Model Driven Architecture
Action Semantics and Action Languages

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Action Semantics
What is it?

- OMG sanctioned approach to define the low-level behavior of modeling elements
- Action semantics **defines how** to perform a transformation of the object graph (side effects)
  - a state transition
  - an operation
- State chart models
  - provide a higher-level view
  - formalize object lifecycle
  - orchestrate method invocations
- contrast with:
  OCL **specifies what** happens (no side effects)
  - the result of an operation
  - postcondition after an operation

Action Semantics

- An action is the fundamental unit of behavior specification.
- An action takes a set of inputs and converts them into a set of outputs [. . .].
- The most basic action provides for implementation-dependent semantics, [. . .].
- [. . .] primitive actions are defined [so] as to enable the maximum range of mappings.
- [. . .] they either carry out a computation or access object memory
- This approach enables clean mappings to a physical model, [. . .].
- In addition, any re-organization of the data structure will leave the specification of the computation unaffected.

From the UML 2 superstructure 11.1

Action Semantics/Why have it?

- build complete and precise models
- formal proofs of correctness of a problem specification
- high-fidelity model-based simulation and verification
- enables reuse of domain models
- stronger basis for model design and eventual coding
- support code generation to multiple software platforms.

From “Software-platform-independent, Precise Action Specifications for UML”, UML’99

Action Semantics/Idea

Basic idea: specify computation so that it is

- data driven and
- inherently parallel
- (sequential execution through data dependency or explicit control dependency)
- independent of concrete syntax

Action Semantics/Action Specification

Basic building blocks:

- Pins: input and output ports of an action; with type and multiplicity
- Variables: intermediate results
- Data flow: connects the output pin of one action to the input pin of another
- Control flow: explicit ordering constraint for action pairs
- Actions: for object manipulation, memory operations, arithmetic, message passing, etc.
- Procedures: packaging of actions with input and output pins

Action Semantics/Action Execution

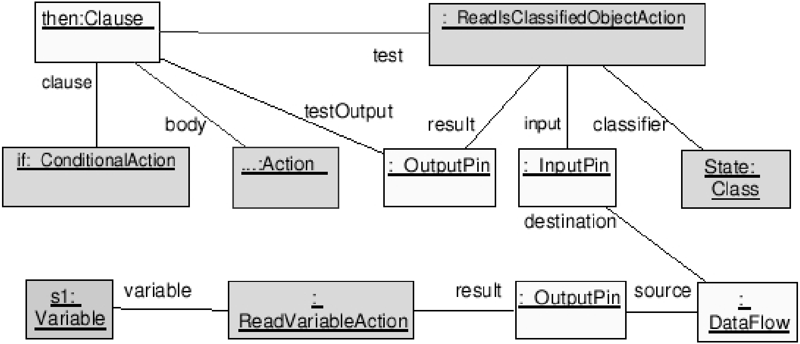
Life-cycle of an action

- Waiting. Initial state after creation of action execution.
- Ready. Action execution with all inputs available and all control dependencies in state **Complete**.
- Executing. Compute outputs from inputs.
- Complete. Values of output pins determined, signal to control-flow dependant actions.

Action Semantics/Types of Actions

- Computation actions *e.g.* mathematical functions (left undefined by standard)
- Composite actions building blocks for control structures like loops and conditionals
- Read and write actions access, navigate, and modify model-level constructs (objects, links, attribute slots, and variables)
- Collection actions $\Rightarrow$ iterators for actions

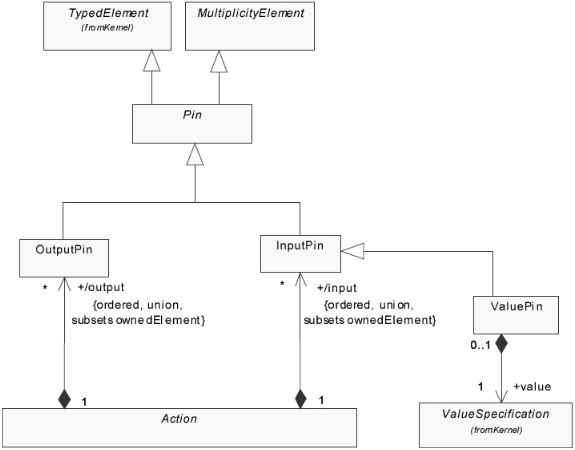
Action Semantics/Example



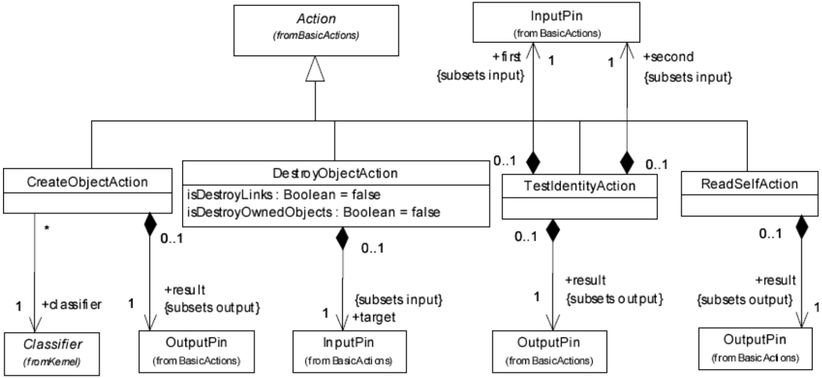
From: UML Action Semantics for Model Transformation Systems, Varró and Pataricza (uses obsolete 1.5 metamodel)

Action Semantics/Basic Pins

From Metamodel



Action Semantics/Object Actions



- Action Semantics can describe object graph transformations
- Current support by tools rather poor (wrt editing, code generation)
- Too low-level for actual programming
  (machine independent intermediate code)
- $\Rightarrow$ higher-level language required to define the meaning of operations
- $\Rightarrow$ Action Languages

Action Languages

- "Executable UML"
  (Mellor and Balcer, Addison Welsey, 2002)
- Programming Languages geared towards specifying detailed operational behavior
  - Specify algorithmic aspects
  - Abstract from implementation choices/design decisions
- Operate directly on UML data model
- Independence of the SW platform
  - no concrete representation
  - no pointer manipulation
  - no tricks

- Types
  - All modeling elements of type `UML::Classifier`
  - Primitive types
- Multiplicity is respected
  (often restricted to multiplicities: `0..1`, `1`, `*`, `1..*`)
- Uniqueness
- Ordering
- Attributes can be read and written
- Local variables treated like attributes

Action Languages

Main Mapping Choices

- A class may map to
  - a class declaration in an OO programming language
  - a structure declaration in a programming language
  - a CORBA IDL
  - an EJB
  - a database table
  - ...
- An association may map to
  - a link between objects
  - a pointer
  - a hashtable
  - a database table
- A generalization may map to
  - a subclass definition
  - a link

Action Languages

Object Creation and Deletion

- Manipulate instances of classes: objects
- Create:

```
thePub = new Publisher
          {name="AW", address="Boston"};
```

just creation, no constructor

- Read attribute:

```
thePub.name
```

- Write attribute:

```
thePub.name = "MGH";
```

- Delete:

```
delete thePub;
```

  - debatable if this should be left to the programmer

- Manipulate instances of associations: links
- Create:

  association.add{ *end*=*obj-ref*, *end*=*obj-ref* };
- Delete:

  association.delete{ *end*=*obj-ref*, *end*=*obj-ref* };
- Traverse:

  obj-ref.*association*
  obj-ref.*association-end*
  obj-ref.*class*
- N-ary associations?
- Association classes?

- over members of classes

```
for(x : class) { ... }
for(x : class) where condition { ... }
```

- over navigable associations

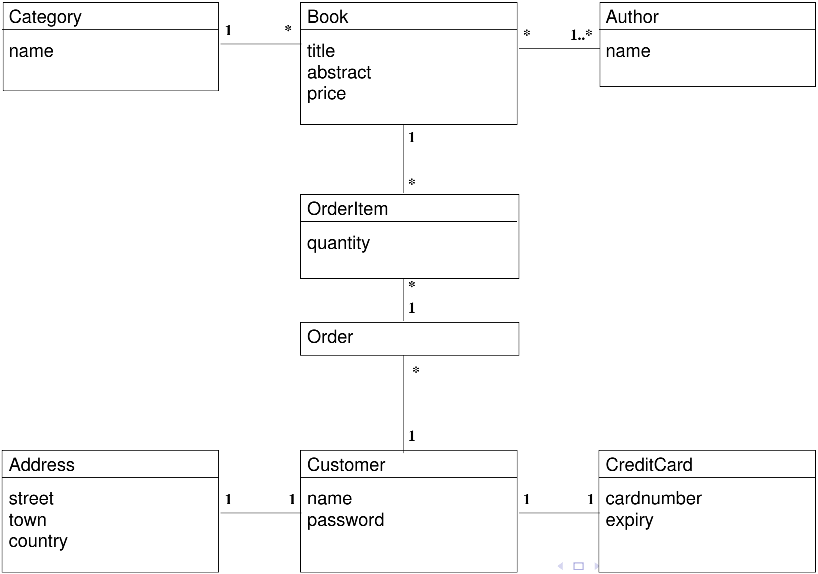
```
for(class x : obj-ref.association) { ... }
for(class x : obj-ref.association)
   where condition { ... }
```

- over associations

```
for({ end=obj-ref, end=obj-ref } : association)
   { ... }
for({ end=obj-ref, end=obj-ref } : association)
    where condition { ... }
```

Example: Using the Action Language

Data Model of a Bookshop



Example: Using the Action Language

Auxiliary Operation

```
Category getCategory (String category) {
  for (cat : Category)
      where cat.name = category {
      return cat;
  }
  return new Category { name= category };
}
```

Example: Using the Action Language

Add a New Book

```
Book newBook (String title, Number price,
              String category, String author) {
  Author theAuthor =
    new Author { name= author };
  Category theCategory =
    getCategory (category);
  Book theBook =
    new Book { title= title, price= price };
  BookHasAuthor.add
    { book= theBook, author= theAuthor };
  BookHasCategory.add
    { book= theBook, category= theCategory };
  return theBook;
}
```

Example: Using the Action Language
A Database Mapping

- All classes mapped to database table
  - Object reference mapped to primary key value
  - `for (...) where` mapped to `select`
  - `new` mapped to `insert`
- Generic choice for associations: table with foreign keys
  - `add` mapped to `insert`
  - traversal mapped to `select`
  - `delete` mapped to `delete`

Support for Relations in Programming Languages

- Action Languages are unusual compared to other programming languages where
  - Support for objects, inheritance etc is abundant
  - Support for relations is virtually non-existent!
- Notable exceptions
  - James Rumbaugh. Relations as Semantic Constructs in an Object-Oriented Language. OOPSLA, 1987.
  - James Noble, John Grundy. Explicit Relationships in Object Oriented Development. TOOLS, 1995.
  - Gavin Bierman, Alisdair Wren. First-Class Relationships in an Object-Oriented Language. ECOOP, 2005.

Relations in Programming Languages

Why?

- Common agreement: relations are useful for conceptual modeling
- Later phases elide relations
  - Relations are implemented on an ad-hoc basis
    - Collaborating methods and attributes in participating classes
    - Collection class “Relation” holding sets of *n*-tuples
  - Relationship patterns exist
  - Relations implemented by model transformation
    - writers of protected regions must know the transformation:
    - name conventions
    - attribute types

Pattern	Problem
Relationship as Attribute	Unidirectional, many-one or one-one relationship
Relationship Object	Large, complex relationship
Collection Object	Unidirectional, one-many relationship
Active Value	Globally important one-one relation-ship
Mutual Friends	Bidirectional relationship

Relationship Patterns

Relationship as Attribute

- Scope: unidirectional, one-one or many-one relationships
- Very common
- Changes only of local importance
- Bookshop example:
  - Book $\longrightarrow$ Category
  - Customer $\longrightarrow$ CreditCard
  - Customer $\longrightarrow$ Address

$\Rightarrow$ Represent by an attribute in the source class

- Scope: large, complex relationships
  - Many participating objects (peers)
  - Bidirectional
- Implementation using attributes possible but
  - the relationship is dispersed
  - it is hard to spot in the program
  - thus hard to maintain
- The relationship object
  - contains all methods and attributes to maintain the relation
  - may contain subordinate objects which are not visible outside
  - mediates between all objects participating in the relation
- Bookshop example: OrderItem $\leftrightarrow$ Order

Relationship Patterns

Collection Object

- Scope: unidirectional, one-many relationships
- Very common

$\Rightarrow$ Represent by an attribute in the "one" object which holds the "many" objects in a collection object

- Example:
  - Book $\longrightarrow$ Author
  - . . . but the other direction is also needed in this case
- Particular kind of Relationship Object

Relationship Patterns

Active Value

- One-one relationship
- With notification if one of the related objects changes
- Example: Window is in one-one relationship with the value of each input field
- Active Value: An object that reifies a single variable
- With setter and getter and change detection via Observer

Relationship Patterns
Mutual Friends

- Bidirectional Relationship
- All participating objects are equally important
- Change at one end requires change at other end
- Example: Book $\leftrightarrow$ Author

$\Rightarrow$ Mutual Friends has to steps
  - Splitting the relationship in two unidirectional ones
  - Keep the moieties consistent
    - one end is the leader, the other the follower
    - leader administers all changes
    - the follower delegates all changes to the leader

- Simplest instance: bidirectional one-one relationship represented by two attributes

Conclusion

- Are patterns good or bad?
- Patterns point to drawbacks of programming languages
  - Composite Pattern: lack of sum types
  - Visitor Pattern: lack of suitable extension mechanisms
  - Relationship Patterns: lack of support for patterns in PLS
- Even worse
  - if other target models are considered (*e.g.* database tables)
  - if multiple target models are considered (*e.g.*, a relation between a database entity and a POJO)
- Relationship manipulation should be part of an action language