Systeme hoher Sicherheit und Qualität
Universität Bremen, WS 2017/2018

Lecture 06:

Formal Modeling with OCL

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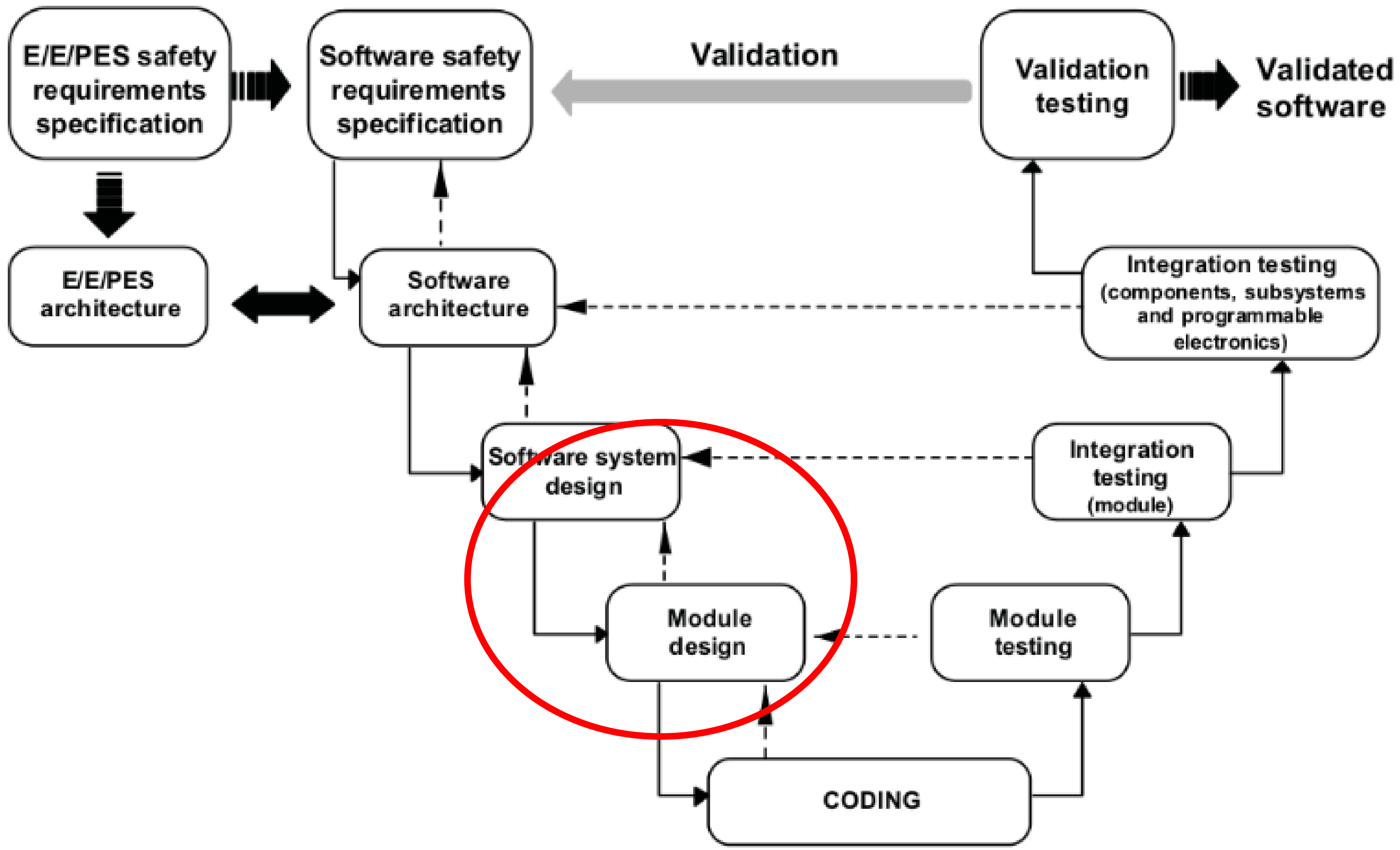
Where are we?

- 01: Concepts of Quality
- 02: Legal Requirements: Norms and Standards
- 03: The Software Development Process
- 04: Hazard Analysis
- 05: High-Level Design with SysML
- 06: Formal Modelling with OCL
- 07: Testing
- 08: Static Program Analysis
- 09-10: Software Verification
- 11-12: Model Checking
- 13: Conclusions

Formal Modeling in the Development Cycle



What is OCL?

- OCL is the **Object Constraint Language**.

- What is OCL?
  - *„A formal language used to describe expressions on UML models. These expressions typically specify invariant conditions that must hold for the system being modeled or queries over objects described in a model.”* (OCL standard, §7)

- Why OCL?
  - *„A UML diagram, such as a class diagram, is typically not refined enough to provide all the relevant aspects of a specification. There is, among other things, a need to describe additional constraints about the objects in the model. “* (OCL standard, §7.1)

Characteristics of the OCL

- OCL is a pure **specification language**
  - OCL expressions do not have side effects
- OCL is **not** a programming language.
  - Expressions are not executable (though some may be)
- OCL is **typed** language
  - Each expression has type; all expressions must be well-typed
  - Types are classes, defined by class diagrams

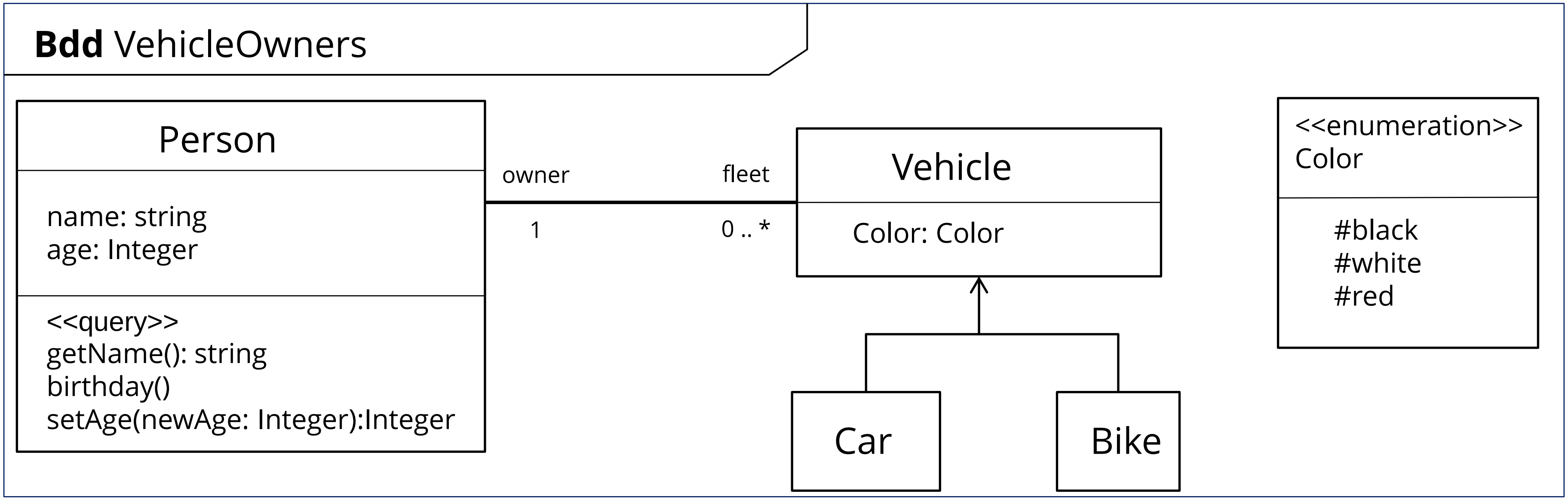
Usage of the OCL

- as a query language
- to specify invariants on classes and types in the class
- to specify type invariant for Stereotypes
- to describe pre- and post conditions on Operations and Methods
- to describe guards
- to specify target (sets) for messages and actions
- to specify constraints on operations
- to specify derivation rules for attributes for any expression over a UML model.

(OCL standard, §7.1.1)

OCL by Example

Why is SysML not enough?



What about requirements like:

- The minimal age of car owners
- The maximal number of cars (of a specific color) owned
- The maximal number of owners of a car

OCL Basics

- The language is **typed**: each expression has a type.
- Multiple-valued logic (true, false, undefined).

- Expressions always live in a **context**:
  - **Invariants** on classes, interfaces, types.

```
context Class
  inv Name: expr
```

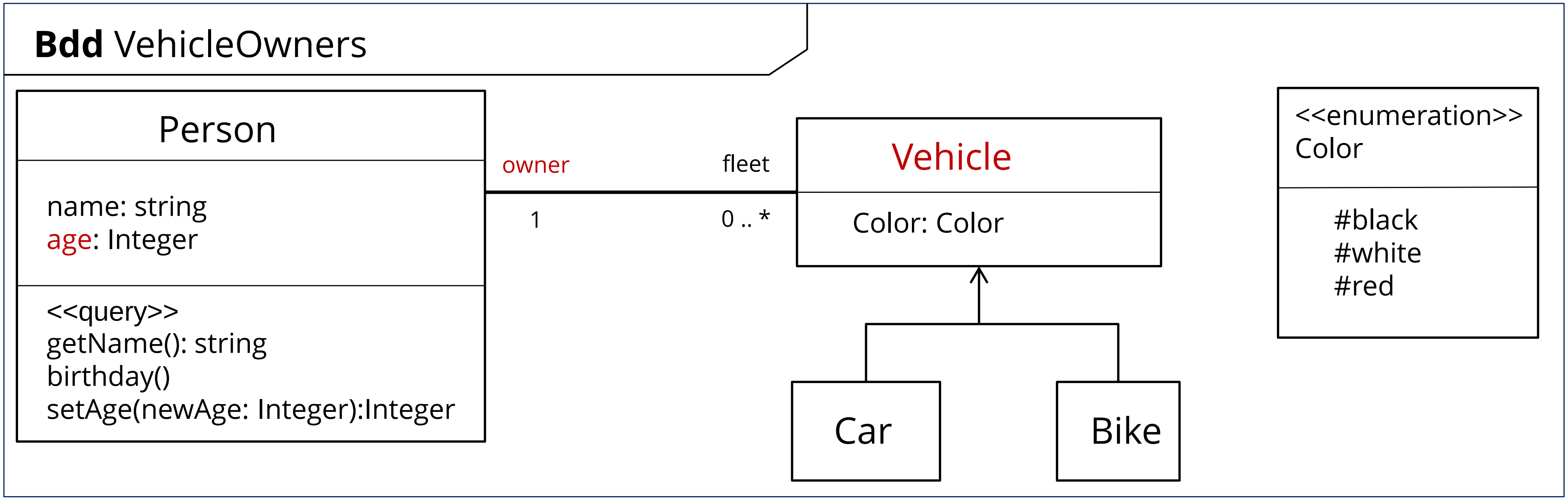
  - **Pre/postconditions** on operations or methods

```
context Type :: op(a1: Type, …, an: Type) : Type
  pre Name: expr
  post Name: expr
```

OCL Types

- Basic types:
  - `Boolean, Integer, Real, String`
  - `OclAny, OclType, OclVoid, OclInvalid`
- Collection types:
  - `Sequences, Bag, OrderedSet, Set`
- Model types

Invariants of Classes



"A vehicle owner must be at least 18 years old"

```
context   Vehicle
inv:      self.owner.age >= 18
```

Basic types and operations

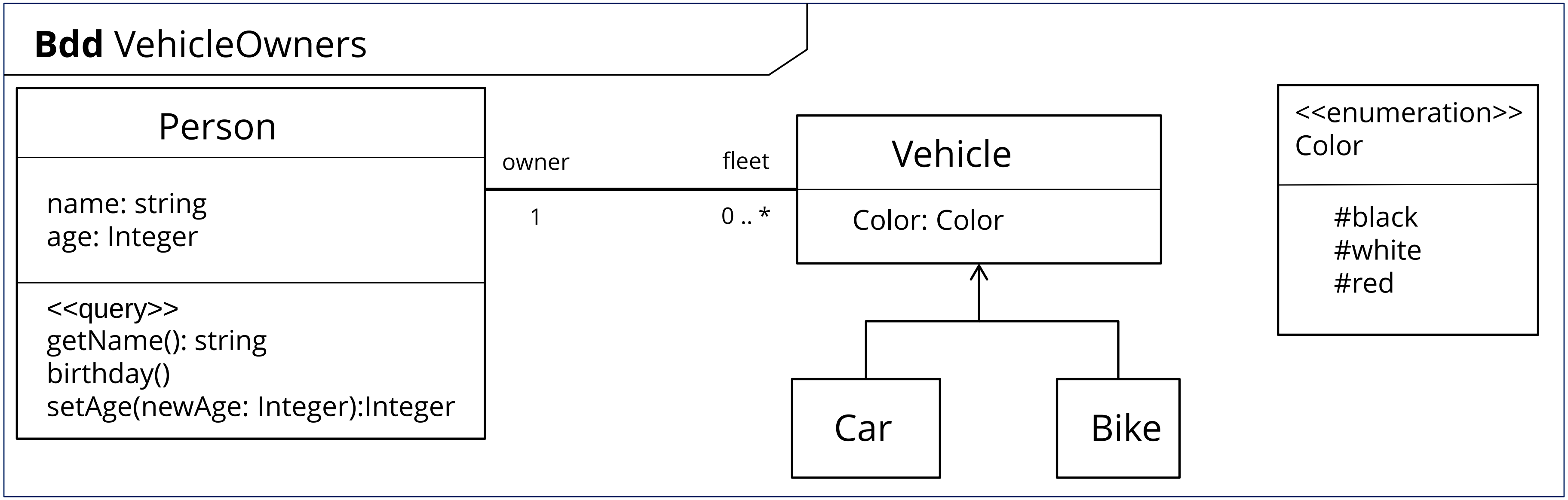
- Integer ($\mathbb{Z}$) OCL-Std. §11.5.2
- Real ($\mathbb{R}$) OCL-Std. §11.5.1
  - `Integer` is a subclass of `Real`
  - `round, floor` from `Real` to `Integer`
- String (Zeichenketten) OCL-Std. §11.5.3
  - `substring, toReal, toInteger, characters`, etc.
- Boolean (Wahrheitswerte) OCL-Std. §11.5.4
  - `or, xor, and, implies`
  - Relationen auf `Real, Integer, String`

Collection Types

Sequence, Bag, OrderedSet, Set — OCL-Std. §11.6, §11.7

- Operations on all collections:
  - `size, includes, count, isEmpty, flatten`
  - Collections are always „flattened“
- Set
  - `union, intersection`
- Bag
  - `union, intersection, count`
- Sequence
  - `first, last, reverse, prepend, append`

Collections



"Nobody has more than 3 vehicles"

```
context      Person
Inv:         self.fleet->size <= 3
```

Collection Types: Quantification

We can quantify over collections: OCL-Std. §11.9.1

- Universal quantification :

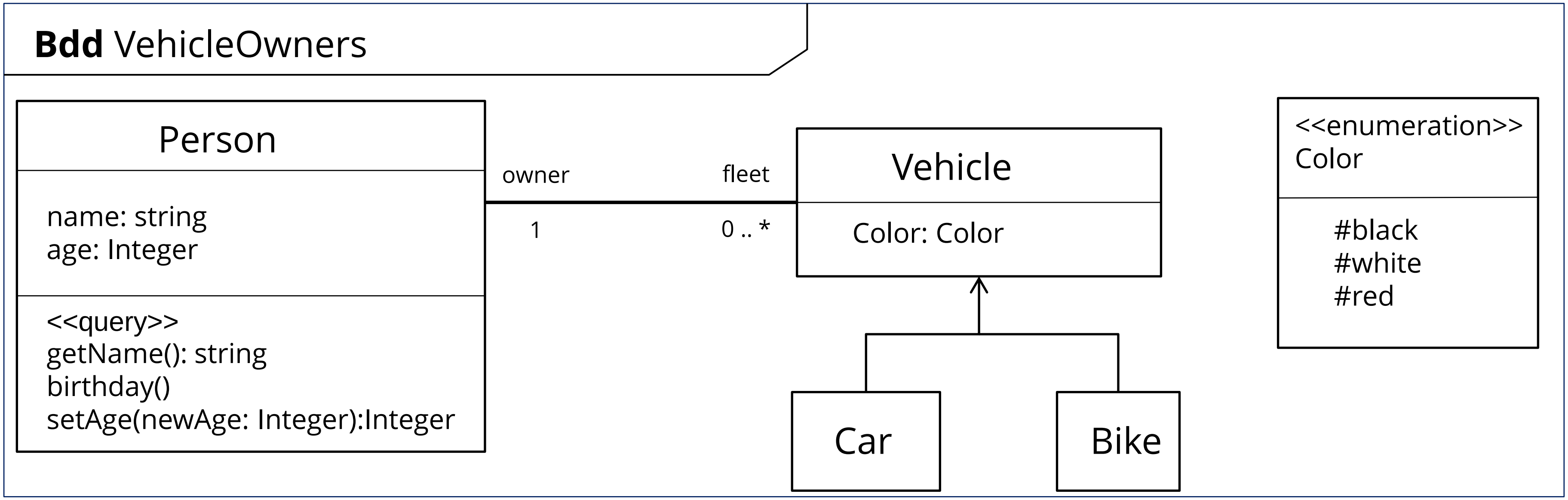
  `coll->forAll(elem: Type| expr[elem]) : Boolean`
- Existential quantification:

  `coll->exists(elem: Type| expr[elem]) : Boolean`
- Comprehension operator:

  `coll->select(elem: Type| expr[elem]) : Coll[Type]`

where `expr` is an expression of type `Boolean`.

Universal Quantification



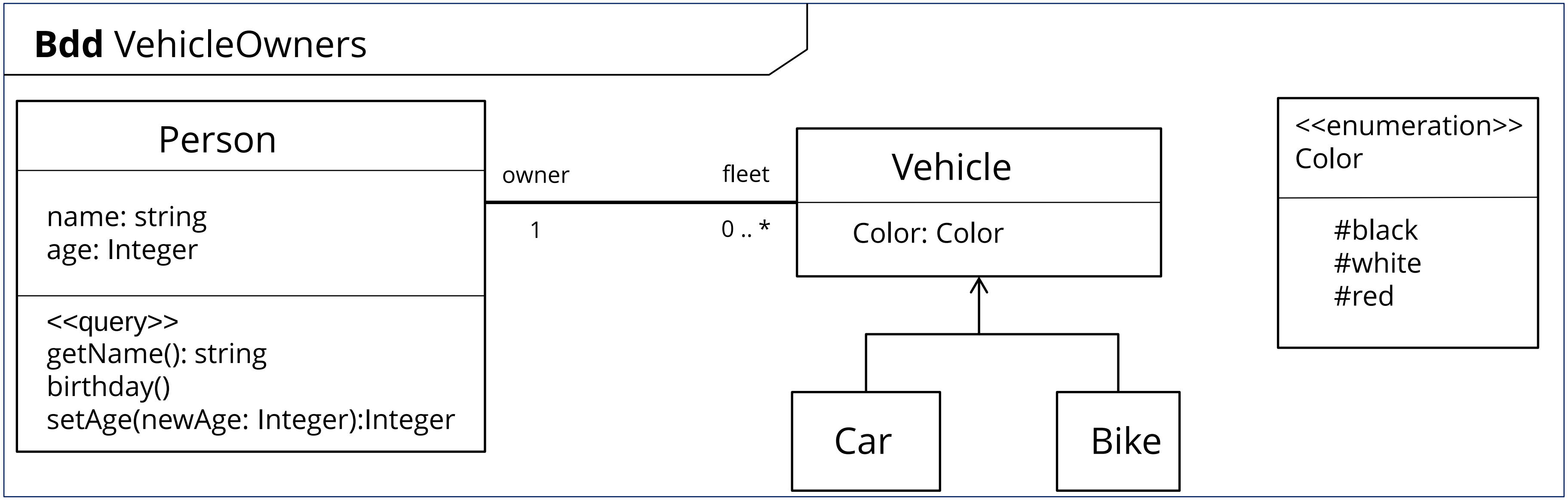
"All vehicles of a person are black"

```
context     Person
inv:        self.fleet->forAll(v | v.color = #black)
```

"No person has more than three black vehicles"

```
context     Person
inv:        self.fleet->select(v | v.color = #black)->size <= 3
```

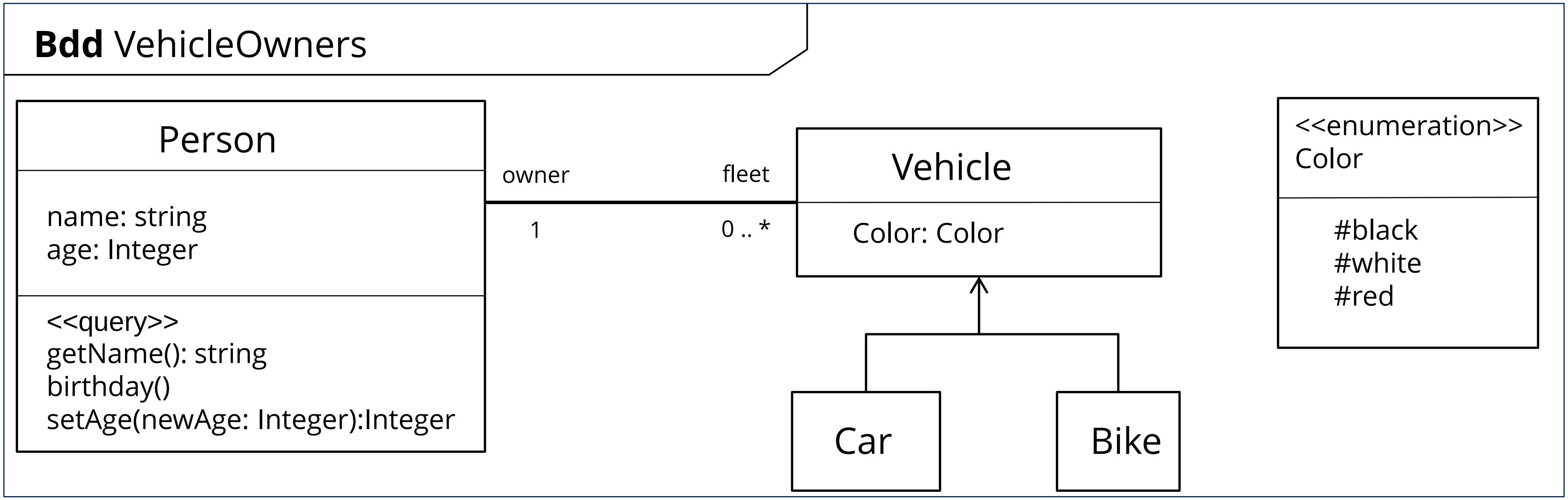
Universal Quantification



“A person younger than 18 owns no cars”

```
context  Person
inv:      self.age < 18 implies
               self.fleet -> forAll(v | not v.oclIsKindOf(Car))
```

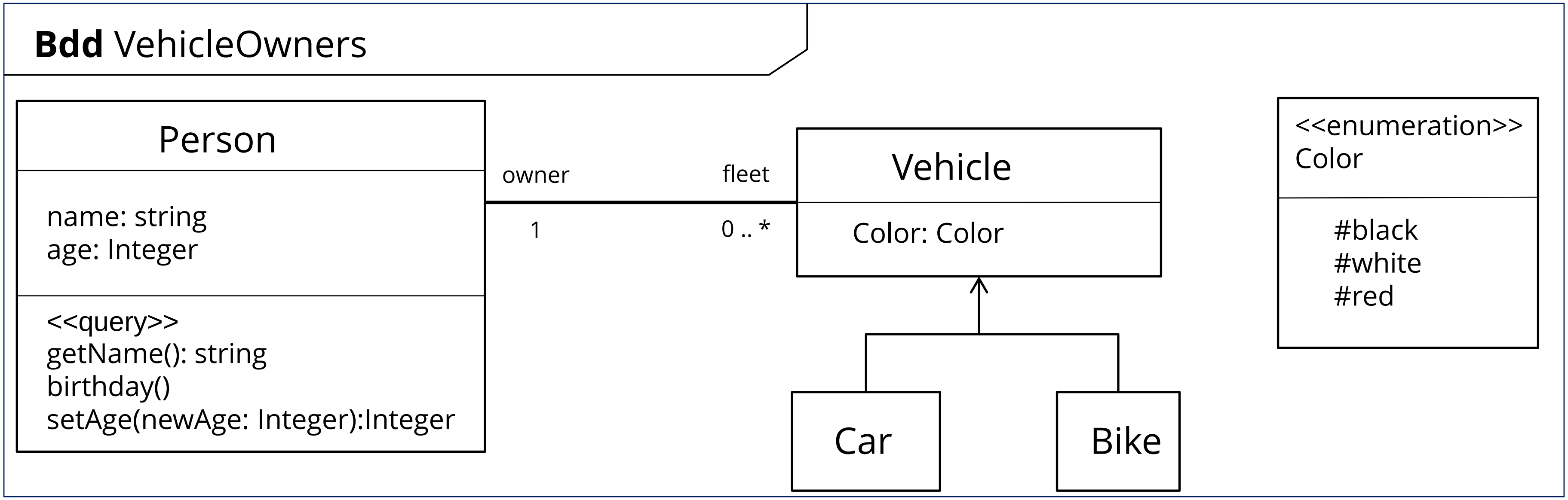
Existential Quantification



"There is a red car"

```
context   Car
inv:      Car.allInstances()->exists(c | c.color=#red)
```

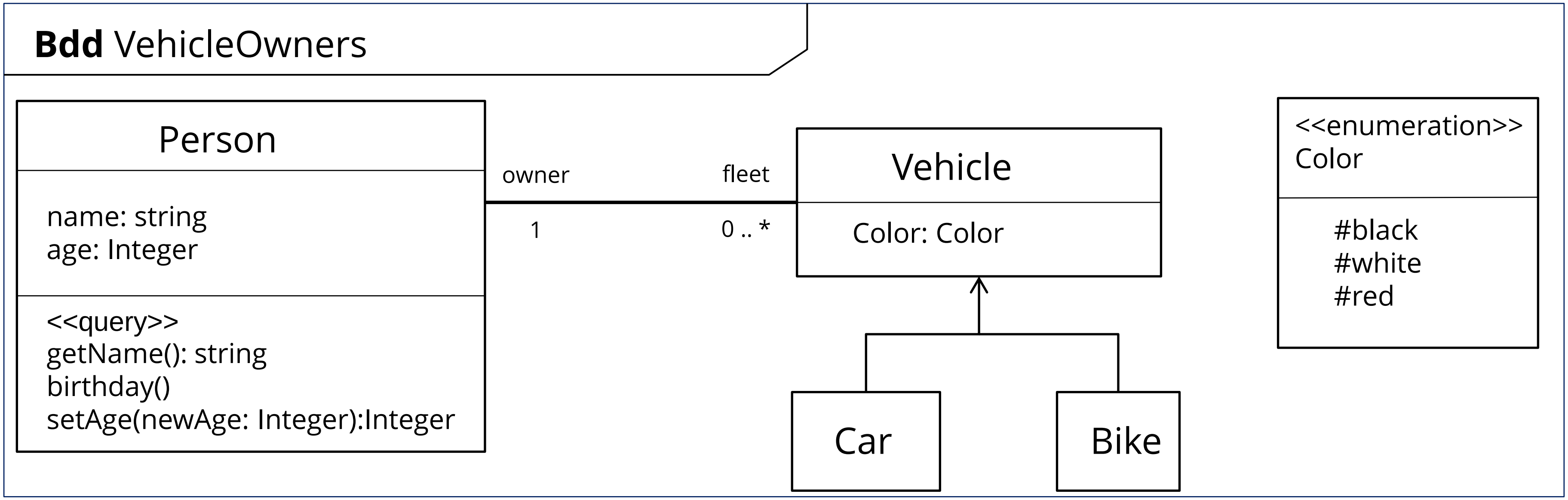
Pre/Post Conditions



"If **`setAge(a)`** is called with a non-negative argument **`a`**, then **`a`** becomes the new value of the attribute age."

```
context    Person::setAge(a:int)
pre:       a >= 0
post:      self.age = a
```

Pre/Post Conditions



"Calling birthday() increments the age of a person by 1."

```
context   Person::birthday()
post:     self.age = self.age@pre + 1
```

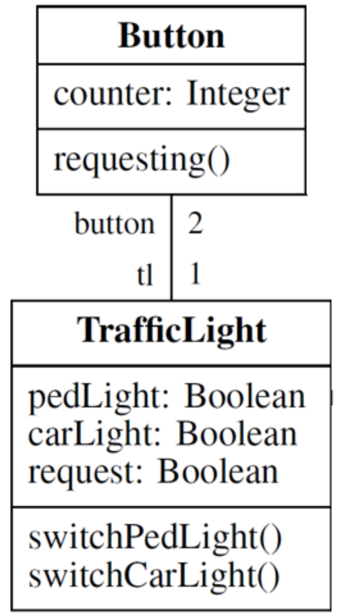
Modelling Dynamic Aspects

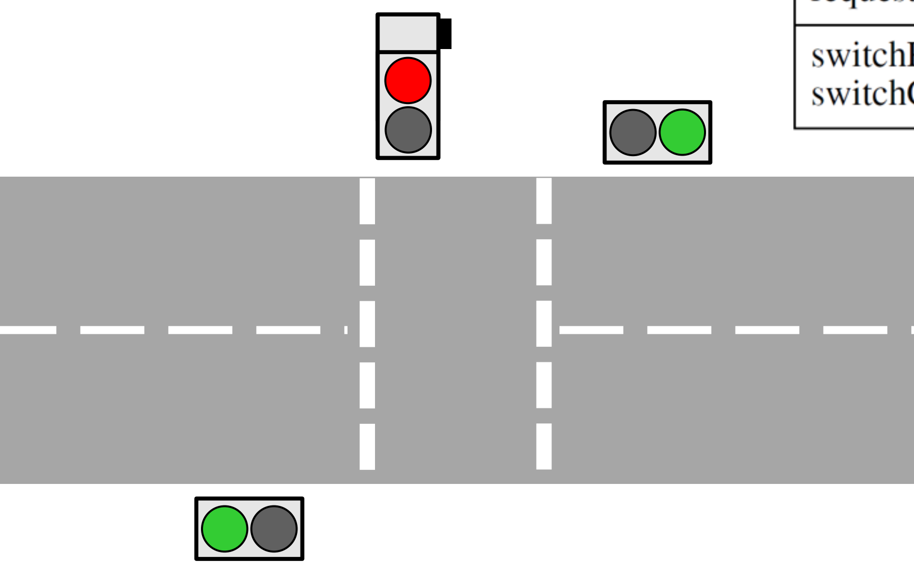
- Block diagrams model the **static structure** of the system: classes, attributes and the type of the operations. The possible **system states** are all instances of these model types.

- Invariants and pre/post conditions can be used to model the **dynamic aspects** of the system. In particular, they model all possible **state transitions** between the system states.

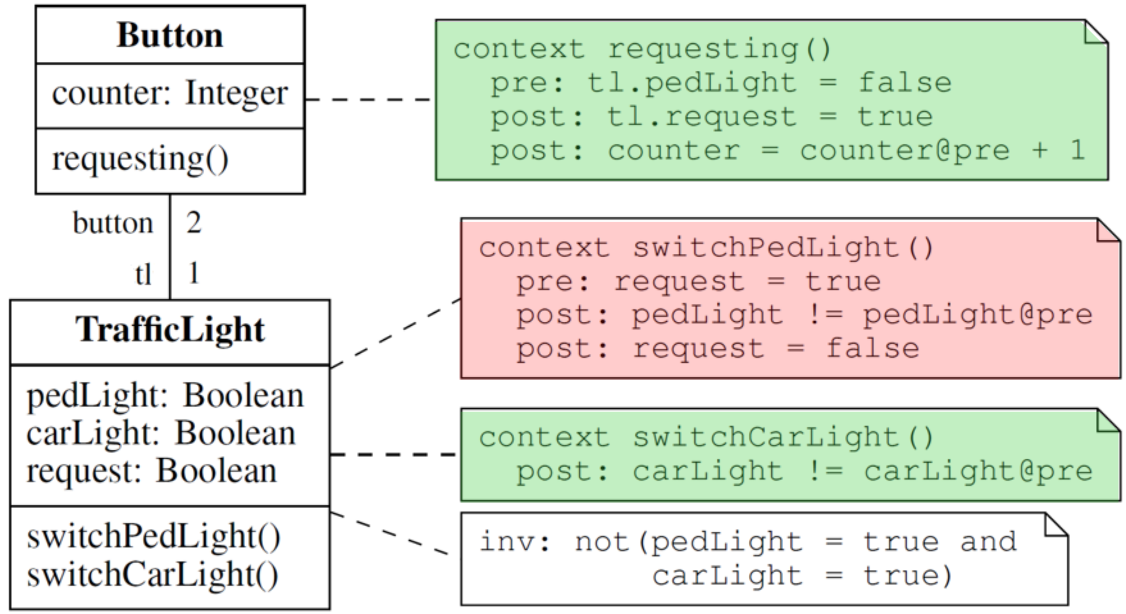
- An operation can become **active** (there is a state transition emanting from it) if the invariant holds, and the precondition holds. If there are no active state transitions, the system is **deadlocked**.
  - Deadlocks must be avoided.

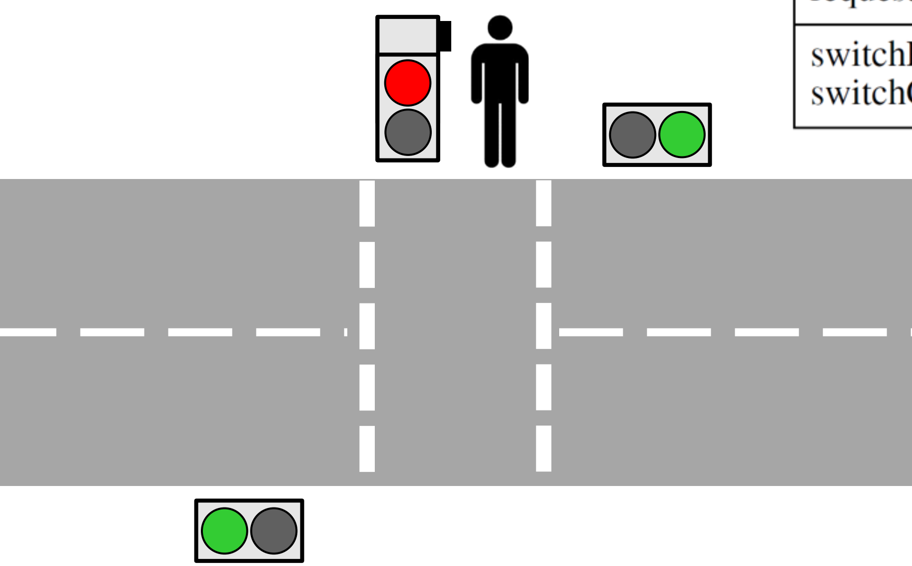
Example: The Traffic Light





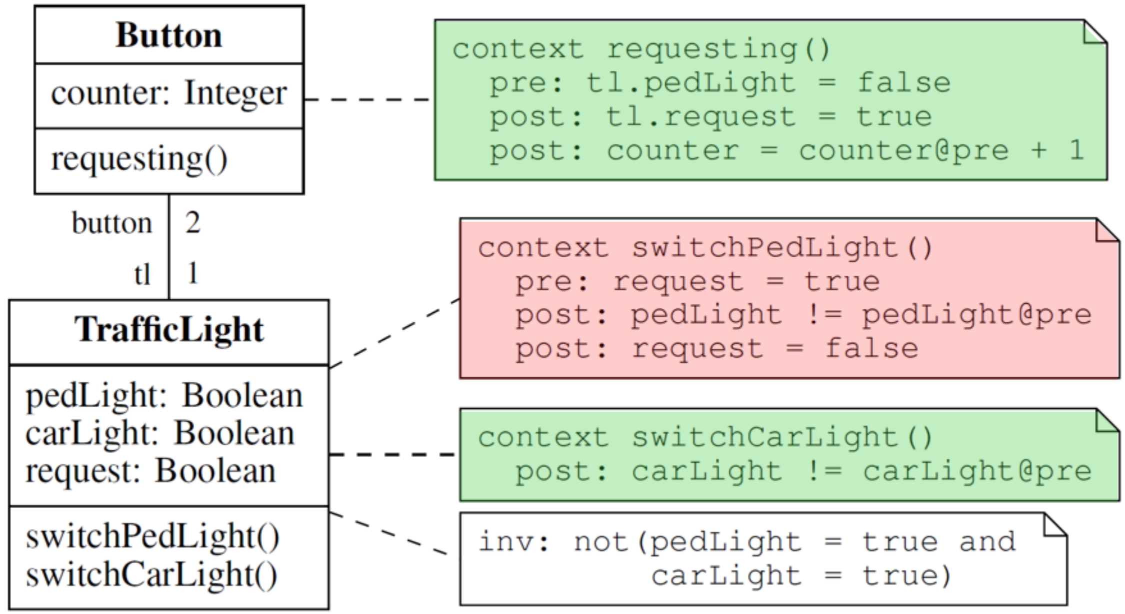
Example: The Traffic Light

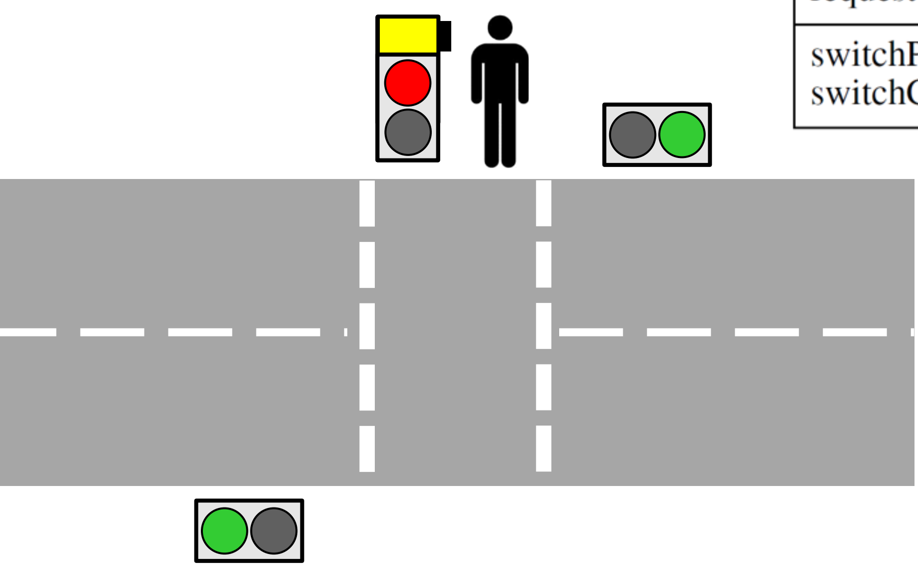




```
pedLight:    False
carLight:    True
request:     False
counter:     0
```

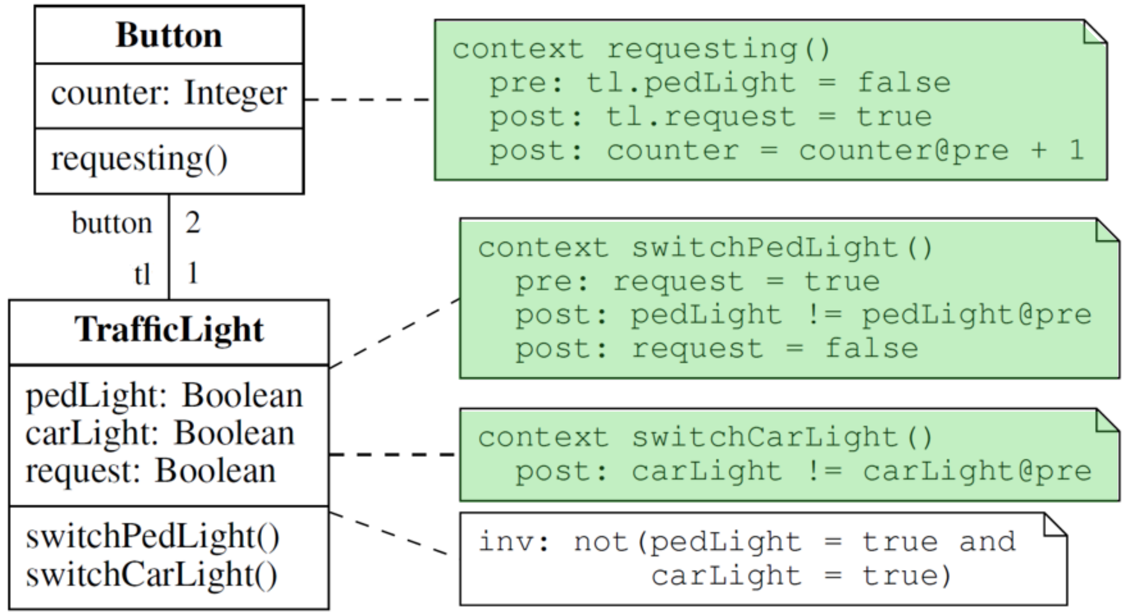
Example: The Traffic Light

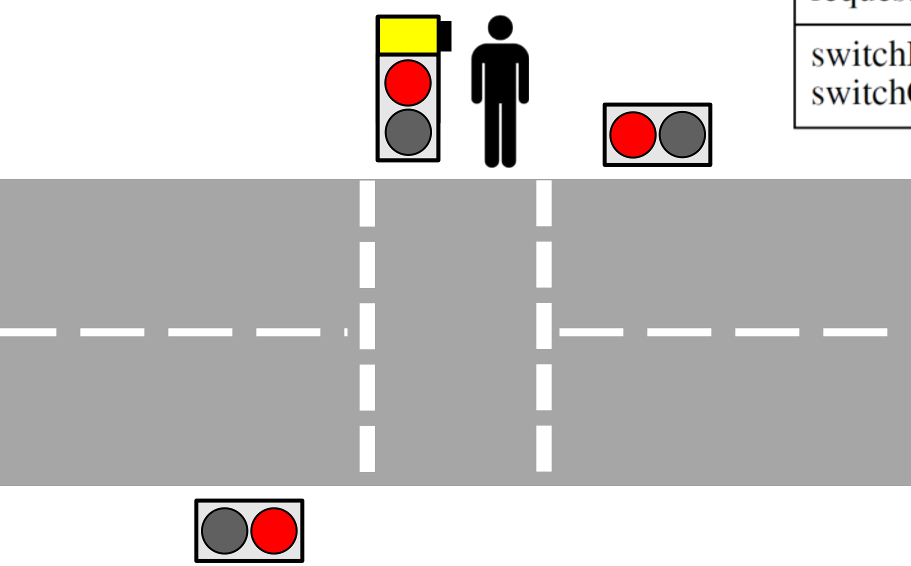




```
pedLight:     False
carLight:     True
request:      True
counter:      1
```

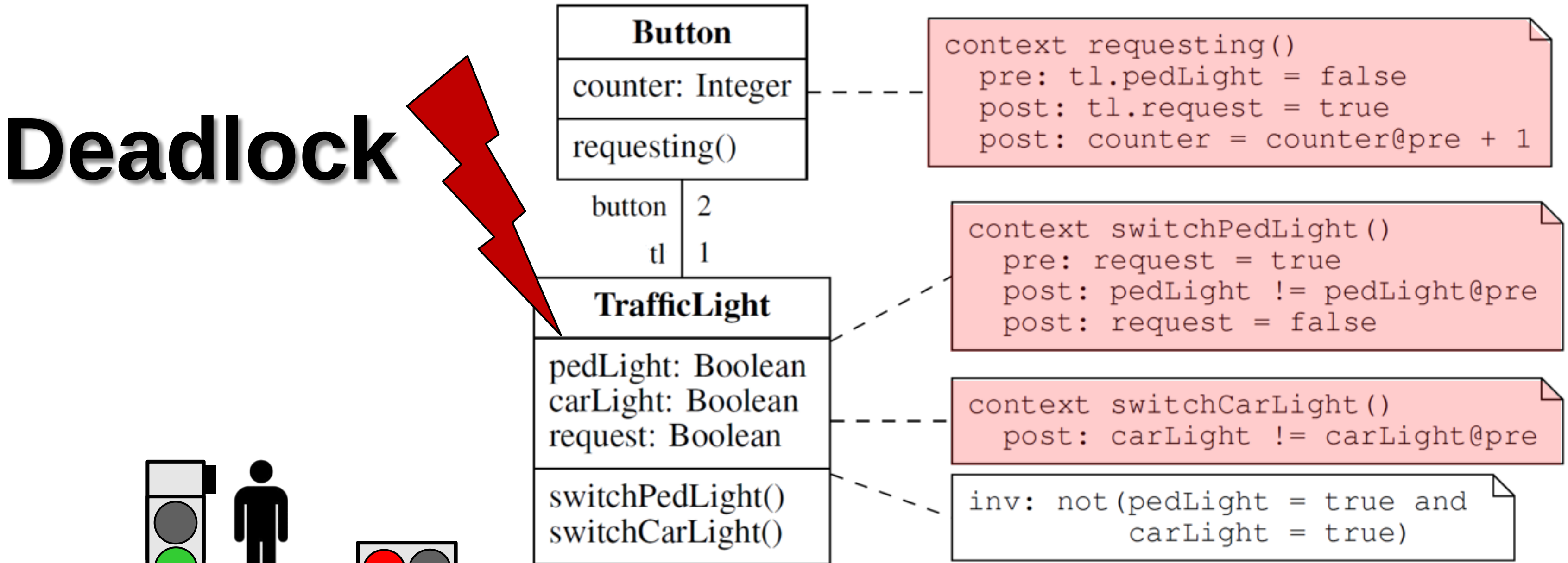
Example: The Traffic Light

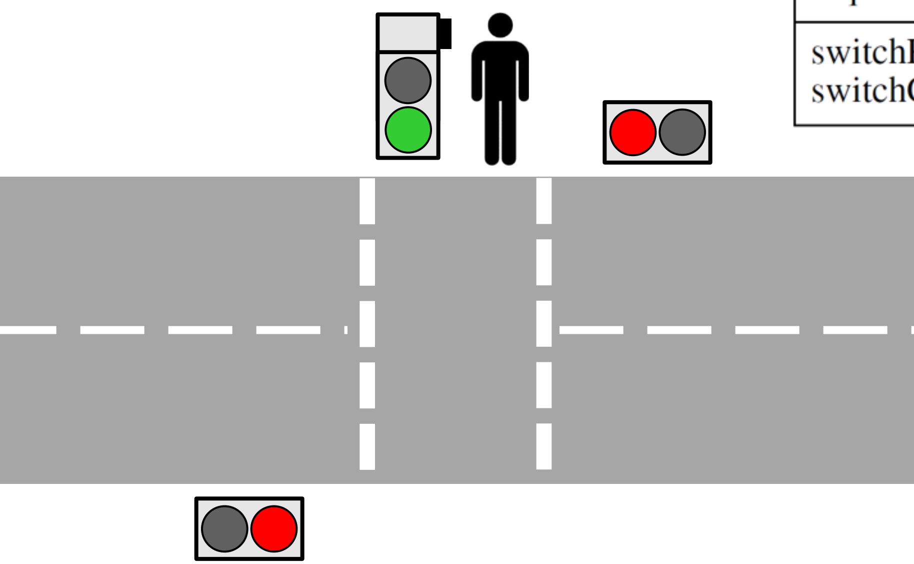




```
pedLight:    False
carLight:    False
request:     True
counter:     1
```

Example: The Traffic Light





pedLight:	True
carLight:	False
request:	False
counter:	1

OCL Details

Model types

- Model types are given by
  - Attributes,
  - Operations, and
  - Associations of the model

- Navigation along the association
  - If cardinality is 1, type is of target type **`T`**
  - Otherwise, it is **`Set(T)`**

- User-defined operations in expressions have to be stateless (stereotype `<<query>>`)

Collection Types: Iterators

- Quantifiers are a special case of iterators.
  - Think of `all/any` in Haskell defined via `foldr`

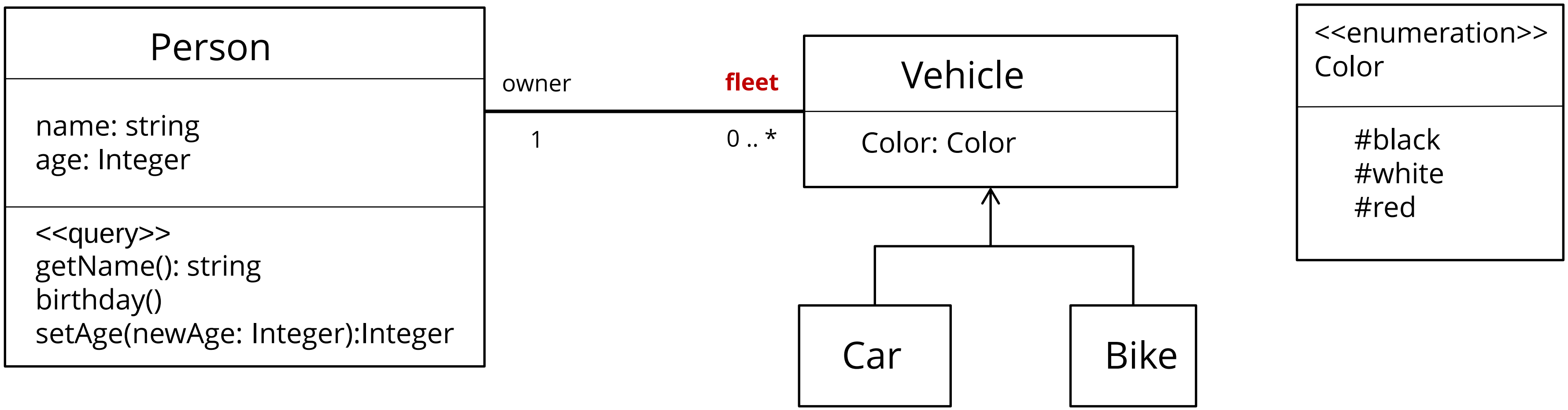
- All iterators defined via `iterate` OCL-Std. §7.6.6

```
coll->iterate(elem: Type, acc: T = initial_expr
              | expr[elem, acc]) : Coll[T]
```

where `expr` of type `T` denotes a function on `elem` and `acc`

```
c.iterate(e: T, acc: T = v) = {
  acc= v;
  for (Enumeration e= c.elements(); e.hasMoreElements();) {
       acc= expr[e, acc];
       e= e.nextElement();
}
  return acc;
}
```

Collection Types: Iterators



"A person owns at most 3 black vehicles"

```
context   Person
inv:       self.fleet->iterate(v; acc:Integer = 0
                              | if (v.color = #black)
                                 then acc + 1 else acc
                                endif ) <= 3
```

Undefinedness in OCL

- Each domain of a basic type has two values denoting "**undefinedness**": OCL-Std §A.2.1.1
  - *null* or ε stands for "undefined", e.g. if an attribute value has not been set or is not defined (Type **`OclVoid`**)
  - *invalid* or $\bot$ stands for "invalid" and signals an error in the evaluation of an expression (e.g. division by 0, or application of a partial function) (Type **`OclInvalid`**)
  - As subtypes: **`OclInvalid`** $\subseteq$ **`OclVoid`** $\subseteq$ all other types
- Undefinedness is **propagated.**
  - In other words, all operations are **strict**: „an *invalid* or *null* operand causes an *invalid* result".

The OCL Logic

- Exceptions to strictness:
  - Boolean operators (see below)
  - Case distinction
  - Test on definedness: **`oclIsUndefined`** with

$$oclIsUndefined(e) = \begin{cases} true & if\ e = \bot \lor e = null \\ false & otherwise \end{cases}$$

- The domain type for **`Boolean`** also contains null and invalid.
  - The resulting logic is **four-valued**.
  - It is a **Kleene-Logic**: $A \rightarrow B \equiv \neg A \lor B$
  - Boolean operators (**`and, or, implies, xor)`** are **non-strict on both sides**.
  - But equality (like all other relations) is strict: $\bot = \bot$ is $\bot$

OCL Boolean Operators: Truth Table

b_1	b_2	b_1 and b_2	b_1 or b_2	b_1 xor b_2	b_1 implies b_2	not b_1
false	false	false	false	false	true	true
false	true	false	true	true	true	true
true	false	false	true	true	false	false
true	true	true	true	false	true	false
false	ε	false	ε	ε	true	true
true	ε	ε	true	ε	ε	false
false	⊥	false	⊥	⊥	true	true
true	⊥	⊥	true	⊥	⊥	false
ε	false	false	ε	ε	ε	ε
ε	true	ε	true	ε	true	ε
ε	ε	ε	ε	ε	ε	ε
ε	⊥	⊥	⊥	⊥	⊥	ε
⊥	false	false	⊥	⊥	⊥	⊥
⊥	true	⊥	true	⊥	true	⊥
⊥	⊥ or ε	⊥	⊥	⊥	⊥	⊥

- Legend: ⊥ is *invalid*, ε is *null*.

OCL-Std §A .2.1.3, Table A.2

OCL Style Guide

- Avoid **complex** navigation („Loose coupling“).
  - Otherwise changes in models break OCL constraints.
- Always choose **adequate context.**
- „Use of `allInstances()` is **discouraged**“
- Split up invariants if possible.
- Consider defining **auxiliary operations** if expressions become too complex.

Summary

- OCL is a typed, state-free specification language which allows us to denote constraints on models.
- We can define or models much more precise.
  - Ideally: no more natural language needed.
- OCL is part of the more „academic" side of UML/SysML.
  - Tool support is not great, some tools ignore OCL, most tools at least type-check OCL, hardly any do proofs.
- However, in critical system development, the kind of specification that OCL allows is **essential.**

- Try yourself: USE – Tool http://useocl.sourceforge.net
  Martin Gogolla, Fabian Büttner, and Mark Richters. USE: A UML-Based Specification Environment for Validating UML and OCL. Science of Computer Programming, 69:27-34, 2007.