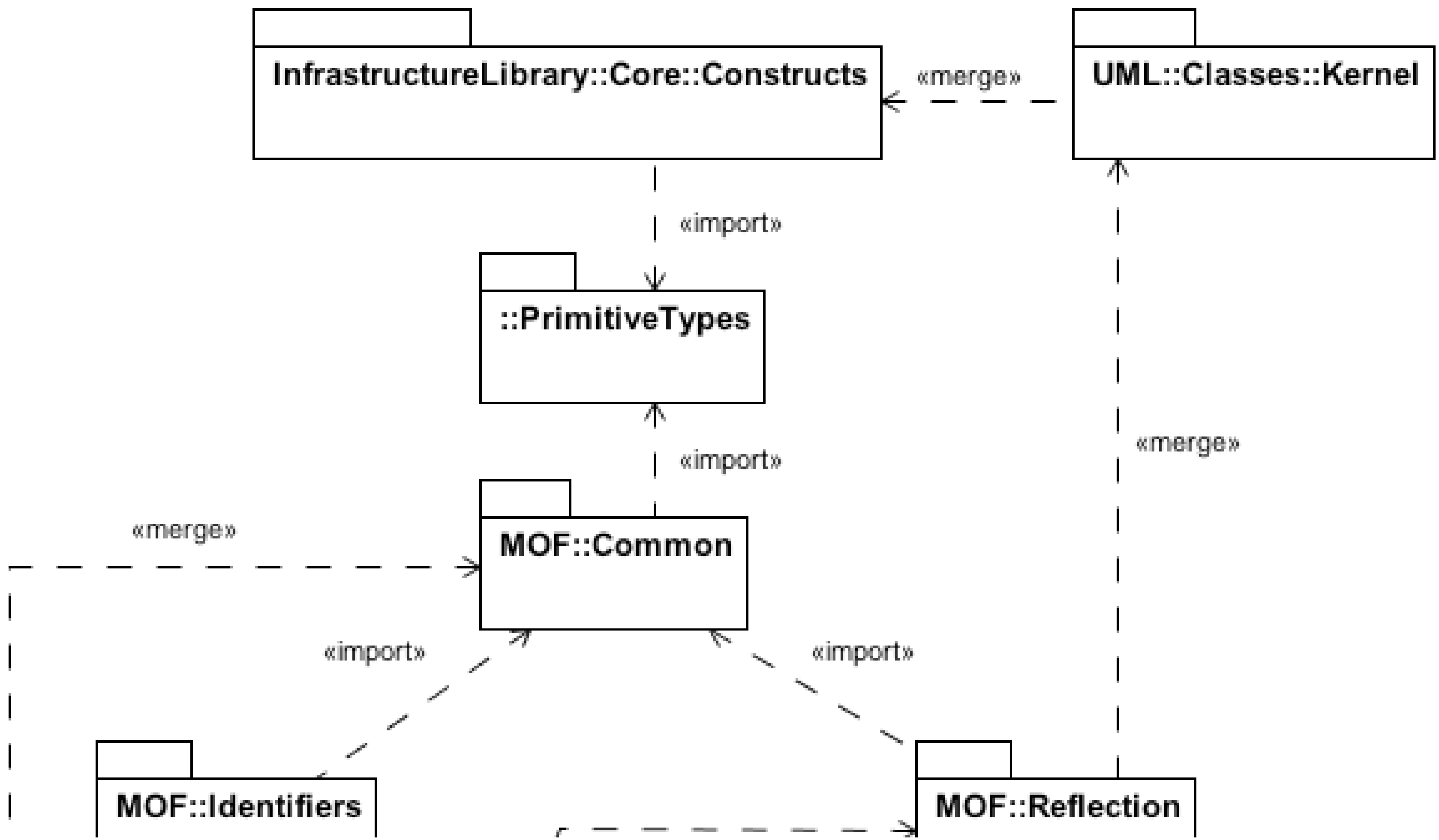
- MOF has **evolved** through several versions
  - MOF 1.x is the one most widely supported by tools
  - MOF 2.0 is the current standard, and it has been substantially influenced by UML 2.0
  - MOF 2.0 is also critical in supporting transformations, e.g., QVT and Model-to-text

http://www.omg.org/spec/MOF/2.0

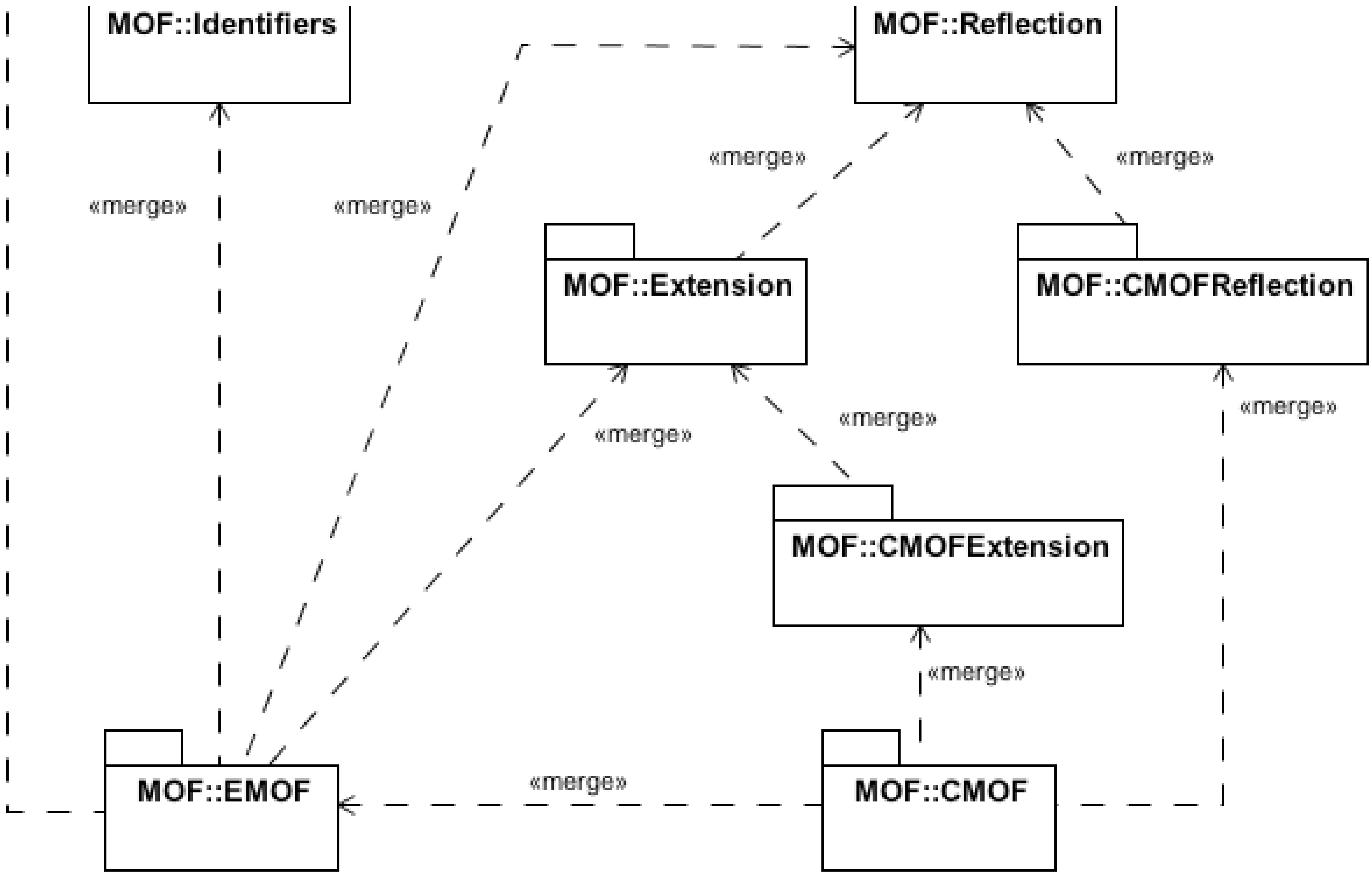
MOF 2.0 Structure

- MOF is separated into **Essential MOF** (**EMOF**) and **Complete MOF** (**CMOF**)
- EMOF corresponds to facilities found in OOP and XML.
  - Easy to map EMOF models to JMI, XMI, etc.
- CMOF is what is used to specify metamodels for languages such as UML 2.
  - It is built from EMOF and the core constructs of UML 2.
  - Both EMOF and CMOF are based on variants of UML 2.

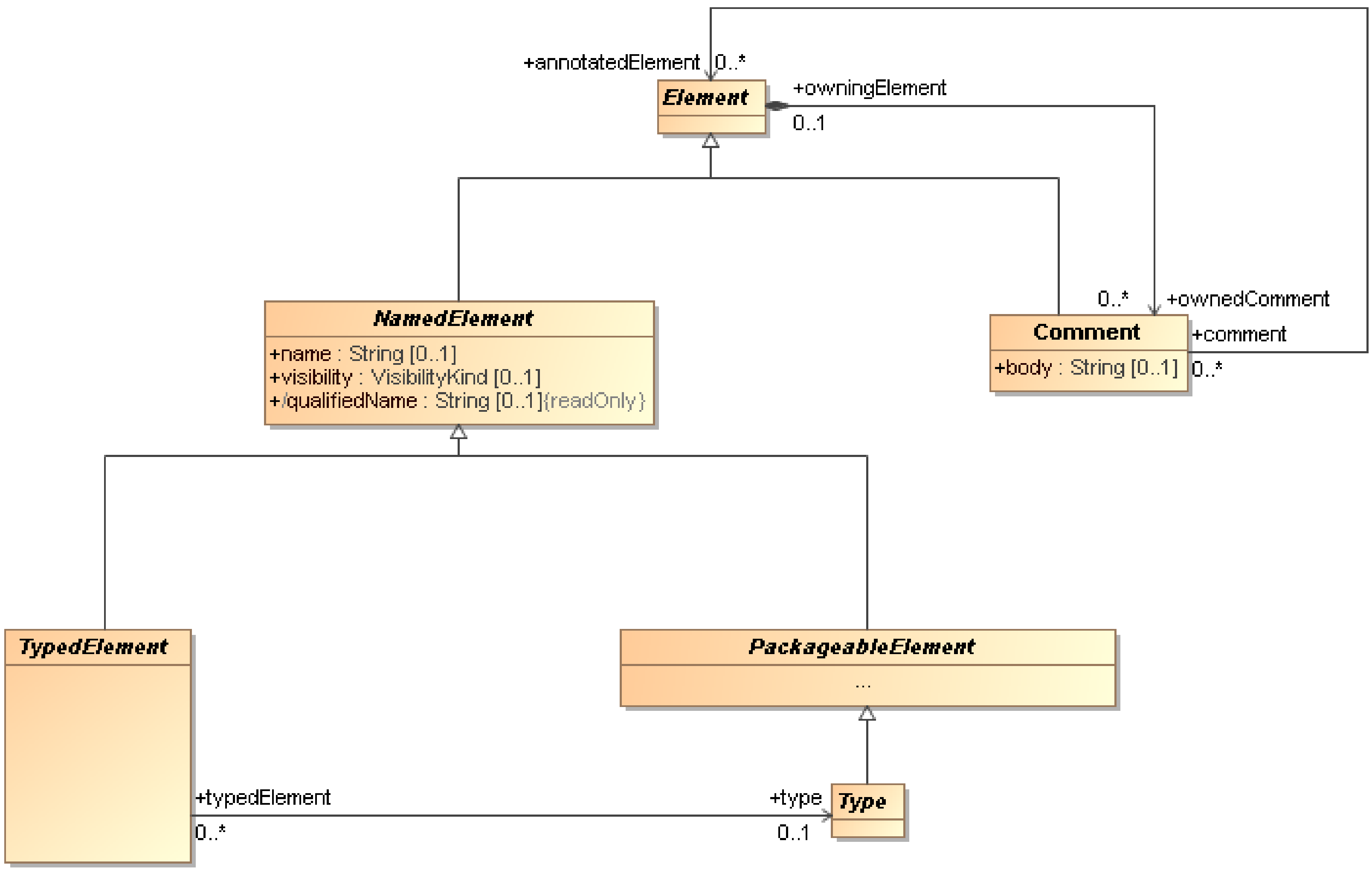
MOF 2.0 Relationships (1)



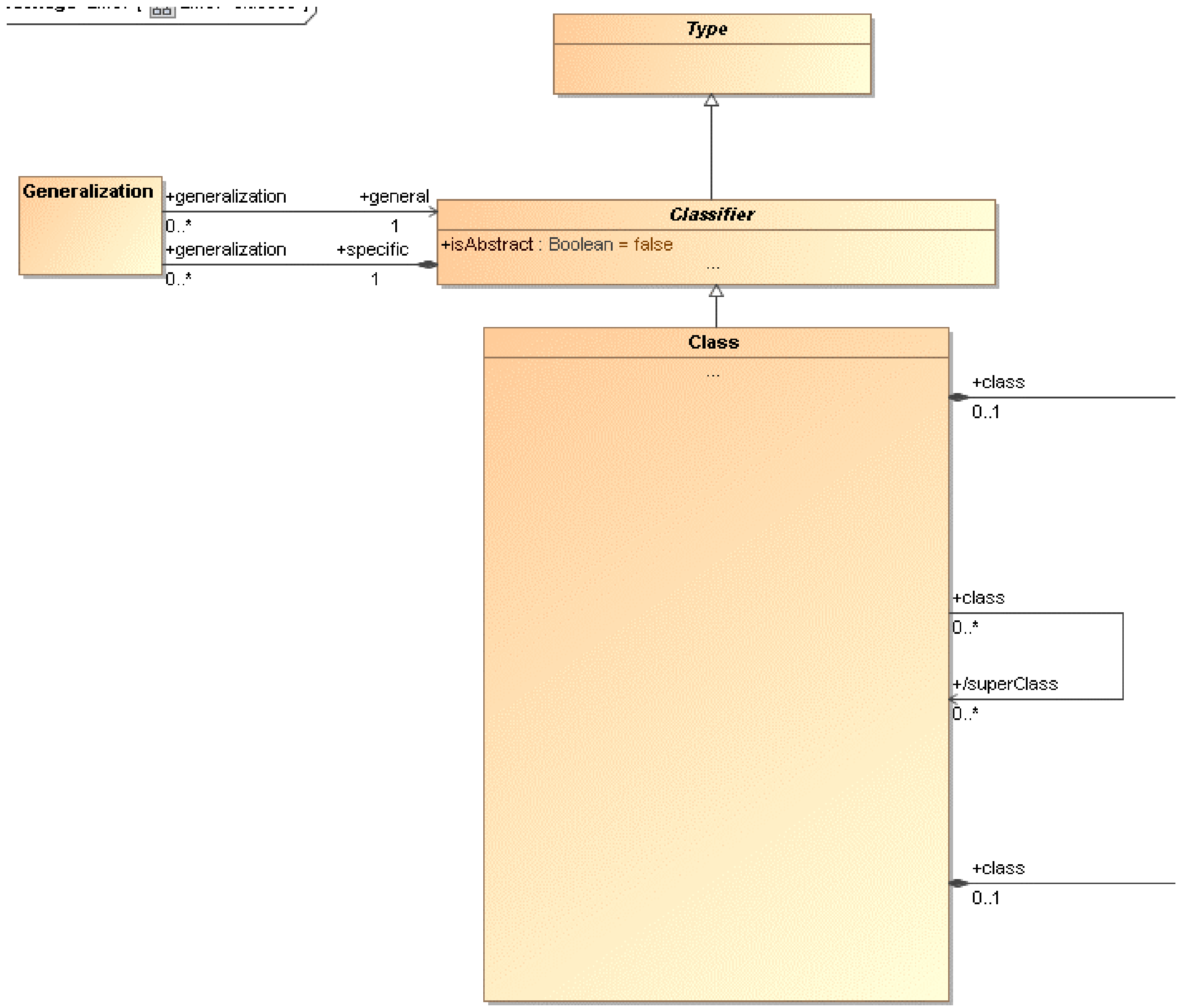
MOF 2.0 Relationships (2)



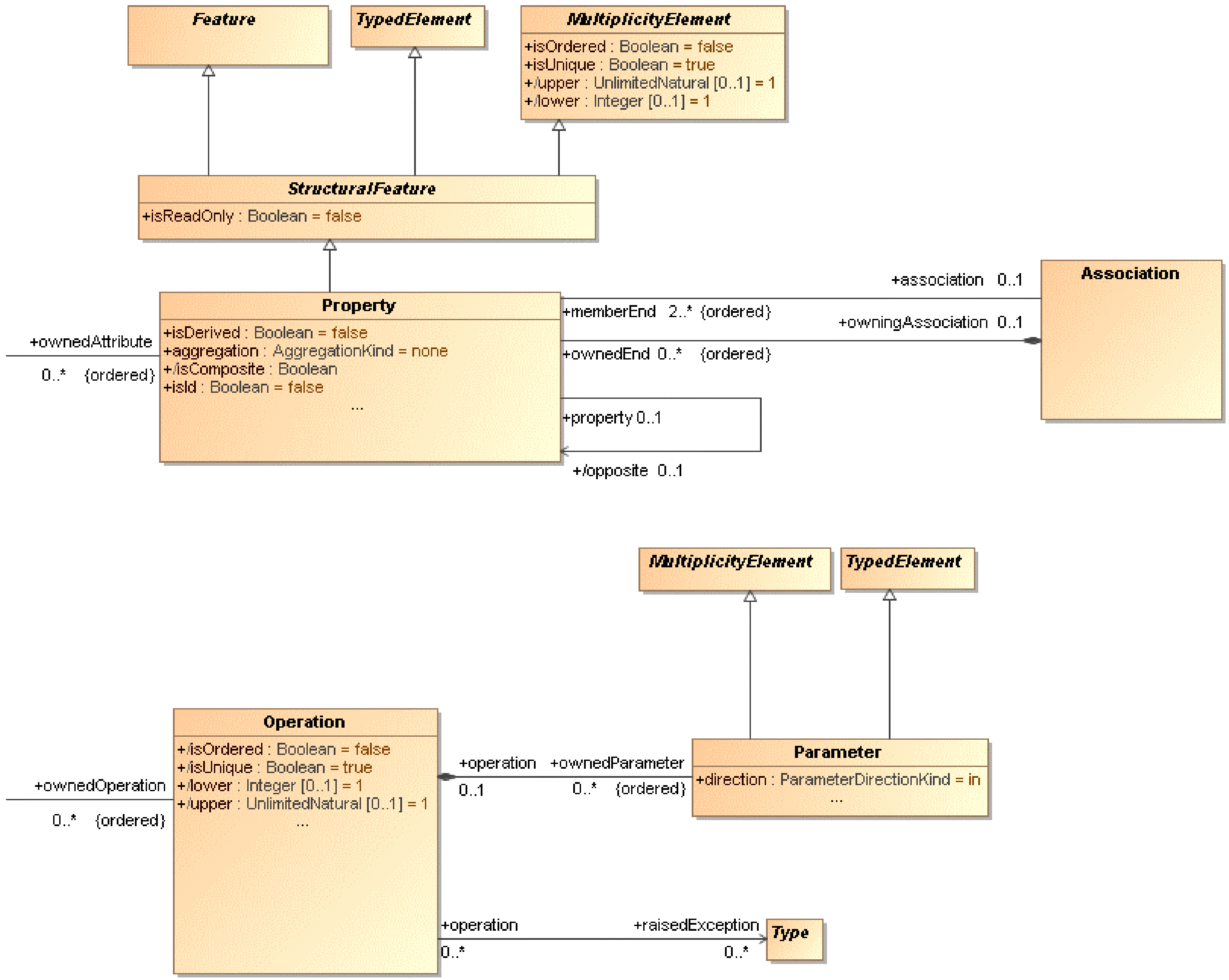
EMOF Types — merged from UML Infrastructure



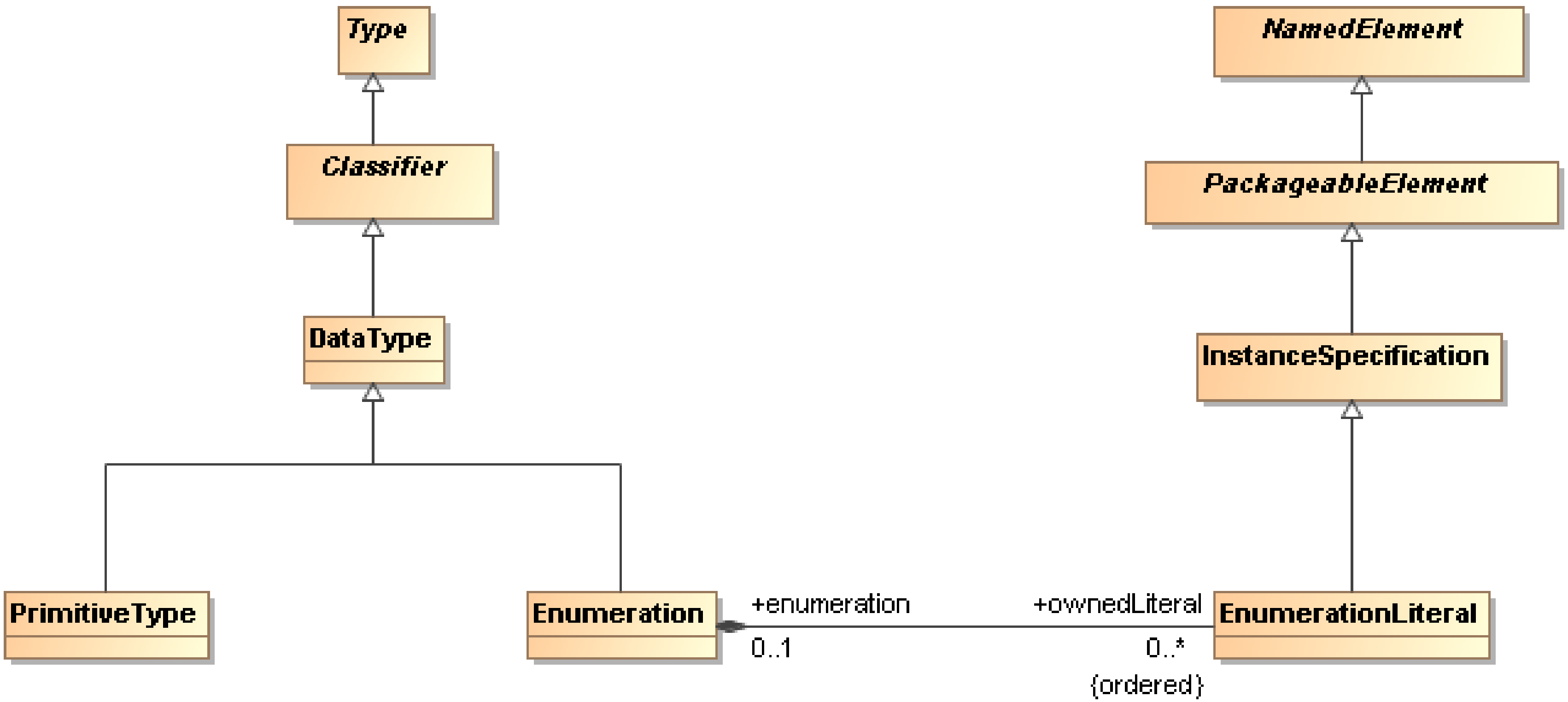
EMOF Classes — merged from UML Infrastructure (1)



EMOF Classes — merged from UML Infrastructure (2)



EMOF Data Types — merged from UML Infrastructure



EMOF Packages — merged from UML Core:Basic