Shlaer-Mellor Method:

The OOA96 Report

Version 1.0

Sally Shlaer
Neil Lang
Project Technology, Inc.
2560 Ninth Street, Suite 214
Berkeley, CA 94710
510-845-1484
http://www.projtech.com

Table of Contents

Table of Contents

1

Why Revise the Shlaer-Mellor Method?

Sally Shlaer
Neil Lang

Since the last published statement of the Shlaer-Mellor method of Object-Oriented Analysis, a certain number of questions have come forward. These questions range in nature from clarifications required on basic conceptual matters to detailed inquiries involving extremely fine points of the method. At the same time, as a result of extensive work on client projects—especially those employing the latest generation of Shlaer-Mellor automation tools—we have made some adjustments and, we believe, improvements to the method.

1.1 Goals

The purpose of this report is to state the rules of OOA as currently defined. We call this statement OOA96; it is the statement of OOA that will be relied upon by the upcoming book on Recursive Design. In developing this statement, we have held four primary goals:

- To define OOA96 so that it is self-consistent.
- To define OOA96 so that it is as consistent as possible with OOA91 (as defined by *Object Lifecycles*) while, at the same time, incorporating lessons learned from a broad spread of client projects.
- To improve the rigor of the method and to tie up various loose ends.
- To ensure that correct OOA models make clear delineations of domain boundaries.

1.2 Role of the Report

The material given here adds to and supersedes portions of that presented in *Object Lifecycles: Modeling the World in States*. As a result, we rely upon the reader's familiarity with the details provided in that work. We have not attempted to provide here a complete and integrated presentation of the method as defined today; such a publication is planned for later in the year.

1.3 Dimensions of the Method

We distinguish between several dimensions of the method, as follows:

Formalism. First and foremost, OOA96 is a mathematical system, built up of axioms, definitions, and theorems. We refer to this mathematical system as a formalism, using the word in much the same way as do mathematical physicists. Note that this report is almost entirely concerned with the formalism.

Representation. Associated with the formalism is a representation, or notation: A defined way to depict the entities of the formalism. The notation that we use has been designed for readability and for ease of use. We have found it necessary to make only a few minor adjustments to the OOA91 notation.

We want to emphasize that we do not attach great significance to the particular notations employed in the work products of OOA. Hence if a CASE vendor chooses to adopt some variant representation—perhaps for compatibility with other tools or for ease of implementation—this does not, in our opinion, detract from the usefulness of the toolset.

Work products. OOA is laid out in a series of steps, each of which is designed to produce certain work products. The steps and work products of OOA96 are the same as those of OOA91 with the following exceptions: (1) The format of the Event List has been slightly modified to account for polymorphic events and (2) a small additional work product has been defined to allow explicit integration of domains.

Techniques. Techniques are procedures and processes conducted by software developers in order to elicit information, develop conceptualizations, etc. Techniques (such as preparation of technical notes, object blitzes, examination of use cases, interviews and the like) are generally not associated directly with the production of a particular work product—or even with a particular method. The scope of this report does not cover techniques: such a publication remains to be prepared.

1.4 Acknowledgments

Virtually all of Project Technology's instructors, consultants, and architects have contributed their capabilities and experiences to the definition of OOA96. In particular, we wish to thank Howard Kradjel, Kent Mingus, Gregory Rochford, Phil Ryals, John Wolfe, and John Yeager for leading numerous spirited debates and thereby forcing us all to clarify our thoughts.

2

Dependence Between Attributes

Sally Shlaer
Neil Lang

There are three kinds of dependencies that may pertain between attributes on the Information Model (IM). This chapter describes these dependencies and explains how they are represented on the graphic form of the IM.

2.1 Functional Dependence

Functional dependence forms the basis of the relational model of data, upon which OOA's rules of attribution are based. This section extracts a few of the results of the relational model[1] to establish some basic principles of OOA.

2.1.1 Structure of an Object

We start out with an axiom:

AXIOM (Structure of an object): For any OOA object P:

- Every instance of P can be represented by a tuple.
- The domain underlying each attribute of P consists of atomic values only.

This axiom ensures that (1) the tabular representation can be used to depict all instances of an object and (2) that an attribute has no internal structure. As a result, an OOA object is a relation of first normal form in the relational model.

2.1.2 Relationships Between Attributes

Functional dependence has to do with what you have to know in order to determine the value of an attribute—that is, how tightly attributes are related to one another in terms of their meanings.

This idea, which is very simple and intuitive for an OOA practitioner, is much more difficult for a practitioner schooled in the relational model. The difference is this: An OOA practitioner starts with the idea of an object as a conceptual entity that can be characterized by attributes; these attributes are tied together in the sense that they characterize the same object.

1. For a more complete presentation, see any standard database text. Especially recommended is C. J. Date's *An Introduction to Database Systems*, second edition, Addison Wesley, 1977.

However, the relational modeler starts with relations made up of *arbitrary sets* of attributes, and is tasked with moving these attributes around between relations until certain “normalization flaws” have been removed. As a result, the relational modeler must consider issues that would never occur to the OOA practitioner (such as the case of multi-valued dependency. See database texts—particularly Ullman, *Principles of Database Systems*, Computer Science Press, 1982—for examples of this “problem;” such examples seem quite paradoxical to the OOAer).

In order to do his work, the relational modeler relies on the following:

DEFINITION (Functional dependence on an attribute): Suppose that we have two attributes A and B. Then attribute B is said to be *functionally dependent* on attribute A if and only if given the value of attribute A (and observational access to instances in the world being modeled), one can determine exactly the value of attribute B.

So when we say that B is functionally dependent on A, we mean that there is a *reason* that guarantees that we can determine the value of attribute B given only the value of attribute A. This reason must be based on the world being modeled (we know that given a dog's name—that is, attribute A—we can determine the dog's weight) and must be of such a nature that it holds for any imaginable instance of the object under consideration.

The definition of functional dependence can be expanded to account for sets of attributes; this is necessary to account for compound identifiers.

DEFINITION (Functional dependence on a set): Suppose we have a set of attributes called A and an attribute B. B is not a member of A. Then B is said to be *functionally dependent* on A if and only if given values for all the attributes in A (and observational access to instances in the world being modeled), one can determine exactly the value of attribute B.

2.1.3 Proper Attribution

PRELIMINARY DEFINITION (Proper attribution): An OOA object P is said to be *properly attributed* if and only if

- Every attribute of P that is not part of any identifier of P is functionally dependent on a complete identifier of the object and not on any proper subset of that identifier.
- If an attribute B of P is functionally dependent on a set A of attributes of P, then A is an identifier of P.

By our definition of proper attribution, any OOA object is in fourth normal form.

In OOA, we commonly say that “the attributes of an object are mutually independent.” What is meant by this statement is the following:

THEOREM (Mutual functional independence of attributes): Given a properly attributed OOA object and two attributes R and S of that object. Neither R nor S is part of an identifier. Then R is not functionally dependent on S.

The proof of this theorem is easy to establish: Suppose that R is functionally dependent on S. Then by the definition of proper attribution, S must be an identifier of the object, contrary to the hypothesis. Therefore, R is not functionally dependent on S.

2.2 Stochastic Dependence

Suppose we have an object

Coin Toss (<u>trial number</u>, time of trial, coin 1, coin 2)

The domain of coin 1 is {H, T}, as is the domain of coin 2. Now we conduct experiments by taking a pair of coins and tossing them in the air. Then we record the results.

It is clear that this object is in fourth normal form, and that coin 1 and coin 2 are functionally independent of one another. But, in addition, coin 1 and coin 2 are said to be *stochastically* independent of one another: that is, knowing the value of coin 1 gives us no clue to the value of coin 2. Probabilists talk about this state of affairs as follows:

$$\Pr[\text{ coin 2} = \text{H} \mid \text{coin 1} = \text{H }] = \Pr[\text{ coin 2} = \text{H }]$$

and you read it as "the probability that coin 2 = H (assuming that I already know coin 1 = H) is the same as the probability coin 2 = H (assuming I know nothing about coin 1)." That is, the value of coin 1 has no predictive power as to the value of coin 2.

DEFINITION (Stochastic dependence and independence): Two attributes A and B are said to be *stochastically independent* if and only if

$$\Pr[\text{ A=a} \mid \text{B=b }] = \Pr[\text{ A=a }]$$

Two attributes that are not stochastically independent are *stochastically dependent.*

Now, in the context of a grade school, consider the object:

School child (<u>student ID</u>, grade, height, weight)

The object is properly attributed, and grade, height, and weight are mutually functionally independent. However, they are not stochastically independent: I could observe a number of students and make a scatter plot of height vs. grade. Then, if you come in with a new student and tell me what grade the student is in, I can make a better-than-random guess of the value of his height.

$$\Pr[\text{ height} > \text{h} \mid \text{grade} = \text{g }] \neq \Pr[\text{ height} > \text{h }]$$

One can therefore say that the value of grade has predictive power as to the value of height, or that height and grade are correlated.

In summary, it is entirely legal for an OOA object to contain attributes that are stochastically dependent upon other attributes of the same object, so long as the rules involving functional dependency are observed—that is, so long as the object is properly attributed.

2.3 Mathematical Dependence

Consider the objects

Material (<u>material ID</u>, density, . . .)

Sample (<u>sample ID</u>, weight, volume, material ID(R))

These objects are both in fourth normal form. There is, however, an obvious violation of the concept of “one fact in one place:” given density and weight, we can determine volume. There are two points to ponder:

- Any one of these attributes is mathematically dependent on the other two. This does not constitute a violation of normalization because the attributes are in different objects.
- This is a stronger form of dependency than functional dependency: We do not need access to instances in the world being modeled in order to determine the value of the third attribute.

Because attributes of this nature arise fairly commonly in applications, we incorporate the standard definition of mathematical dependence into OOA:

> DEFINITION: An attribute Y is said to be *mathematically dependent* on a set of attributes X if and only if, given values of the attributes in X, the value of Y can be determined by a formula or algorithm.

Now suppose we have an object

Crate (<u>crate ID</u>, width, height, depth, volume, destination, . . .)

Is Crate in fourth normal form? Because the relational model does not take into account the concept of mathematical dependence, this question cannot really be answered satisfactorily. However, we can produce structures compatible with the relational model:

Rectangular Solid (<u>width</u>, <u>depth</u>, <u>height</u>, volume)

Crate (<u>crate ID</u>, width (R), depth(R), height(R), destination, . . .)

These two objects are properly normalized, but at a cost. You can think through about how you would want to keep the Rectangular Solid table up to date, and whether or not you would want to keep entries that describe volumes of non-existent crates. But in any case, you would have to search the table every time you added a crate. In summary, creating a Rectangular Solid table is not an engineering-style solution.

We resolve this situation as follows:

- If the model contains a set of attributes that are related through a formula or algorithm, determine a proper subset of these attributes to act as independent variables. Mark the remaining attributes in the set—the dependent variables—with an (M) following the attribute name, as shown in Figure 2.1. This is to be done regardless of whether or not all the attributes in the set are attributes of the same object.
- In the description of an attribute that represents a dependent variable, cite the formula or algorithm used to determine the value of the attribute.

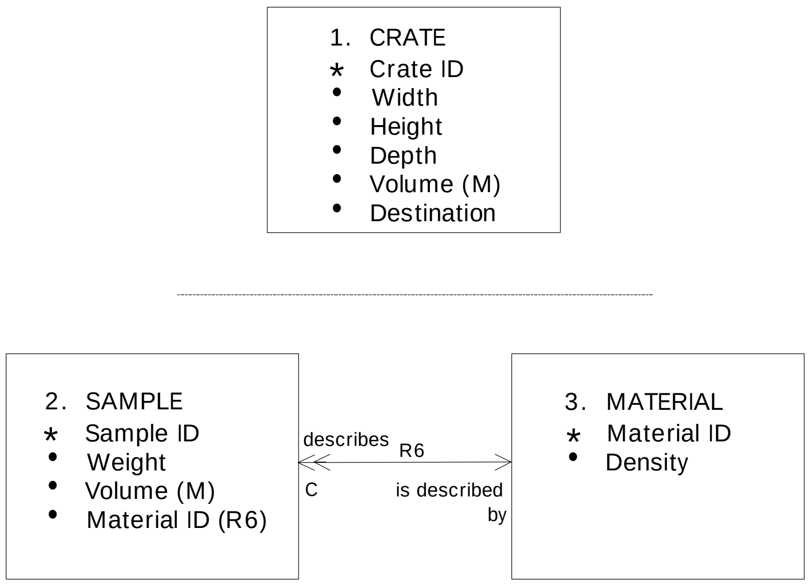


Figure 2.1: Mark a mathematically dependent attribute with an (M) following the name of the attribute.

Finally, inclusion of mathematically dependent attributes requires us to refine our definition of proper attribution.

FINAL DEFINITION (Proper attribution): An OOA object P is said to be *properly attributed* if and only if

- Every attribute of P that is not part of any identifier of P is functionally dependent on a complete identifier of the object and not on any proper subset of that identifier.
- If an attribute B of P is functionally but not mathematically dependent on a set A of attributes of P, then A is an identifier of P.

3

Relationship Loops

Neil Lang

During the course of building an Information Model, an analyst may add a relationship between two objects that are already connected by a chain of relationships. In so doing, the analyst creates a loop of relationships. In this chapter we discuss a set of issues that require consideration when forming loops of relationships. In particular we discuss when to form loops, the need to characterize such loops as dependent or independent, and how to represent such loops in the OOA Models.

3.1 Loops of Relationships

When abstracting a relationship that closes a loop of relationships, the analyst first needs to verify that the relationship is required. Does it capture an association not already captured by the other relationships in the loop? Consider the fragment of an Information Model in Figure 3.1 in which relationship

R3: Parent RAISES CHILD WHO ATTENDS School

completes a loop with

R1: Parent RAISES Child and R2: Child ATTENDS School.

But the R3 relationship is nothing more than the concatenation of R1 and R2 and captures no new associations. R3 is therefore redundant and should not be added to the model.

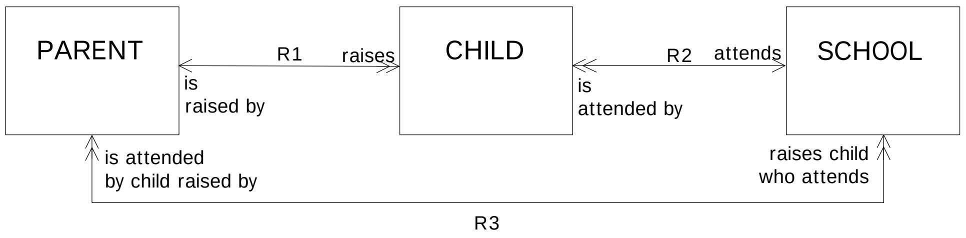


Figure 3.1: R3 is a redundant loop-closing relationship.

On the other hand, consider the relationship

R4: Parent GRADUATED FROM School

in Figure 3.2. Here R4 captures an association that is clearly different from that captured by the combination of the R1 and R2 relationships. Therefore R4 is not redundant and it is most appropriate to add this relationship to the model.

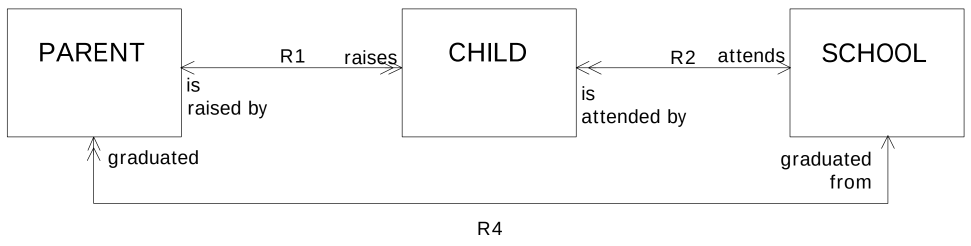


Figure 3.2: R4 is a non-redundant loop-closing relationship. This is a "loop of independent relationships".

3.2 Characterizing Loops

Loops of Dependent and Independent Relationships. In some loops instances of the relationships in the loop are completely independent. That is, the value of one of more referential attributes does not constrain the values of the remaining referential attributes. Consider the model in Figure 3.2. Knowing the children being raised by a parent and the schools they attend does not tell us anything about the school from which the parent graduated.

On the other hand, there are loops in which instances of the participating relationships are constrained. Consider the model in Figure 3.3. Here knowing what children a parent is raising and the schools they attend indicates something about the school or schools on whose PTA the parent serves.

A loop of relationships in which the instances of the relationships are unconstrained is known as *a loop of independent relationships* while a loop in which the instances of relationships are required to be constrained is known as *a loop of dependent relationships.* Note that it is the set of relationships composing the loop that we describe as being dependent or independent. We do not categorize individual relationships in a loop as dependent or independent.

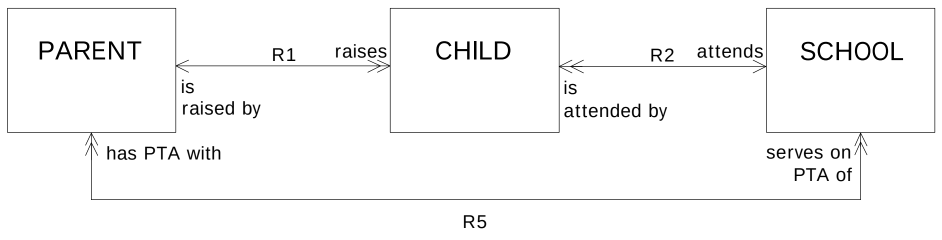


Figure 3.3: Example of a "loop of dependent relationships".

Determining Loop Dependency. Determining the dependency of a loop requires more than just a cursory inspection of the objects and relationships. Rather it is the real-world policy underlying the relationships that governs the loop dependency. A loop with a given set of objects and relationships can be either dependent or independent, depending on the underlying policy. Consider a university in which Professors work for a single Department, Students major in one and only one Department, and Students are advised by one and only one Professor. These objects and relationships are captured in the Information Model shown in Figure 3.4.

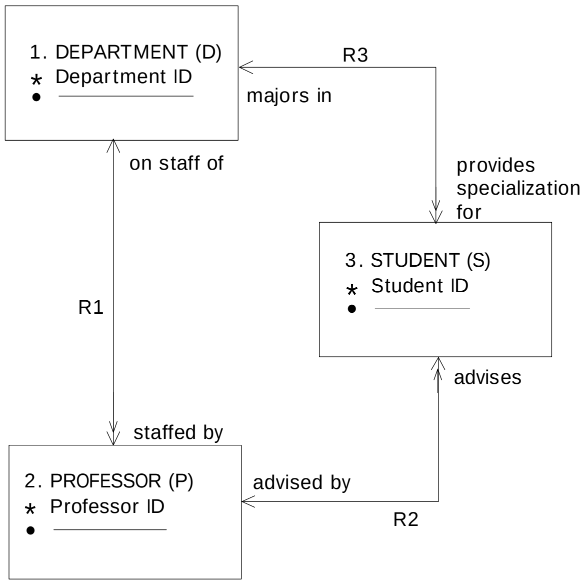


Figure 3.4: Fragment of an Object Information Model for a university.

Note that the relationships form a loop, but it is impossible to determine the dependency of this loop. Whether the instances of relationship R2

Professor ADVISES Student

are required to be constrained by instances of relationship R3

Student MAJORS IN Department

depends on the rules and policies of the university. One university (which we'll identify as University A) allows students to select an advisor from any department regardless of the department in which the student is majoring, while another university (University B) requires that students select advisors only from their major department. Understanding the underlying policy that determines whether a loop of relationships is dependent or independent is an important part of building the Information Model. The analyst must build models that correctly reflect all real-world policies in order to ensure that any design or code derived from these models permit only those associations allowed by these policies.

3.3 Depicting Loop Dependency

Loops of Independent Relationships. Once the analyst has determined the dependency of a loop, that dependency needs to be expressed in the model itself. To show that a loop is independent, formalize each relationship in the loop separately. Note that this produces a model in which the instances of the participating relationships can be populated in a completely unconstrained manner. Because the policies at University A require the loop to be modeled as a loop of independent relationships, we need to formalize each relationship separately to complete the model for University A (see Figure 3.5).

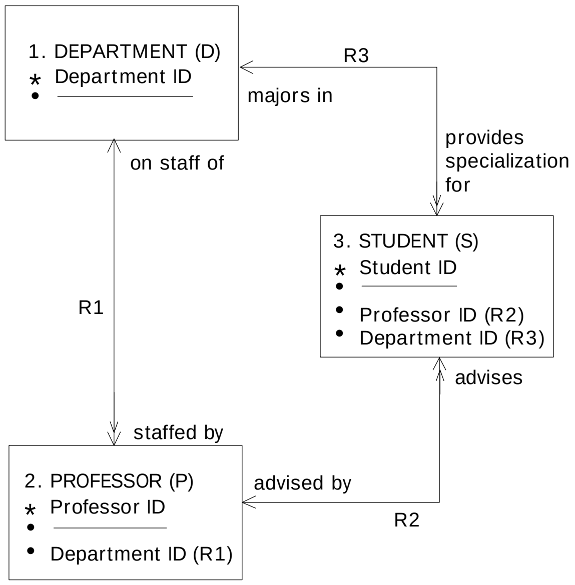


Figure 3.5: Relationships formalized to indicate a loop of independent relationships.

Loops of Dependent Relationships. To model a loop of dependent relationships, first formalize all relationships as usual. Then tag a referential attribute in the object with the most instances with a "c" to show that its allowable values are constrained by the actual value of other referential attributes formalizing the loop. Since the object with the most instances will almost always have a pair of referential attributes, we can choose to tag either of them. (See Figure 3.6 for two ways to build the loop of dependent relationships for University B.) In either case, we will also need to document the actual constraint in the object and attribute descriptions. Note that this tagging is simply a reminder to the analyst who will still have to incorporate the constraint formally somewhere in the complete OOA model. In this example, the analyst will most likely add extra processing to the state model for the Student object to check that the advisor belongs to the Department in which the Student is majoring.

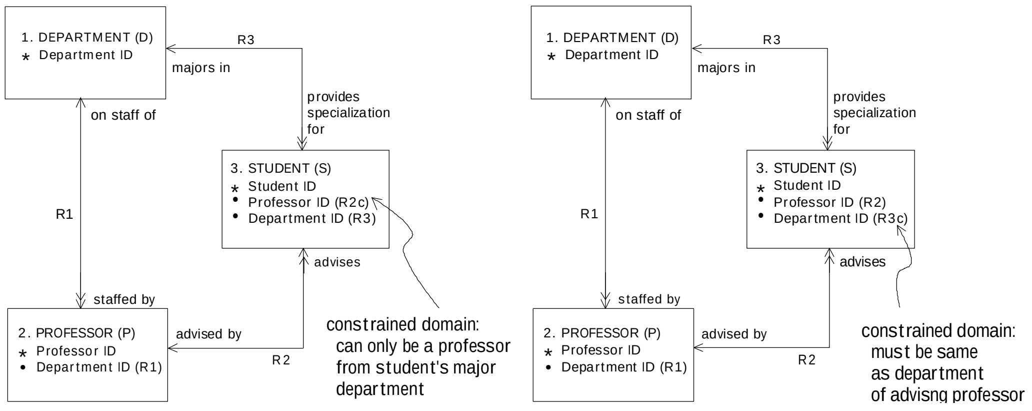


Figure 3.6: Two ways to formalize a loop of dependent relationships using constrained referential attributes.

In certain cases we may be able to modify the models developed above so that the loop dependency is expressed directly in data. This would then guarantee that regardless of how the model was populated the instances of the relationships would always be constrained as necessary. The two following sections present two situations in which such modification is possible.

Collapsed Referentials. Consider what occurs if we replace the arbitrary identifiers for the Professor and Student objects with compound identifiers involving a Department ID (see Figure 3.7). When we formalize R2 and R3, we add two sets of referential attributes incorporating Department ID to the Student object (Major Department ID(R3) and Advisor Department ID(R2)).

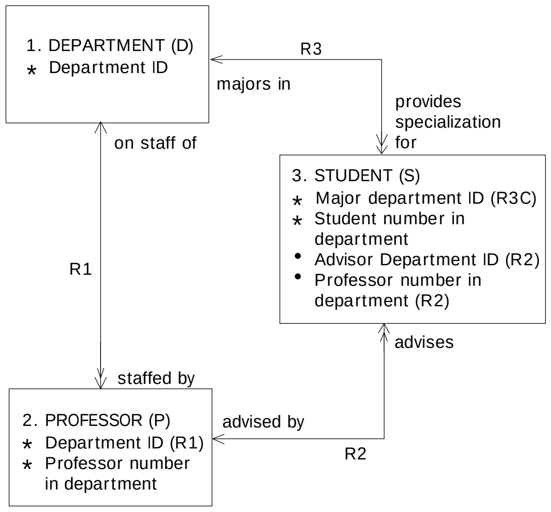

1. DEPARTMENT (D)
* Department ID
R3
majors in
provides specialization for
on staff of
3. STUDENT (S)
* Major department ID (R3C)
* Student number in department
• Advisor Department ID (R2)
• Professor number in department (R2)
R1
advises
staffed by
2. PROFESSOR (P)
* Department ID (R1)
* Professor number in department
advised by
R2

Figure 3.7: Formalizing a loop of dependent relationships using compound identifiers with constraints.

The loop constraint is now very easy to capture as Major Department ID(R3) must always equal Advisor Department ID(R2). We show this (see Figure 3.8) with Department ID(R2,R3), that is, a single referential attribute formalizing two relationships simultaneously. The use of collapsed referentials in loops often allows us to represent the loop dependency directly in data. Doing so guarantees that whenever we populate the model the constraints are automatically satisfied.

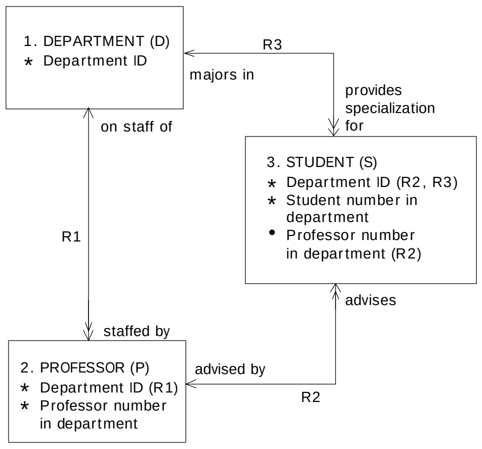


Figure 3.8: Formalizing a loop of dependent relationships using collapsed referentials.

Composed Relationships. Another special case occurs when the constraint on the referential attribute is such that it identifies a single instance of the associated object. Consider the model for University B (right half of Figure 3.6) in which we choose to constrain the R3 referential attribute in the Student object. Here the constraint identifies a single instance of the associated instance of Department. This is equivalent to requiring that the query across R2 (to determine a student's advisor) followed by a query across R1 (to determine the professor's department) must always produce the same result as the query directly across R3 (to determine a student's major department). When the two sets of queries must produce the same single instance, we can declare the loop-closing relationship to be formalized by the query along the other relationships in the loop. Such a relationship is said to be *composed* and is indicated by the R3 = R2 + R1 in Figure 3.9. Since composition of relationships tracks queries across relationships, a composed relationship does not require referential attributes.

This notation R3 = R2 + R1 is not intended to convey that the relationship R3 means the same as the combination of relationships R1 and R2. Otherwise R3 would be redundant and should not be added to the model.

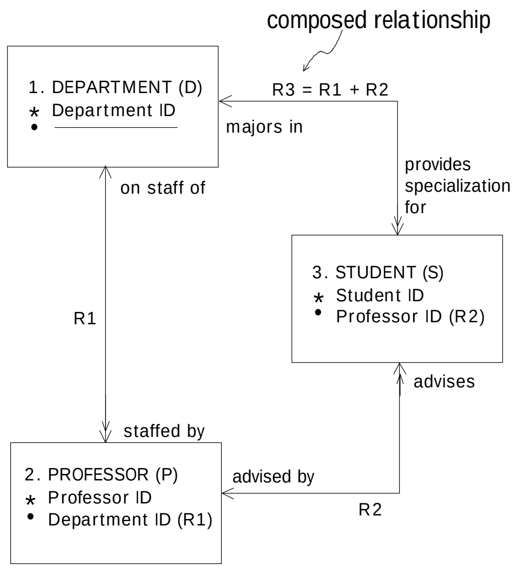


Figure 3.9: Formalizing a loop of dependent relationships using composition of relationships.

Composition of relationships captures the constraint directly in data and the model as it appears in Figure 3.9 will always guarantee that a student's major and advising departments are the same. However the use of composition is limited in that it requires that the constraint always identify a single associated instance. If R2 were conditional (say a student is not required to have an advisor) then we cannot compose R3 since there would be no guarantee that we could actually complete the query across R2. Furthermore not every relationship in a loop can be composed. Consider what happens if we try to compose R2 instead of R3. This is equivalent to asserting that the query across R2 (to determine a student's advisor) is equivalent to the queries across R3 and R1. This pair of queries identifies only a set of professors who belong to the major department. However it does not identify a single professor who serves as the advisor. This is what we expect since the corresponding constraint in Figure 3.6 involves a set of allowable instances of professor.

3.4 Summary

Adding a relationship that closes a loop in an Information Model requires that the analyst first verify that the relationship is not a redundant relationship. Then he or she must understand the underlying real-world policy in order to determine whether the loop is a loop of dependent or independent relationships. If the loop is an independent loop, formalize each relationship in the loop separately. If the loop is a dependent loop, use either constrained referential attributes, collapsed referentials, or composition of relationships as appropriate to capture the loop constraints. This effort ensures that the model reflects all real-world constraints correctly. Furthermore any design and code produced by translating the analysis model will then automatically incorporate such constraints.

4

Reflexive Relationships

Neil Lang

In the Shlaer-Mellor method, relationships are abstractions of associations that hold systematically between instances of objects. Analysts usually recognize associations between instances of different objects and abstract the corresponding relationships. Occasionally an analyst models a relationship that abstracts systematic associations between instances of the same object. In OOA96 we refer to such relationships as *reflexive* and in this chapter we will discuss a variety of ways to model reflexive relationships.

4.1 Role of Instances in Reflexive Relationships

Consider the following reflexive relationship:

Employee WORKS WITH Employee (Mc:Mc)

The order of the associated instances is not significant. 'Fred works with Ginger' conveys the same fact as 'Ginger works with Fred'. The instances play identical roles, and the multiplicity and conditionality of the relationship must be the same from the perspective of each of the participating instances. We refer to such reflexive relationships as non-directional or *role-symmetric*.

Now consider the following reflexive relationship:

Employee SUPERVISES Employee (1:Mc)

In this case, the order of the instances is significant: 'Lou supervises Mary' is very different from 'Mary supervises Lou'. Each instance in a relationship assumes a specific role. One instance of Employee is a supervising employee while the other is an employee being supervised. Furthermore the multiplicity and conditionality of such relationships can be different at each end. An employee being supervised must have exactly one supervisor while a supervising employee may supervise one or more employees. Such a relationship has a very directional character; we term it *asymmetric.*

4.2 Modeling Symmetric Reflexive Relationships

On the Information Model, show a symmetric relationship with a relationship line that loops back to the object. Since, by definition, such a relationship must have the same name, multiplicity, and conditionality at each end, name and characterize the relationship at one end only. To ensure that an instance of the relationship appears only once in the model, always formalize the relationship with an associative object regardless of the multiplicity of the relationship itself. In Figure 4.1 we show the Employee WORKS WITH Employee relationship so formalized.

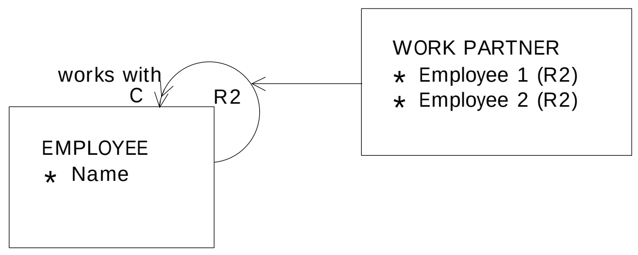


Figure 4.1: Symmetric relationship formalized according to OOA96.

4.3 Modeling Asymmetric Reflexive Relationships

Asymmetric reflexive relationships should be modeled using subtypes to capture the differing roles played by the participating instances. One way to do this for the Employee SUPERVISES Employee (1:Mc) relationship is to subtype the Employee object into three subtypes: Employees who are supervised only (and have no supervising role), employees who supervise only (and have no supervisor), and employees who assume both roles *in different instances* of the relationship. Next abstract two role supertypes: Employee as Supervisor and Employee as Supervisee as shown in Figure 4.2.

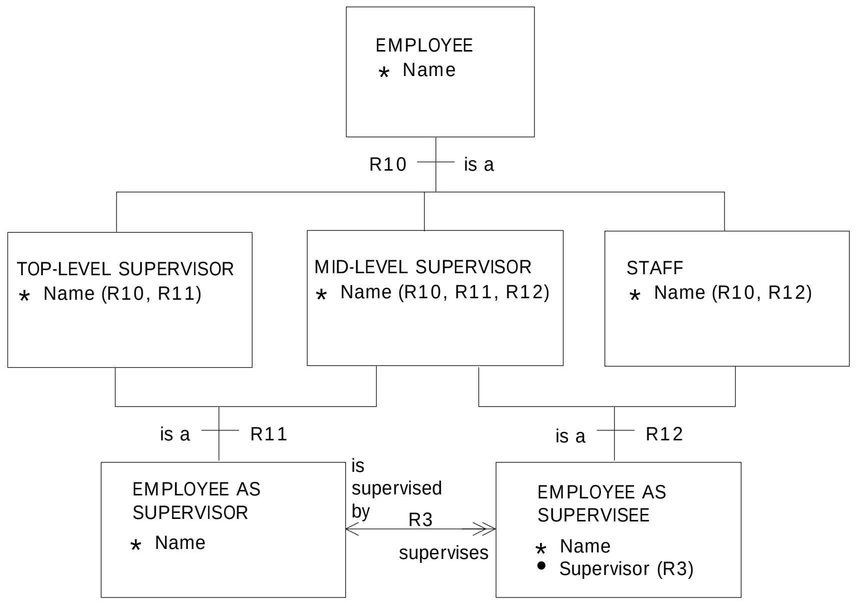


Figure 4.2: Modeling a reflexive relationship using a full set of subtypes.

Abstracting the various roles allows us to model the meaning of an Employee SUPERVISES Employee (1:Mc) relationship explicitly between the differentiated role objects. In our example this meaning is now cast as Employee As Supervisor SUPERVISES Employee As Supervisee. Note that we can now capture the desired conditionality and multiplicity very directly and clearly.

We need to use this form whenever the three subtypes have different characteristics. Mid-Level and Top-Level Supervisors may have additional attributes as a result of their respective responsibilities. In cases where two or more of the subtypes have no distinguishing attributes, we can use a partially collapsed form of the model as shown in Figure 4.3. Here we replaced Top-Level Supervisor and Mid-Level Supervisor with Supervisor. We now have one subtype to represent those employees who are only supervised (Staff) and one subtype for those employees that do some supervising (Supervisor). When we do this, we model the SUPERVISES relationship between one of the subtypes and the supertype. Note that we also had to make the relationship conditional since not all instances of Employee (the supertype) are necessarily supervised.

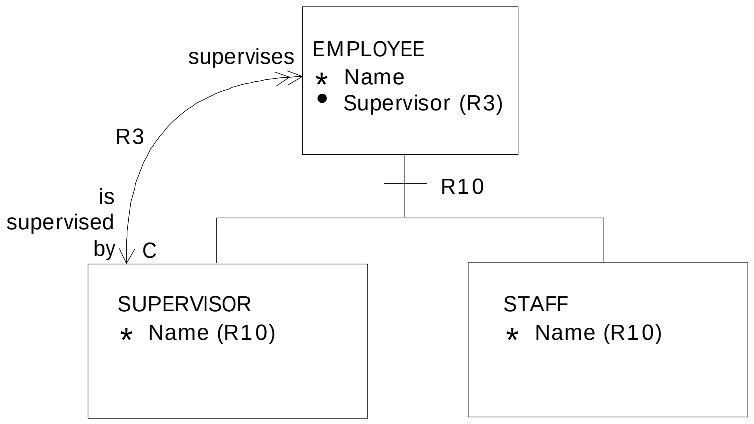


Figure 4.3: Modeling a reflexive relationship using a partial set of subtypes.

Let us consider one more example. Suppose that we wish to capture the design of an archery target as a series of concentric nested rings. Figure 4.4a represents our first attempt to model this situation. This model succeeds in capturing the dimensions of the outer rings (the inner diameter of a ring is the same as the outer diameter of the ring it surrounds), but it fails to treat the central "ring"—the bullseye—correctly: (1) the central ring doesn't surround any ring and (2) the inner diameter of the central ring is zero. Since this relationship has an asymmetric nature (Ring 3 SURROUNDS Ring 2 means something very different from Ring 2 SURROUNDS Ring 3) we now model it using subtypes. In Figure 4.4b we recast the model using two subtypes: Innermost Ring and Surrounding Ring. Note how this version of the model allows us to capture the fact that the innermost ring does not surround another ring, something that was impossible with the form in Figure 4.4a. In addition, by separating out the innermost ring, we have made it possible to apply a different policy to it. Should we want to calculate the area of each ring, we can use one formula for the bullseye and a different formula for the outer rings.

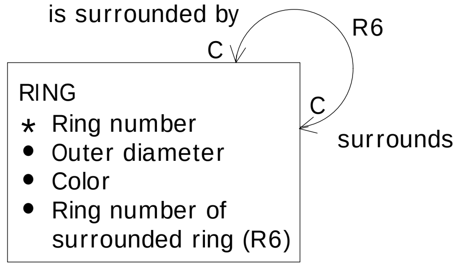


Figure 4.4a: A weak model of the rings of an archery target.

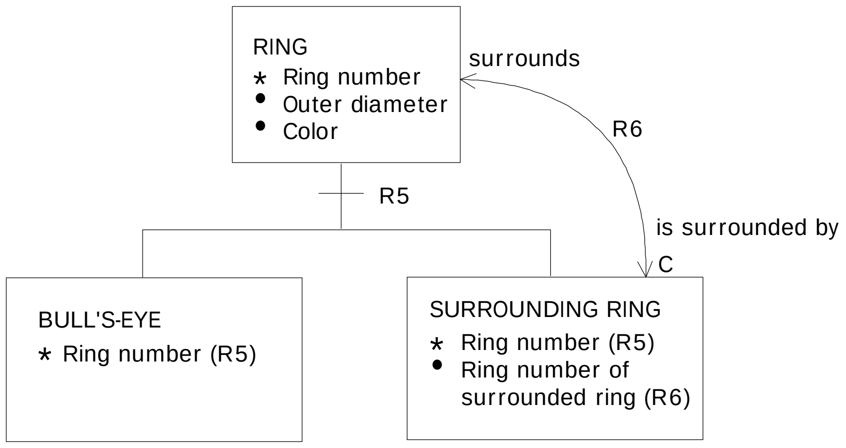


Figure 4.4b: A more accurate model for the archery target.

4.4 Summary

Modeling reflexive relationships—those that involve associations between instances of the same object—requires some additional considerations. Inspect typical associations to determine whether the order of associated instances is significant. For symmetric relationships—those in which the order of related instances is not significant—draw the relationship line to loop back to the object and name and characterize the relationship at one end only. For asymmetric relationships—those in which each instance assumes a different role in the relationship—abstract additional subtypes and model the relationship between the supertype and one of the subtypes.

5

Events

Sally Shlaer
Neil Lang

The concept of an event remains the same as in OOA91. However, some rules have been strengthened to eliminate certain rare ambiguous cases. In addition, the formalism has been extended to include the concept of polymorphic events.

5.1 Event Labels

Object Lifecycles (p. 42) suggests two different conventions for assigning event labels. Because one of these conventions—destination-based labeling—has been virtually universally adopted by the user community, we now promote the convention to a rule:

RULE (event labeled by destination): If a non-polymorphic event is directed to an object, the label of that event must begin with the key letter of that object.

5.2 Data Carried by an Event

In OOA91, an event could carry supplemental data as well as an identifier of the instance to which it was directed. These two types of event data remain in OOA96; the only difference is that we now make a precise distinction between them on the models.

The syntax for an OOA96 event is

E1: event meaning (identifying attribute(s); supplemental data item(s))

where either the identifier or the supplemental data items (or both) may be missing. Hence an event directed to an existing instance has one of the forms

E2: event meaning (identifying attribute(s);)

E3: event meaning (identifying attribute(s); supplemental data item(s))

while an event directed to a single-instance assigner[1] may have either of the forms

E4: event meaning (; supplemental data item(s))

[1] The assigners that were defined in OOA91 are now known as single-instance assigners. OOA96 also allows for multi-instance assigners. See Chapter 7.

E5: event meaning (;)

Finally, because a creation event is not directed at an existing instance, it has the form

E6: create instance (; supplemental data item(s)).

In this case, it is likely—but not required—that values for the identifying attributes for the instance to be created will be carried in the supplemental data items.

5.3 Event List

Now that we distinguish between identifying attributes and supplemental data carried by an event, the format of the Event List becomes:

Label	**Meaning**	**Identifying attributes**	**Supplemental data**	**Source(s)**
V1	Button pushed	oven ID	(none)	button
L1	Turn on light	light ID	(none)	oven
A5	create account	(none)	customer ID, deposit amount	external
. . .	. . .	. . .	. . .	. . .

The Destination column has been removed from the event list because, as a result of the event labeling rule of Section 5.1, it is now redundant with the Event Label column.

5.4 Same Data Rule

Now that the form of an event has been defined more precisely, the "same data" rule (*Object Lifecycles*, page 43) is modified as follows:

RULE (same data for a transition)*:* All events that cause a transition into a particular state must carry exactly the same ~~event data~~ identifying attributes and the same supplemental data items.

5.5 Events Within a Domain

Events generated in an action in a domain must be received by an instance in the same domain. It is no longer permitted to generate an event that is intended for an object in another domain.

For information about communication between instances in different domains, see Chapter 9.

5.6 Order of Receiving Events

In OOA91, the only rule regulating the order in which events are received applied to events transmitted between a single sender/receiver pair. In all other cases OOA91 made no assumptions, and the analyst was directed to ensure that the state models operated properly regardless of the order in which events were received.

However, in some cases this policy required the analyst to provide additional logic that had no real value in the domain under consideration. To remedy this problem, OOA96 imposes an additional rule:

> RULE (expedite self-directed events): If an instance of an object sends an event to itself, that event will be accepted before any other events that have yet to be accepted by the same instance.

5.7 Polymorphic Events

5.7.1 Concepts

Figure 5.1 shows a fragment of an Information Model in schematic form. Let us suppose that we have defined lifecycle state models for objects T, U and V. Object S, the supertype of T, U and V, has no lifecycle model.

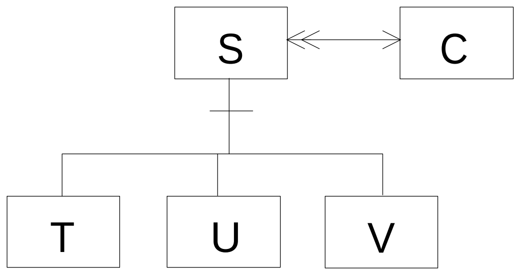


Figure 5.1: C would like to generate an event to an instance of a subtype of S. C has the identifier of the instance, but does not know what subtype the instance belongs to.

Now suppose that an instance of object C would like to generate an event to an instance of S (and therefore to an instance of one of the subtypes of S). C knows the identifier of the intended recipient, but doesn't know what subtype the intended recipient belongs to.

This situation is analogous to the notion of polymorphism in OOP, in which one would like to invoke a particular method of a child class. Each child class has its own version of the method, and all the caller knows is the name of the method and the fact that the instance of interest belongs to a child class of a known parent class. In such a case, an OO language allows one to invoke the method as if it were a method of the parent class. The semantics of the programming language—and therefore its inherent mechanisms—ensure that a method of the same name in the appropriate child class is actually invoked. Such an invocation is known as a polymorphic invocation.

In OOA96, we allow for the concept of "polymorphic events." Returning to our example, we allow C to generate an event that *appears* to be directed at the supertype S, but which will, in fact, be received by an instance of one of the subtypes T, U or V.

5.7.2 Defining Polymorphic Events

Naming a polymorphic event. A polymorphic event has multiple event labels. The label used by the sender employs the key letter of the supertype that is the apparent recipient. The labels used by the true recipients employ their own key letters. Hence in the example of Figure 5.1, the sender (object C) labels the event with an S, while the true recipients know this event by, say, T3, U1, and V6.

Polymorphic event table. To define the relationship between the polymorphic event and the actual events as known to the true recipients, the analyst must prepare a polymorphic event table as shown below. This table, like the event list, applies to the entire domain.

Polymorphic (sender's) label	**True (recipient's) label**
S1	T3
S1	U1
S1	V6
. . .	. . .

It is the analyst's responsibility to supply true event labels so that a polymorphic event can be received by *every* instance of the supertype, regardless of which subtype the instance also inhabits.

Because the polymorphic event label is only an alias for the true event labels, the following rule applies to all polymorphic events.

RULE (same data for polymorphic aliases): If two or more true events are aliased to the same polymorphic event, the true events must carry values for exactly the same identifying attributes and the same supplemental data items.

State models. To specify the generation of a polymorphic event, an action description in the state model of C must contain

generate S1*: event name (S ident;)

The purpose of the asterisk is simply to remind the reader of the model that the event is polymorphic, and that the true recipient of such an event is not the object implied by the event label.

Object Communication Model. Like any other event, a polymorphic event is shown on the Object Communication Model (Figure 5.2) as a labeled arrow from the sender of the event to the true (and not the apparent) receiver. Note that the arrows are annotated with the event labels known by both the sender and the various true receivers. Object S does not appear on the OCM because, in this example, we are assuming that S doesn't have a state model.

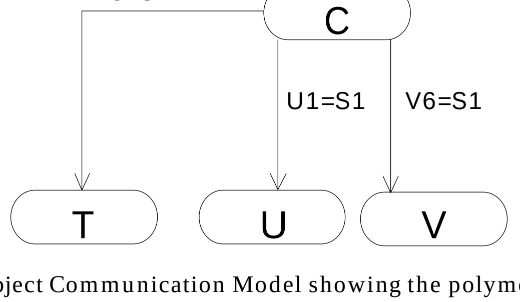


Figure 5.2: Object Communication Model showing the polymorphic event S1 and the related true events T3, U1, and V6.

This leads to a very important point: the state model (if any—see further discussion below) of the supertype object plays no role in the routing of a polymorphic event. This chore is specifically defined as a mechanism within the formalism of OOA.

5.7.3 Can an Instance Have More Than One State Model?

Figure 5.3 depicts a structure in which a single instance of an object (in this case, an instance of S) has two separate and different state models. Should this be legal in OOA? We have two answers: one based on experience, and one based on theory.

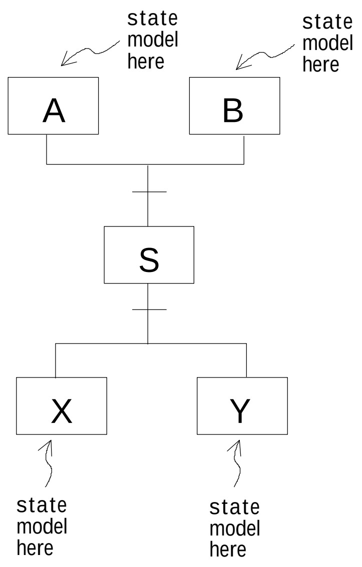


Figure 5.3: Can an instance have more than one state model?

The experience-based answer says no. In the models we have seen showing this kind of construction, we have found other seemingly unrelated analysis errors. When the models were reconstructed to eliminate these errors, the need for multiple state models disappeared. Hence *experience* indicates that multiple state models for a single instance is unlikely to make sense.

On the other hand, theoretical arguments have not yet provided us with a definitive answer yea or nay. In particular, we haven't been able to prove that a multiple state model construction would necessarily lead to an inconsistency in the model. However, we have also not been able to come up with a reasonable interpretation of such a construction: What could it mean for an instance to have multiple lifecycles? So, while theory does not provide us with a conclusive answer, it tends to indicate that the answer should be “yes”.

Hence, faced with this division of evidence, for OOA96 we continue to advise:

1. Avoid, if you can, constructing a model in which a single instance has multiple state models.

2. If an instance must have multiple state models, make sure that the state models are independent of one another—that is, that an action in one state model does not need to know what state the instance occupies in its other state model in order to operate correctly.

6

The FSM Mechanism

Sally Shlaer

This section describes the FSM mechanism of OOA96. This mechanism is used to process the events that drive object instances through their lifecycles, as well as to process those events that are directed at assigner state machines. The mechanism described here is very similar to that used in OOA91; it has been modified only (1) to account for the classification of event data into identifying attributes and supplemental data, (2) to support polymorphic events and (3) to allow for multiple instances of an assigner.

6.1 Tables Supplied by the Analyst

The FSM mechanism[1] of the OOA formalism requires that a table be specified for every finite state machine in the model. This table—the state transition table supplied by the analyst—has the form

	E_1	E_2	. . .	E_k	. . .	E_n
(none)	T_{01}	T_{02}	. . .	T_{0k}	. . .	T_{0n}
S_1	T_{11}	T_{12}	. . .	T_{1k}	. . .	T_{1n}
S_2						
S_i				T_{ik}		T_{in}
. . .						
S_m	T_{m1}	T_{m2}	. . .	T_{mk}		T_{mn}

where the S_i are states and the E_k are events (both appropriately labeled for the state machine of interest). The T_{ik} entries indicate either "event ignored", "cannot happen", or the new state to which the instance of an object or assigner is to transition.

In addition, the analyst must supply the polymorphic event list (see Chapter 5) to define polymorphic events together with their aliases.

6.2 Static Event Checking

The FSM mechanism as defined in Section 6.3 makes certain assumptions about the events that are submitted to it for processing. These assumptions can be verified by static checking of the OOA models. The required checking is presented in Figure 6.1.

1. A finite state machine, as defined in most writings on automata, applies to a single entity that is presumed to exist for all time. Because so many real world problems require instances to come into and fall out of existence, OOA requires an extension the traditional definition—hence this chapter.

```
Key letter corresponds to . . .?

    Active object or multiple instance assigner:
        Does event appear in STT?
            yes:
                Is there a 'can't happen' entry for this event in the 'none' row?
                    yes:  (event is a non-creation event)
                        Does the event carry identifying attributes?
                            yes:OK
                            no: ERROR (a non-creation event must have identifying attributes)
                    no:
                        Is there a 'event ignored' entry for this event in the 'none' row?
                            yes: ERROR (only valid entries in 'none' row are 'can't happen' or 'new
                              state')
                            no:
                                Is there a 'new state' entry for this event in the 'none' row only?
                                    yes:  (event must be a creation event)
                                        Does the event carry identifying attributes?
                                            yes:ERROR  (creation event incorrectly formed)
                                            no: OK
                                    no: ERROR  (a non-creation event is also a creation event)
            no: ERROR (undefined event)

Passive object:  (checking a possibly polymorphic event)
    Is object a supertype?
        yes:
            Are there complete entries for this event in the polymorphic event table?
                yes:
                    Does the event carry identifying attributes?
                        yes:OK
                        no: ERROR.  (polymorphic event cannot be a creation event)
                no: ERROR  (aliases not completely defined)
        no: ERROR (polymorphic event must carry identifier of supertype)

Single-instance assigner:
    Does event appear in STT?
        yes:
            Is there a 'can't happen' entry for this event in the 'none' row?
                yes:  (event is a non-creation event)
                    Does the event carry identifying attributes?
                        yes:ERROR   (events to single-instance assigners cannot have identifying
                          attributes)
                        no: OK
                no: ERROR  (creation events to single-instance assigners are not allowed)
        no: ERROR (undefined event)

Otherwise: ERROR (event to non-existent object)
```

Figure 6.1: Static checking for events. This check is done at analysis time to verify that all events in the models can be processed by the FSM mechanism.

6.3 The Algorithm of the FSM Mechanism

Each event is submitted to the FSM mechanism, which determines to which object or assigner the event is directed and then to which instance of that object or assigner. As a result of the static checking performed earlier, we know that:

- Any event submitted to the FSM mechanism bears the key letter of an object or assigner.
- Any polymorphic event can be delivered (provided that the targeted instance exists).
- Any event directed to a single-instance assigner carries no identifying attributes.

The algorithm of the FSM mechanism is given in Figure 6.2. Note that in OOA96, it is the responsibility of the FSM mechanism to maintain the current state of all instances in the model that have state machines. This is consistent with the policy (see Chapter 9) that makes "current state" part of the formalism itself so that the analyst no longer has the need (or capability) to set the current state of an instance directly.

```
Is the event polymorphic?
    yes:
        Find instance in supertype object corresponding to polymorphic event label.
        Find same instance in some subtype.
        Find true event label corresponding to the identified subtype in the polymorphic event table.
        Using this event as the submitted event, go to 'Key letter corresponds to'
    no:
        go to 'Key letter corresponds to'

Key letter corresponds to:
    active object or multiple-instance assigner:
        Does the event carrying identifying attributes?
            yes:  (non-creation event)
                Does the instance exist?
                    yes:
                        Find entry in STT corresponding to this event and the instance's current state.
                        Is entry . . .?
                            event ignored:  DONE
                            can't happen:  ERROR
                            new state:  Set current state to new state and invoke action of new state.
                    no: ERROR
            no: (creation event)
                Find entry corresponding to the event in "none" row of the STT.
                Is entry . . .?
                    can't happen:  ERROR
                    new state:  Invoke action of new state.

    single-instance assigner:
        Find entry in STT corresponding to this event and the current state.
        Is entry . . .?
            event ignored:  DONE
            can't happen:  ERROR
            new state:  Set current state to new state and invoke action of new state.
```

Figure 6.2: How events are processed by the FSM mechanism.

6.4 Analysis Errors Detected by the FSM Mechanism

As shown in Figure 6.2, there are two errors that can only be detected by the FSM mechanism.

- Can't happen: If an event is received in a given state and the analyst has declared that such an event cannot occur when the instance is in that state, then the analysis is defective and must be repaired.

- Instance does not exist: The FSM mechanism has received an event directed at an instance that does not exist. This generally indicates an hole in the application protocol such that events have been received in an order not intended by the analyst: either the targeted instance has not yet been created, or it has already been deleted.

- It is the responsibility of the analyst to develop an application protocol such that events can be received only in an order that makes sense. In this case, a solution may be developed by routing all events to a common recipient through a common sender.

7

Assigners

Neil Lang

Assigners were introduced in OOA91 to manage the creation of relationships in which there is competition for instances. In OOA96 we have made the following changes and extensions to assigners:

- Assigners are associated with relationships instead of associative objects
- Assignment protocols have been modified to reflect the fact that current state is now maintained internally by the architecture.
- The concept of an assigner has been extended to allow for multiple assigners to permit concurrent management of assignments where appropriate.

7.1 Competitive Relationships

Instances of relationships are often formed and deleted during the lifecycles of interacting objects. In many cases the selection of the pair of instances to be related can appear in the state model of one of the participating objects. However this will not work in all situations; consider the Clerk SERVES Customer relationship in Figure 7.1. If we place the selection of clerks in the Customer state model, multiple instances of one object (Customer) could all simultaneously select the same instance of the other object (Clerk). We refer to this as *competition for instances,* and in OOA96 we refer to relationships such as R3 as *competitive relationships.*

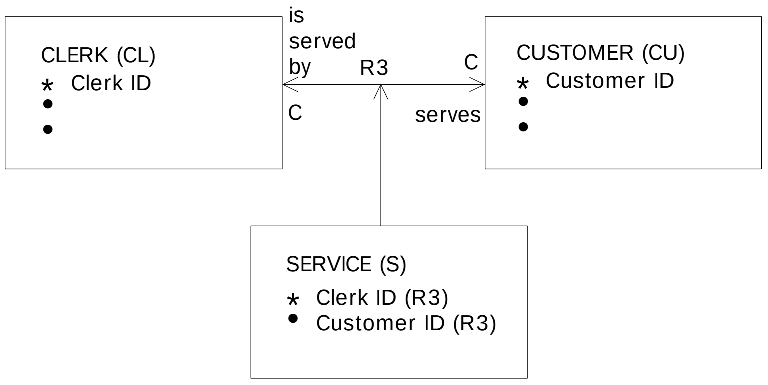


Figure 7.1: Information model for Customer-Clerk problem.

Objects participating in a competitive relationship must have both state(s) in which instances are available for assignment as well as state(s) in which the relationship exists. Competitive relationships must therefore be conditional at both ends. This was implied but not made explicit in OOA91.

7.2 Assigners for Relationships

The key to managing competitive relationships is the use of a single point of control to assign instances of the participating objects to each other. In OOA91 we introduced the assigner as this single point of control. The assigner, in OOA91, was a special state model associated with the associative object formalizing a competitive relationship. The assigner state model had one purpose only and that was to create instances of the associative object. The assigner state model had nothing to do with the behavior of the associative object. A separate lifecycle state model would be developed whenever there was interesting behavior.

An assigner fundamentally creates instances of a competitive relationship. In OOA96, we associate the assigner directly with the competitive relationship. Assigners bear the name of the relationship, and event identifiers for events directed to an assigner are based on the relationship number.

Associating assigners with relationships has two very desirable consequences. First, the analyst is now free to choose how to formalize the competitive relationship and is no longer forced to do so with an associative object. Secondly, all objects have, at most, one possible state model: a lifecycle model.

7.3 Assigner Protocol

In OOA91 the checking and selection performed by an assigner was based on the current state attribute. In OOA96 the current state attribute is maintained by the architecture and will be inaccessible to the application domain models. Therefore we now must add an attribute to each of the objects involved in a competitive relationship to maintain status with respect to its assignment (we refer to this attribute as availability status). The analyst defines appropriate values for these attributes and specifies processing in the state models in the domain being modeled to manage these attributes. Figure 7.2 shows the example involving Clerks and Customers with availability status attributes added to both the Clerk and the Customer objects. Also note that we have chosen to formalize the competitive relationship R3 by copying the identifier of the Customer object into the Clerk object rather than using the previously required associative object.

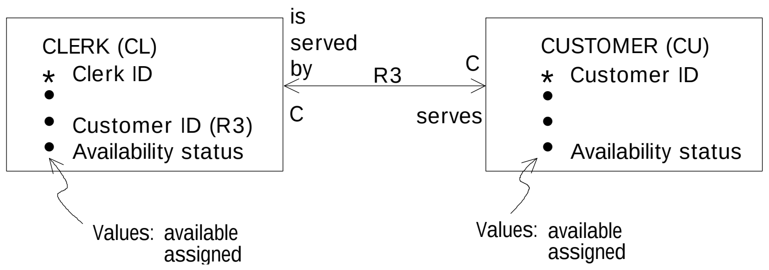


Figure 7.2: Revised information model for Customer-Clerk problem.

A slightly modified assigner protocol is used:

- Instances ready for assignment first set their availability status attribute to indicate that they are available.
- They then generate an event to notify the assigner they are available.

- The assigner waits until a pair of instances becomes available, selects the participating instances, and then sets each availability status attribute to indicate that the instance has been assigned. This protocol requires that only the assigner can set the participating availability status to “assigned”.
- The assigner then creates the instance of the relationship.
- The assigner then generates the customary set of events to the participating instances.

This protocol is illustrated in the state models in Figure 7.3.

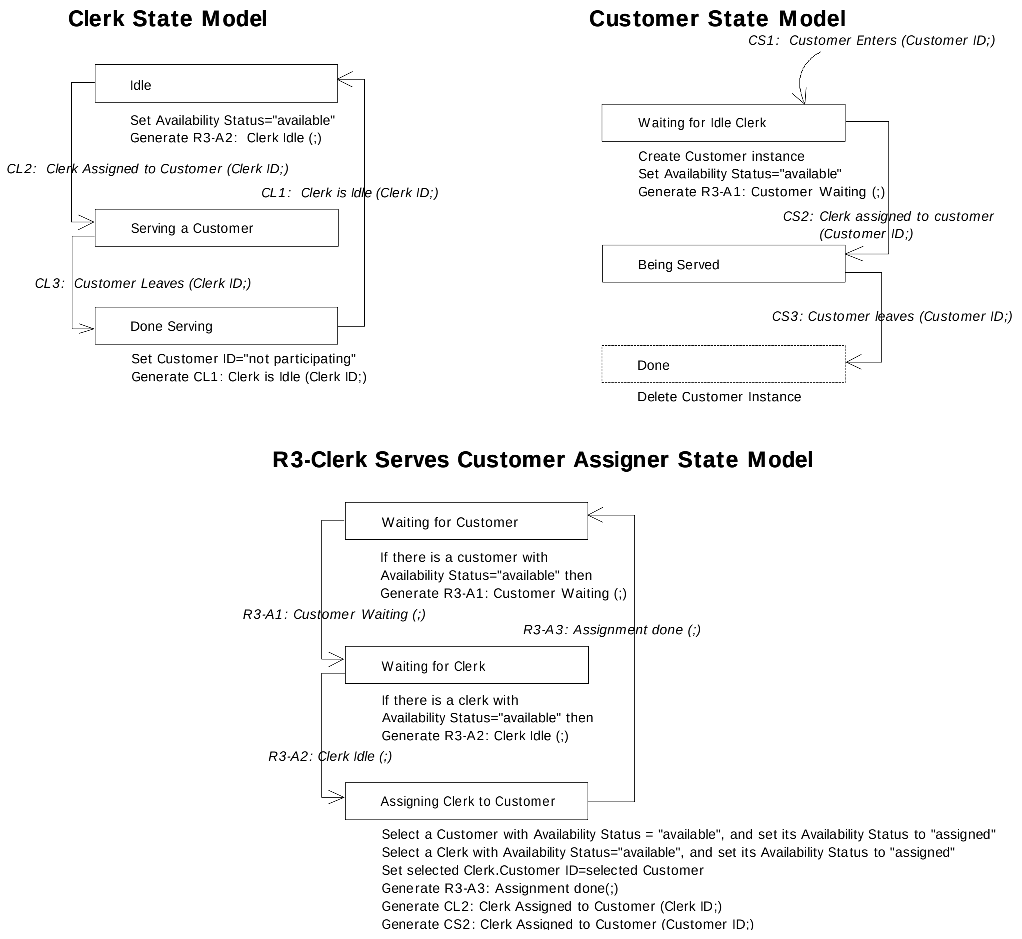

Clerk State Model
Idle
Set Availability Status="available"
Generate R3-A2: Clerk Idle (;)
CL2: Clerk Assigned to Customer (Clerk ID;)
CL1: Clerk is Idle (Clerk ID;)
Serving a Customer
CL3: Customer Leaves (Clerk ID;)
Done Serving
Set Customer ID="not participating"
Generate CL1: Clerk is Idle (Clerk ID;)
Customer State Model
CS1: Customer Enters (Customer ID;)
Waiting for Idle Clerk
Create Customer instance
Set Availability Status="available"
Generate R3-A1: Customer Waiting (;)
CS2: Clerk assigned to customer (Customer ID;)
Being Served
CS3: Customer leaves (Customer ID;)
Done
Delete Customer Instance
R3-Clerk Serves Customer Assigner State Model
Waiting for Customer
If there is a customer with Availability Status="available" then Generate R3-A1: Customer Waiting (;)
R3-A1: Customer Waiting (;)
R3-A3: Assignment done (;)
Waiting for Clerk
If there is a clerk with Availability Status="available" then Generate R3-A2: Clerk Idle (;)
R3-A2: Clerk Idle (;)
Assigning Clerk to Customer
Select a Customer with Availability Status = "available", and set its Availability Status to "assigned"
Select a Clerk with Availability Status="available", and set its Availability Status to "assigned"
Set selected Clerk.Customer ID=selected Customer
Generate R3-A3: Assignment done(;)
Generate CL2: Clerk Assigned to Customer (Clerk ID;)
Generate CS2: Clerk Assigned to Customer (Customer ID;)

Figure 7.3: State Models for the Customer-Clerk problem.

The major difference in the OOA96 protocol is that the assigner directly sets the availability status in the participating instances. In OOA91, assigners could only signal the participating instances that they had been assigned. The assigned instances would change their current state only after they had accepted the event from the assigner. Since the current state was set asynchronously with respect to the assigner, extra processing had to be specified to ensure that the assigner didn't recognize a previously-assigned instance as still available. We see that the new protocol has a major advantage: the ability of the assigner to change the availability status of the participating instances synchronously. This eliminates the need for the double check in the existing assigner protocol.

7.4 Multiple Assigners

The assigner protocol outlined above provides a framework for building assigners, but says nothing about selection policy. In the Customer-Clerk example, the selection policy could be simple (assign any available clerk to any waiting customer) or complex (assign preferred customers to the more senior sales staff). In this section we'll examine another type of assignment policy that permits multiple instances of an assigner to concurrently manage exclusive subsets of competing instances.

The fragment of the Customer-Clerk Information Model in Figure 7.3 says nothing about the scope of assignment. Are we in a small store where any clerk can serve any customer or are we in a large department store where clerks work in specific departments? Here the assignment of clerks to customers is more complicated since idle clerks in household goods are not able to serve waiting customers in women's shoes.

To correctly model the case of a store in which clerks are assigned to a single department, first add to the Information Model a Department object and two new relationships to capture the facts that clerks work in a single department and that customers shop in a single department. We could then proceed by creating a single assigner to manage assignments in all departments. However each department has its own set of clerks and customers that can be assigned independently of other departments. We can take advantage of this by creating a separate assigner to manage the assignments within each department. Each of these assigners uses a copy of the same Clerk-Customer assigner state model in a fashion that is entirely analogous to lifecycle state machines and an object's state model.

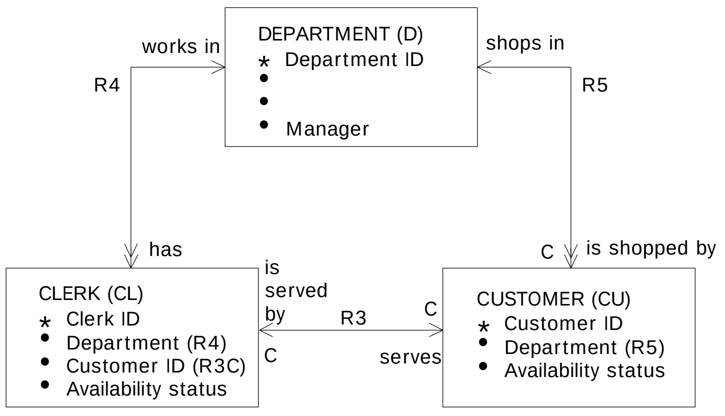


Figure 7.4: Information Model for Customer-Clerk problem extended to incorporate the Department.

OOA96 creates a new type of assigner called a multiple-instance assigner (or more simply a multiple assigner) which allows us to do exactly this. Multiple assigners are associated with competitive relationships that are part of a loop of dependent relationships. In many cases the object with the fewest instances in the loop (the Department object in our example) partitions the instances of the other objects in the loop into separate equivalence classes. Each equivalence class is associated with an instance of the partitioning object, and each equivalence class has a separate instance of the assigner. Therefore we identify an instance of a multiple assigner by the identifier of the instance of the corresponding partitioning object. Events directed to a multiple assigner carry an identifying attribute just like regular lifecycle events. Figure 7.5 shows a multiple assigner model for the Clerk-Customer-Department. There is almost no change from the single assigner case except that events to the multiple-instance assigner must carry an identifying attribute.

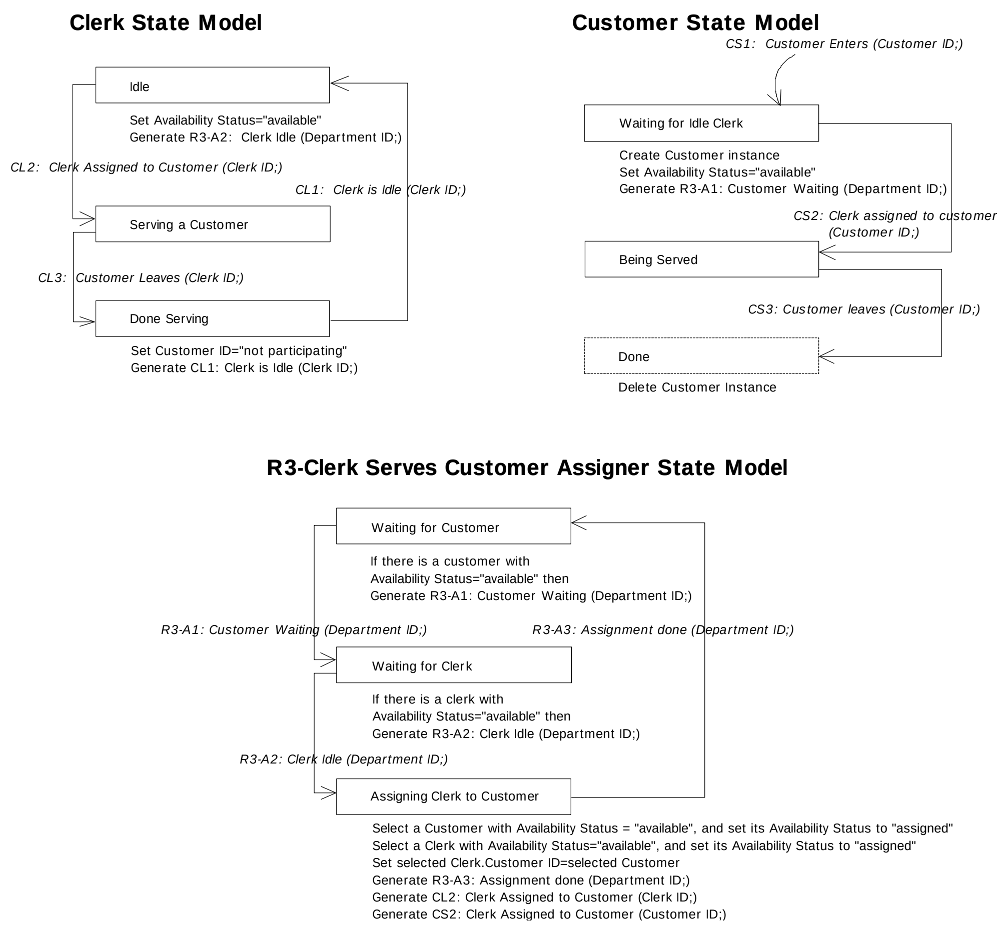

Clerk State Model
Idle
Set Availability Status="available"
Generate R3-A2: Clerk Idle (Department ID;)
CL2: Clerk Assigned to Customer (Clerk ID;)
CL1: Clerk is Idle (Clerk ID;)
Serving a Customer
CL3: Customer Leaves (Clerk ID;)
Done Serving
Set Customer ID="not participating"
Generate CL1: Clerk is Idle (Clerk ID;)
Customer State Model
CS1: Customer Enters (Customer ID;)
Waiting for Idle Clerk
Create Customer instance
Set Availability Status="available"
Generate R3-A1: Customer Waiting (Department ID;)
CS2: Clerk assigned to customer (Customer ID;)
Being Served
CS3: Customer leaves (Customer ID;)
Done
Delete Customer Instance
R3-Clerk Serves Customer Assigner State Model
Waiting for Customer
If there is a customer with Availability Status="available" then Generate R3-A1: Customer Waiting (Department ID;)
R3-A1: Customer Waiting (Department ID;)
R3-A3: Assignment done (Department ID;)
Waiting for Clerk
If there is a clerk with Availability Status="available" then Generate R3-A2: Clerk Idle (Department ID;)
R3-A2: Clerk Idle (Department ID;)
Assigning Clerk to Customer
Select a Customer with Availability Status = "available", and set its Availability Status to "assigned"
Select a Clerk with Availability Status="available", and set its Availability Status to "assigned"
Set selected Clerk.Customer ID=selected Customer
Generate R3-A3: Assignment done (Department ID;)
Generate CL2: Clerk Assigned to Customer (Clerk ID;)
Generate CS2: Clerk Assigned to Customer (Customer ID;)

Figure 7.5: State Models for the Customer-Clerk Department problem using multiple assigners.

Given the fact that a single assigner could manage assignments among all the equivalence classes, when should an analyst choose to use multiple assigners? Multiple assigners should be considered when assignments must be managed as expeditiously as possible. An assigner state model may deviate from the simple three state form and extra states may be required to properly synchronize it with the newly assigned instances. This extra synchronization can slow down the effective assignment rate. Having multiple assigners working concurrently on separate equivalence classes can improve performance significantly. Multiple assigners will be much easier to map to multi-tasking and multi-processor architectures, especially if the task or processor boundaries coincide with the partitioning objects.

8

Creation and Deletion of Instances

Sally Shlaer
Neil Lang

Because a particular instance of an object can be created or deleted in either the lifecycle of the same instance or in the lifecycle of a different instance—of either the same or a different object—there are a number of cases that need to be understood in order to construct lifecycles with the intended behavior. The purpose of this chapter is to enumerate these cases and to clarify exactly what occurs in each.

8.1 Time Scope of the Analysis

Every set of analysis models presupposes a particular time frame or *time scope*. For example, in a manufacturing application, one normally assumes that the lathes, milling machines, and the like simply exist: they are not created during the manufacturing process that is the subject of the analysis. In OOA, such instances are called *pre-existing instances.*

By contrast, manufactured products are created during the manufacturing process. Similarly, units of raw material are introduced into the manufacture, and are therefore also abstracted as being “created” during the time scope of the analysis. Although it is extremely common for a model to contain such objects, there is no special term in OOA for such an object or its instances.

8.2 How Instances Are Created: Axioms and Definitions

Basic concepts regulating the creation of instances are stated in the following axioms and definitions.

AXIOM (Method of instance creation). Any instance is created by invoking a create accessor[1]. This is the only way an instance can be created in the time scope of the analysis.

AXIOM (Coming into existence). For an instance that is created during the time scope of the analysis:

- The instance does not exist before the create accessor is invoked.
- The instance does exist after the create accessor completes.

[1] Create accessors are discussed in Chapter 9.

AXIOM (Responsibility for creation). Every instance of a non-associative object that is created in the time scope of the analysis is created by the lifecycle of some object.

Note that this axiom specifically forbids Assigners from creating instances of non-associative objects. This is consistent with the role of an Assigner in OOA: to manage competition for instances across a competitive relationship.

DEFINITION (creation state): If there is a state in an object's lifecycle model where

- an instance of the same object is (or can be) created, and
- an event causing the action of the state to be executed contains only supplemental data

we call the state a *creation state*.

DEFINITION (creation event): An event that causes execution of the action of a creation state is called a *creation event.*

AXIOM: When an instance is created in an action of a creation state (and is not subsequently deleted during the same execution of the action) the instance remains in that state upon completion of the action.

DEFINITION (Self- and non-self creation[2]): If an instance of an object is created in the action of a creation state in the lifecycle of the same object, we say that the instance is *self-created*. If an instance of an object is created

- in an action of the lifecycle of a different object, or
- in an action of a different instance of the same object's lifecycle,

we say that the instance is *non-self-created*.

AXIOM: If a non-self-created instance is an instance of an active object, the analyst must specify the state of the newly created instance.

8.3 How Instances Are Created: Questions and Answers

1. If an instance is non-self-created, is the action—the one associated with the state in which the instance is left—executed?

No. If the analyst wants such an action executed, he or she should either generate a standard creation event (causing self-creation) or incorporate the desired processing in the action where the non-self-creation occurs.

[2] In earlier papers on OOA, self-created instances were referred to as "asynchronously created" instances, and non-self created instances were termed "synchronously created." This terminology seemed counter-intuitive to a number of analysts; for this reason it has been retired.

2. Does the action of a creation state have to create an instance of itself (the object whose lifecycle contains the creation state)?

There must be a create accessor in the action of a creation state, by definition. The processing can be such that this accessor is not invoked, or such that this accessor fails to create an instance[3].

3. Can the action of a creation state delete instances of itself (the object whose lifecycle contains the creation state)?

Yes, if the analyst so desires.

4. Can the action of a creation state create or delete instances of other objects?

Yes.

5. Can a state model show a transition from another state into a creation state?

No. By the definition of a creation state, there must be at least one event that causes execution of the action of that state. Such an event must carry only supplemental data. However, if there is an event that causes a transition from another state into the same creation state, that event must carry an identifier of the instance that is to make the transition. Such a construction is forbidden by the Same Data rule, as stated in Chapter 5.

Now let us consider the state transition table from Chapter 6, re-drawn below. Suppose that E_1 and E_2 are creation events, and that $E_3, \ldots, E_n$ are not. Suppose further that E_1 and E_2 cause an instance to be created in states S_1 and S_2 respectively. Then:

- All entries in the “none” row (other than those for E_1 and E_2) must read “cannot happen.” This is a consequence of the fact that $E_3, \ldots, E_n$ are not creation events—that is, it is a consequence of the formalism and not the domain being modeled.
- All entries in the E_1 and E_2 columns (other than those in the “none” row) must be “cannot happen”, since a creation event cannot cause a transition from a state in which the instance already exists (as discussed in question 5, above).
- All entries in the remainder of the table must prescribe transitions to the non-creation states $S_3, \ldots, S_m$.

[3] A create accessor can fail only when it is supplied an identifier for the instance to be created and another instance carrying the same identifier already exists. This is the only “analysis reason” for failure of a create accessor. There may be, of course, other “design” reasons for creation failure: for example, there may be insufficient memory available to store the instance. Such a failure must be dealt with in the software architecture domain, and nowhere else.

	E_1	E_2	E3	. . .	E_k	. . .	E_n
(none)	S_1	S_2	cannot happen	. . .	. . .	. . .	cannot happen
S_1	cannot happen	cannot happen	T_{13}	. . .	T_{1k}	. . .	T_{1n}
S_2	”	”					
	”	”					
S_i	”	”			T_{ik}		T_{in}
. . .	”	”					
S_m	cannot happen	cannot happen	T_{m3}	. . .	T_{mk}		T_{mn}

6. Can a creation state create multiple instances of itself?

Yes. Note that all such instances would be self-created.

7. Can states other than creation states create instances of the “same” object (where “same” indicates the object whose lifecycle contains the creation state)?

Yes. If an instance is created in the action of a state other than a creation state, the instance is non-self-created.

8. In the case of non-self-creation of an active object, how does one specify the state in which the newly-created instance is to be left?

See Chapter 9.

9. Is there a concept of a “created state”? That is, what can one say about a state into which an active object is non-self-created?

Any state in an object's lifecycle can act as a “created state”. But remember, non-self-creation does not cause execution of the action associated with the state in which the newly created instance is left.

8.4 How Instances Are Deleted: Axioms and Definitions

The axioms and definitions regarding instance deletion are as follows:

AXIOM: Any instance is deleted by invoking a delete accessor. This is the only way an instance can be deleted.

AXIOM (Ceasing to exist): For an instance that is deleted during the time scope of the analysis:

- The instance exists prior to the invocation of the delete accessor.
- The instance does not exist after the delete accessor completes.

DEFINITION (self- and non-self deletion): If, in the lifecycle of some object, an instance of the same object is deleted, we say that the deleted instance was *self-deleted*. If an instance of an object is deleted

- in an action of the lifecycle of a different object, or
- in an action of a different instance of the same object's lifecycle,

we say that the instance is *non-self-deleted*.

8.5 How Instances Are Deleted: Questions and Answers

1. Assume that we are using the simultaneous interpretation of time, so that two or more actions may be executing simultaneously. Then, if an instance in the midst of executing an action is non-self deleted, is the action completed before the instance is deleted?

Yes. The action will continue to execute to completion. However, by the axiom on ceasing to exist, the instance ceases to exist upon completion of the delete accessor.

2. Does the action of a final state have to delete an instance of itself?

No. A final state is any state for which there are no transitions out of that state. The instance may persist indefinitely in a final state.

3. Can the action of a final state delete instances of other objects?

Yes.

4. Can a final state delete multiple instances of the same object?

Yes. However, recognize that the deletion of any instance other than the one associated with the executing state model is non-self-deletion. Incorporating multiple instance deletion is probably poor modeling.

5. Can the action of a state other than a final state delete an instance of itself?

Yes. Suppose you have a state in which a delete accessor is *conditionally* invoked. Such a state can have transitions defined that move a surviving instance onwards in its lifecycle, so the state is not a final state.

However, if an action specifies *unconditional* self-deletion, the instance ceases to exist after the deletion accessor completes and therefore this state cannot accept any events. Such a state by definition must be a final state.

9

Process Models in OOA96

Sally Shlaer
Neil Lang

9.1 Small Changes and Clarifications

Transient data. In OOA91, data items that were produced by one process and immediately consumed by another were treated as a special case: they did not have to be attributed to any object on the Information Model. This provided a loophole for the analysis in that both the meaning and the set of legal values for each such data item were unspecified. This irregularity in the formalism is removed in OOA96:

RULE (data items are attributes or current time): All items of data appearing with an event and all items appearing on data flows must either represent current time or appear as attributes on the Object Information Model.

Transient (non-persistent) data is still permitted on ADFDs, but is not to be labeled as such: the fact that such data need not be stored is shown in the connectivity of the ADFD itself.

This rule underscores a view of the IM as *not* being a statement of stored data requirements. However, stored data requirements can be inferred from the ADFDs: If a data item is never retrieved from a data store, it need not be stored[1].

Actual parameters. The data flows appearing on an ADFD are actual (not formal) parameters. This was implied but not made explicit in OOA91.

ADFDs are directed acyclic graphs. An ADFD forms one or more directed acyclic graphs; loops on the ADFD are not permitted. This was implied but not made explicit in OOA91. We do so now because this rule was sometimes overlooked by new users of the method.

No current state attribute. In order to delineate the responsibilities of the various domains more clearly OOA96 now limits access to the current state attribute to the architectural domain alone. As a result, accessor processes may no longer read or write the current state of an instance[2], and the attribute no longer appears on the Information Model. The architecture will maintain the correct value of the current state attribute.

This does not prevent an analyst from defining an analogous status attribute in the Information Model should he or she so desire. This is generally not recommended (except for assignment

1. This comment applies only to architectures that translate each action as a unit. Transient data items may still need to be stored in architectures that distribute the processes of an action to different calling hierarchies.

2. With the exception of certain create accessors, as described in Section 9.3.

status attributes for objects that participate in competitive relationships), but there is nothing in the formalism that would prevent it.

Literals. Where appropriate, literal values for attributes may be shown on an ADFD. The attribute name and value must both appear, as depicted in Figure 9.1.

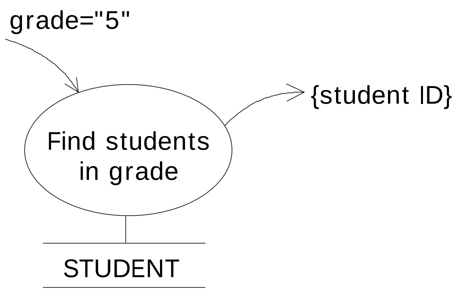


Figure 9.1: ADFD illustrating syntax for a literal value.

9.2 Multiple Data Items

The following notation is used for representing multiple data items on the ADFDs:

$\{ a \}$	means a set of a's (set size unspecified but ≥ 1)
$\{ a \}_N$	means a set of a's. There are $N \geq 1$ elements in the set.
$< c >$	means an ordered set of c's (set size unspecified, but ≥ 1)
$< c >_N$	means an ordered set of c's. There are $N \geq 1$ elements in the set.

Base Processes. The bubbles that appear on an ADFD represent invocations of processes and not the processes themselves. Because one process can be invoked on many ADFDs, the process is defined only once—in its process description.

Now consider the two invocations shown in Figure 9.2. Are the processes being invoked here the same or different processes? OOA96 takes the perspective that the invocations are of the same process and that, therefore, only one process description is required. By convention, the process description defines the "single invocation" form of the process, using input and output datasets of the smallest cardinality that makes sense[3]. We call this a *base process* because it captures the semantics of the process in the simplest form.

RULE: A process is to be defined in its base, or single invocation, form.

The cardinality of all inputs and outputs of the base process must be defined. Once such a base process has been defined, the process may be "reused" with inputs and outputs of higher cardinality, as illustrated in Figure 9.2

[3]. We use the standard definition of cardinality of a set: the number of members of the set.

.

DEFINITION (derived process): A process is said to be *derived* from a base process if (1) it has the same name, inputs, and outputs and (2) the cardinalities of the input and output data sets bear the same relationship one to another as do the cardinalities of the corresponding datasets of the base process.

A process derived from a base process is considered to be the same process as the base process.

Finally, OOA defines the concept of cardinality of invocation. The cardinality of an invocation is the number of times the base process must be invoked to produce an equivalent result.

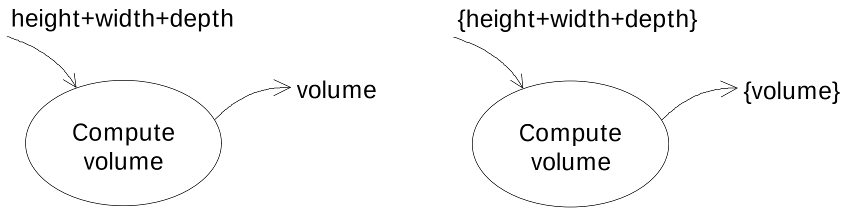


Figure 9.2: The process on the right is derived from the base process on the left.

Parameterized Base Processes. Note that a process appearing with multiple inputs on an ADFD is not necessarily a derived process. Consider the process shown in Figure 9.3. This process cannot be derived from another with fewer inputs, since it produces a single output regardless of the cardinality of the input dataset. Such a process is considered to be a base process that has been parameterized to accept an input dataset of any size. When such a process is shown on an ADFD, it is assumed that the process has access to the size of the input dataset; this information is not shown as a separate input to the process.

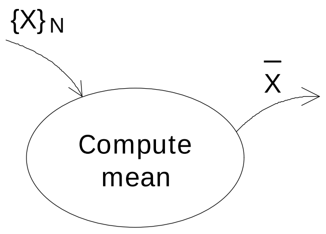


Figure 9.3: A parameterized base process.

Ordered datasets. When a set of data items are input to a process, it may be necessary to keep these items ordered in some way so we can make correspondences between them and other data items used in subsequent processes, as in Figure 9.4.

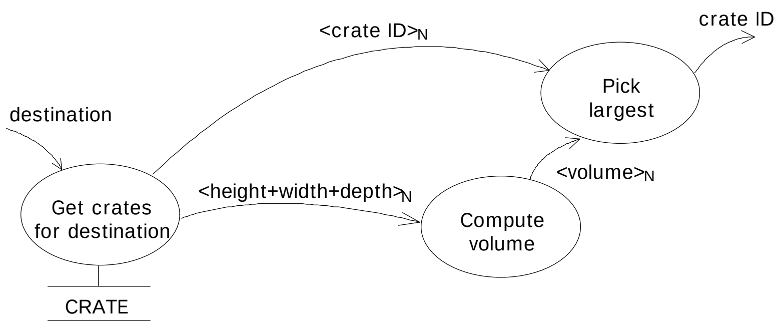


Figure 9.4: Example of ordered datasets.

In this example, we do not supply {Crate ID} to the Compute Volume process. Aside from the unaesthetic properties of such a solution, this strategy would mislead during translation and/or impede identification of Compute Volume as a reusable process. Hence:

NOTATION (ordered datasets): Should a dataset need to be ordered for later correspondence with other datasets, the dataset appears on the ADFD as <data item>. To specify the cardinality of an ordered dataset, write <data item>$_N$.

RULE (order of input datasets): If a derived process receives as input an ordered dataset, all other input datasets of the same cardinality must be ordered in the same order.

RULE (order of output datasets): If a derived process produces as output an ordered dataset, this dataset must be ordered in the same order as any input datasets of the same cardinality.

Iteration and derived processes. If multiple instances of the same data item appear as input to a derived process, nothing is stated about where any implied iteration takes place. The placement of iteration is established when mapping the ADFDs to the architecture. For example, using the ADFD fragment shown on the right in Figure 9.2, the translation may require iteration within the process. In such a case, the process will be translated so that it can accept a set of inputs and provide a set of outputs.

```
state 3::
    . . .
    volume ( N, h, w, d, v )
    . . .
end state 3
function volume ( ct, ht, wt, dp, vol)
    do k = 1 to ct
    vol (k) := ht(k)*wt(k)*dp(k)
    end do
end
```

Alternatively, the translation may require that the iteration be done—perhaps across several processes—in the “state action” module for the entire action:

```
state 3::
    . . .
    do k=1 to N
    v(k) = volume ( h(k), w(k), d(k) )
    end do
    . . .
end state 3
```

Finally, on an ADFD exhibiting both multiple instances and conditional output, the analyst must annotate the ADFD to indicate the required scope of iteration. Such an example is shown in Figure 9.5. When the analyst specifies a scope of iteration, the entire group of processes within the scope will be treated as one for purposes of iteration. As a result, datasets appearing on dataflows internal to the scope of iteration are of size one.

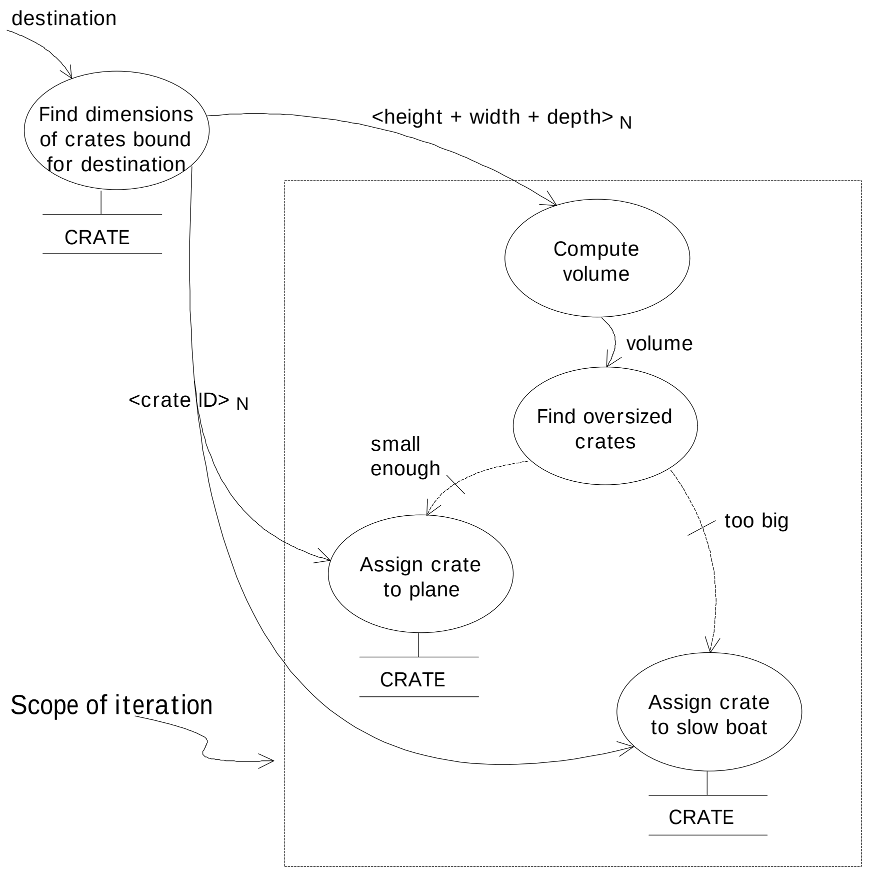


Figure 9.5: An ADFD annotated to indicate the required scope of iteration.

Arrival of output. If multiple instances of the same data item appear as output from a base process, it is assumed that they arrive at any downstream process all at the same time. However, if multiple instances of the same data item appear as output from a derived process, nothing is stated at analysis time with respect to whether the data items appear as a set (all becoming available to the downstream process at the same time) or whether they appear one by one. This will be established when the scope and placement of the iteration is stated: during the mapping of the ADFDs to the architecture.

9.3 Process Types

OOA96 allows for exactly four types of processes on an ADFD: accessors, event generators, transformations, and tests.

9.3.1 Accessors

An accessor is now the only process type that can access an object data store. The required forms of accessors in OOA96 are shown in Table 9.1. Note that this is the minimum set of accessor forms that must be supported by any architectural domain. Should a project wish to provide additional forms (say, an existence test, or an accessor that can do a compound query), the minimal responsibilities of the architectural domain will have to be expanded.

Type and form name	**Suggested name**	**Purpose of process**	**Input data flow**	**Output data flow**	**To/from data store (net flow of data)**	**Output conditional control flow**
Read R1	read	Retrieve attribute(s) of specified instance	identifier	attr val + . . . + attr val	attr val + . . . + attr val	
Read R2	read where	Retrieve attributes of all instances that meet stated criteria	attr val + . . . + attr val (criteria)	{attr val + . . . + attr val}$_N$ (result)	{attr val + . . . + attr val}$_N$ (result) (conditional)	no such instances
Read R3	find where	Retrieve identifiers of all instances that meet stated criteria	attr val+attr val+ . . . +attr val (criteria)	{identifier}$_N$	{identifier}$_N$ (conditional)	no such instances
Write W1	write	Write attribute(s) of specified instance	identifier + attr val + . . . + attr val		attr val + . . . + attr val	
Write W2	write where	Write attributes of all instances that meet stated criteria	attr val + . . . + attr val (criteria) + attr val + . . . + attr val (result)		{attr val + . . . + attr val}$_N$ (result) (conditional)	no such instances
Create C1	create	Create instance given identifier and, optionally, attribute values	identifier [+ attr val + . . . + attr val]		identifier [+ attr val + . . . + attr val]	
Create C2	create unique	Create instance given only attribute value(s)	attr val + . . . + attr val	identifier	identifier + attr val + . . . + attr val	
Create C3	create in	Create instance given identifier, state and, optionally, attribute values	identifier [+ attr val + . . . + attr val]		identifier [+ attr val + . . . + attr val]	
Create C4	create unique in	Create instance given state and attribute value(s)	attr val + . . . + attr val	identifier	identifier + attr val + . . . + attr val	
Delete D1	delete	Delete instance	identifier			
Delete D2	delete where	Delete instances meeting stated criteria	attr val + . . . + attr val			instances deleted | no such instances

Table 9.1: Required Forms for Accessors in OOA96

By examination of Table 9.1, we see that the net flow of data to or from the object data store is entirely determined by the input and the form of the process. Hence, we have an additional rule:

NOTATION: The net flow of data between an accessor and its data store need not be shown on the ADFD. Alternatively, should a project elect to establish the convention that this data flow be labeled, it will be necessary to verify consistency between the data flow to/from the data store and the inputs and form of the accessor.

In order to support self- and non-self-creation, four forms of create accessors have been specified. 'Create' and 'create unique' are to be used for self-creation and creation of passive objects, while 'create in' and 'create unique in' are to be used for non-self creation of active objects. When using either of these two latter forms, the name of the state into which the instance is to be created is included in the process name, as “create account in 'account established' state”.

9.3.2 Event Generators

An event generator may only generate one type of event and may not access an object data store. An event generator may appear on an ADFD as either a base or derived process, as shown in Figure 9.6.

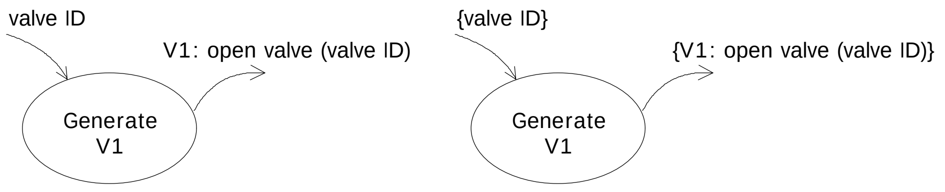


Figure 9.6: An event generator in base and derived forms.

9.3.3 Tests and Transformations

In OOA96, a test or transformation may no longer access an object data store. In addition:

- A transformation is allowed only to transform data*sets*. This includes the traditional computational idea behind transformations; it also allows for picking a data value out of a set (pick the largest volume given a set of volumes, for example).
- A test is allowed only to test relationships between its inputs.
- The output of a derived test process is conceptually a set of conditions. The condition set is of the same relative cardinality as the condition set of the base process.
- The complete output condition set from a derived test process is not shown on the ADFD explicitly. See Figure 9.7 for the proper representation of a derived test.

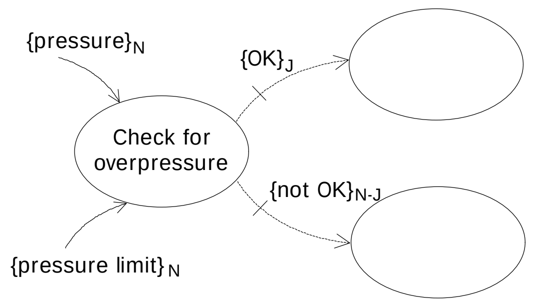


Figure 9.7: A derived test shows the output condition set as two (or more) subsets.

9.4 Delayed Events and Timers

Timers, as prescribed in OOA91, required the analyst to combine information from the domain under consideration with the domain of the formalism itself. This situation has been remedied in OOA96, wherein the functionality previously ascribed to a timer is now associated with a new concept: a delayed event. Three processes have been defined to provide the required functionality. These processes, which are shown in Figure 9.8, may be invoked on any ADFD of any domain.

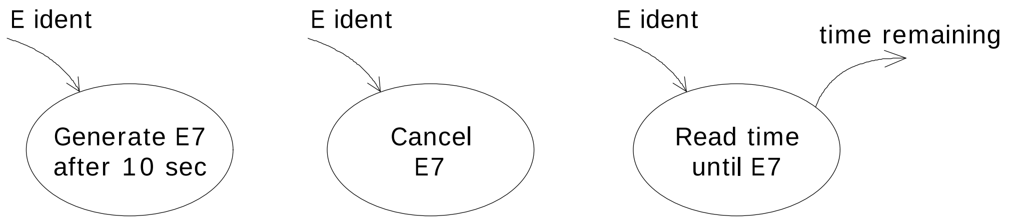


Figure 9.8: Timer processes in OOA96.

Canceling a delayed event causes one instance of the delayed event to be canceled. If there are multiple instances of the specified delayed event outstanding, the event which will be generated soonest will be canceled. If there are no delayed events of the specified type outstanding, nothing happens. Similarly, reading the time until a specified delayed event is to be generated returns the time remaining until the next instance of the specified event is to fire. If there are no such events waiting, a time of zero is returned.

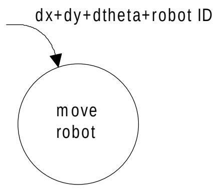
9.5 Connecting to Other Domains

9.5.1 The Problem

Although not defined in OOA91, two types of constructs have come into use to connect one domain to another:

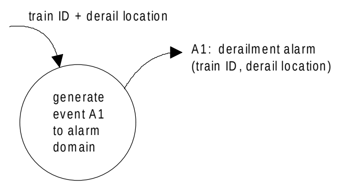
- bridging process: a process implemented in one domain and invoked on an ADFD associated with another domain.
- domain-crossing event: an event that is generated in one domain and received by an object in another domain.

Both of these schemes, as currently used, have deficiencies. In particular, consider the Move Robot bridging process (from some manufacturing application ADFD) shown to the right. This application uses the services of a Process InputOutput (PIO) domain for hardware control.



- Move Robot is not a process in the same sense as, for example, a test or transformation: Analysts working in the application domain cannot provide an implementable description for this process, since they have no knowledge of the inner workings of the PIO domain.
- While the intent of the process has been captured in the process name, the requirements on the process may not been stated completely. In many cases, the process would more properly be named “move robot and return event 'R2: Robot move complete (robot ID)' when complete.”
- The nature of the contract between the application and PIO domains may not have been examined. The extent of the robot move appears to have been given by the application domain as displacements in x, y, and θ. However, it could equally well have been specified as a new absolute position, and this matter should be carefully considered by the analysts working on both domains.

Now let us consider a domain-crossing event as shown in the figure to the right. This event is generated by the application domain and intended to be received in the alarm domain. This “event”, like the bridging “process”, is not what it seems:



- The destination object is not known to the sender. That is, the key letter here does not have the same meaning as does the key letter of events internal to a domain.
- The intent of the communication is captured only partially in the event name. If a return communication is intended, that fact is not recorded on the model.

9.5.2 Wormholes

In OOA96, we use the wormhole symbol—a double-walled bubble—to indicate a transfer of control between two domains. The appearance of a wormhole implies specific detailed requirements on the bridge connecting the two domains. These requirements are made explicit in the process description of the “wormhole process” which must include statements of:

- What the calling domain (server or client) expects the other domain to do (stated in the semantic world of the caller).
- Any return communication required by the caller.

In the general case, the analyst cannot determine whether the wormhole represents an accessor, event generator, test, or transformation—or, in fact, a connected set of such processes. This will be determined during design when the wormholes are finally resolved.

Finally, note that the appearance of a wormhole on an ADFD does not prescribe whether the communication between the domains is implemented via a synchronous or an asynchronous mechanism. This matter will also be determined when the wormholes are resolved and the bridge connecting the two domains is developed—generally shortly prior to translation.

9.6 Particular Constructs

Common processing after conditional flows. Occasionally, after a test or other process that makes conditional output, one wishes to indicate common processing on an ADFD. This can be done by merging the data (or control) flows as shown schematically in Figure 9.9.

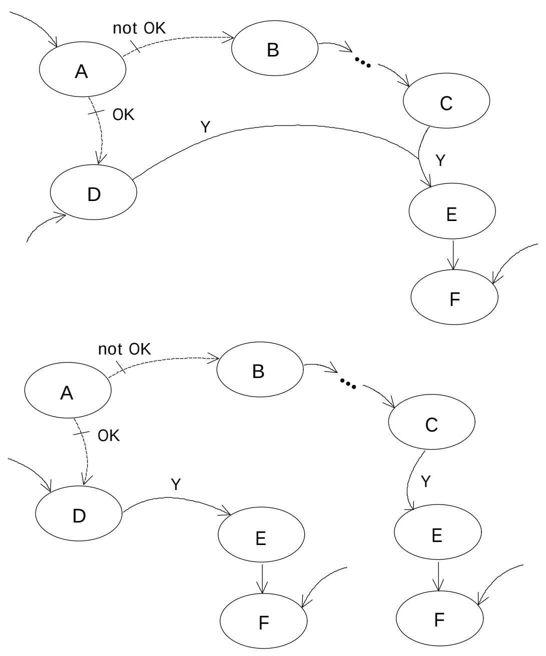


Figure 9.9: An ADFD with a merge and the corresponding defining ADFD.

A merge is considered to be only a representational shorthand: its meaning is defined by an ADFD that shows the common processing replicated wherever it is to occur. Such a "defining" ADFD cannot show any merges.

For an ADFD with a merge, it is the responsibility of the analyst to verify that only one of the processes that produces the merged output can execute by nature of the topology of the entire ADFD.