OPEN Relationships — Compositions and Containments

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RELATIONSHIPS

Relationships are critical to object modelling. It is generally agreed that associations (of several flavours), generalizations and aggregations are useful, although the exact semantics differ between authors. It is important that we, the object-oriented community, gain a common understanding and, in that context, recent formalisms have helped to clarify the situation: the OMG-inspired work of various groups — in particular the metamodels of UML (refs. 1,2) and OML (ref. 3). A second approach, based on mathematical logic as embodied in Object-Z, is presented by Kilov and Ross (ref. 4). In this column and the next, we evaluate the various definitions of object modelling relationships and make recommendations for their use in OPEN (ref. 5) and in other methodologies. This month we look at composition (aggregation) and containment.

AGGREGATION

Aggregation is also often known as composition (refs. 4,6). It is also sometimes called containment (e.g. ref. 7) but this is misleading as we shall show below. It is important to note that, for the aggregation relationship to be valid, an aggregate (a.k.a. composite) must have at least one emergent property (a property of the aggregate that cannot be deduced from the evaluation of the properties of the individual components) (ref. 4). In addition, at least one property of the composite/aggregate should be dependent upon the value of one or more properties of one or more of its components/parts. Furthermore,
aggregations are generally considered to be antisymmetric and transitive (e.g. ref. 8). Also some operations to the aggregate are propagated to the parts (e.g. ref. 4). An important use of aggregation is in support of abstraction leading to layered diagrams at different granularities (ref. 9). Kilov and Ross (ref. 4) regard the need for aggregation (in contrast to the arguments in the UML documentation) as resulting, in effect, from the industry’s identification of the aggregate–part “pattern” as being ubiquitous and useful.

Subtypes of aggregation

In the work of Winston et al. (ref. 10), summarized and modified later by Odell (ref. 6), three classification criteria are used to identify six subtypes of meronymic (or whole–part) relationship which Odell equates with the word composition. The relationships are defined by application of three different dimensions: functional, homeomerous and separable. These six types of aggregation are shown in Figure 1. Three of the categories are worthy of further analysis here:

a) Stuff–object, with examples such as “a bicycle is partly steel”, “water is partly hydrogen”, does not seem to be unequivocally non-functional (see also discussion below with regard to the modifications made in ref. 6). If this category of Stuff–object were changed to functional/homeomerous/invariant it would be indistinguishable from Feature–activity — yet clearly there is a large “semantic distance” (ref. 11) between the two. Similarly, if Stuff–object happened to be homeomeric, it would be the same as Place–area and the same argument (of semantic distance) would apply.

b) Portion-mass, with examples such as “this slice is part of the pie”, is not obviously separable (non-invariant) in the sense that whilst it is clearly possible to remove a slice from a pie, it is also clear that what is left is no longer the original (fully functional)
pie. In other words, removal of any single component would appear to destroy the whole — and hence the existence of the relationship.

c) Place-area, with examples in ref. 10 such as Everglades/Florida and oasis/desert. The non-functionality of this relationship is unclear (clarified in ref. 6) and, more importantly, it is obvious that an oasis and a desert (to continue the example) are not made of the same stuff (one is water and palm trees, the other is sand). In other words, Place-area cannot be homeomorphic.

This paper of Winston et al. (ref. 10) has been used in the object community in at least two further studies (refs. 6 and 12). Odell (ref. 6) modified the structure of Figure 1 by changing the criterion of “functional” to “configurational”, thus extending the definition of this first criterion by permitting structural relationships as well as functional ones. Configurational applies to a functional or a structural relationship in which the component parts of the relationship are expressible as a directed graph (ref. 11). Indeed, it is generally considered that aggregation is most useful for structural relationships i.e. when the whole is (more than the) sum of the parts. This is supported by Kilov and Ross (ref. 4) who insist that an aggregate must have at least one emergent property (as noted earlier).

Odell’s six types of aggregation, as shown in Figure 2, are:

1. Component–integral object composition. This is a functional/structural relationship such that the component objects bear a particular relationship to each other and to the whole they constitute. Example: bristles are a part of a toothbrush; scenes are a part of a film. Note that if the parts are forcibly removed (i.e. the aggregate is damaged or destroyed), it ceases to be a component part of the whole.
2. Material–object composition. This is invariant and usually represents the notion of “partly made from”. Example here is capuccino which is partly milk.

3. Portion–object composition. The part is the same kind as that of the whole. Example: a slice of bread is the same substance as the loaf of which it is part. [This is of course the same as category 1 but with the whole and part being of the same substance.]

4. Place–area composition where the pieces cannot be removed. Example: Austin is part of Texas.

5. Member–bunch composition which is used for collections. Example: a tree is part of a forest.

6. Member–partnership is an invariant form of membership (class 5 above). This category is not found in ref. 10. Example: Ginger and Fred are a dance couple.

[Feature–activity is omitted in ref. 6 since it was considered to be process-oriented and inadequately defined in ref. 10.] In Figure 2, Stuff–object (renamed Material–object) is clearly configurational — when a bike is made of steel it is clearly important where the steel resides (in this case equally distributed through the frame at least). Similarly, Places and Areas are clearly structurally related. In the relationship expressed as “a peak is part of a mountain”, the peak must be a specific (structurally related) part of the mountain, namely the top.

All of these categories (in both Figures 1 and 2) can readily be seen to possess emergent properties. In addition, they support propagation of semantics.

**Figure 3** attempts to rationalize the proposals in refs. 6 and 10. It follows Odell with respect to Material–object, Member–bunch and Member–partnership; and includes
Winston et al.’s Feature–activity. It changes Place–area to be configurational/non-homeomeric/invariant and Portion–object to be non-configurational and homeomeric. We feel that the invariant character of this particular relationship is still arguable and undecided. In addition, there are some viewpoints in which it is possible to consider Place–area as homeomeric e.g. San Francisco as a homeomeric part of California from a realtor’s viewpoint (ref. 11).

It is also worth noting that whilst the Membership relations remain non-configurational (called non-functional in ref. 10), it could be argued that some of the examples used in the various papers are of dubious validity. As a single example, whilst a ship is a member of a fleet, when sailing the seas, there is a strong configurational relationship between the various ships, the flagship and the overall spatial pattern (and its spatial limits) of the fleet. Nevertheless, the fleet clearly has emergent properties, is asymmetric and has propagation of some operations thus readily identifying it as a meronymic relationship.

The most interesting aspect of the newly derived Figure 3 is that three of the entries are now identical with respect to the chosen classification criteria. Either they are indeed equivalent, such that the invariants of the three relationships are the same whilst the context remains different (stuff, geographical location, process), or else further discrimination can only be done on some fourth, as yet unidentified, criterion (see also discussion below on appropriate notations).

Transitivity

Aggregations are also transitive, but only if the same subtype of aggregation holds. Thus, if an engine is part of a car and pistons are part of an engine, then pistons are part of a car since both aggregation relationships are component–integral object. On the
other hand, if Bob’s arm is part of Bob (component–integral object) and Bob is part of the Computer Science Department (member–bunch), it is incorrect to say that Bob’s arm is part of the CS Department since the two aggregation relationships are dissimilar. Conversely, it is not true to say that all “mixtures” of relationships lead to non-transitivity — for example, “a loaf is partly flour” can be deduced in a transitive manner from the two statements (correcting the error in the original) that

- a slice of bread is partly flour (material–object)
- a slice of bread is part of a loaf (portion–object)

(ref. 6).

Quoting the same source (ref. 10), Kolp and Pirotte (ref. 12) replace Feature–Activity by two relationships: Feature–Event and Phase–Activity. They then go on to evaluate Component–integral object as the main example of the “parts” relationship. As a subtype to the “Parts relationship”, they define “Part association” in which all component instances belong to the same class (e.g. a Compilation consists of Articles). As a subtype to this, they introduce a “Part recursion” relationship in which only a single type is permitted. They then go on to demonstrate “upwards” transitivity whereby transitivity holds not only for the same subtype (e.g. if A is part of B and B is part of C, then A is part of C only if the two “is part of” relationships are the same i.e. either part relationship, part association or part recursion) but also when the first “part-of” is a subtype of the second. Thus we could have A is part of B (part recursion) and B is part of C (part association) \( \Rightarrow \) A is part of C (part association); but A is part of B (part association) and B is part of C (part recursion) does not give A is part of C.

*Choices made in the literature*
There are other, varied choices made in the literature to define the term “aggregation”. SOMA (ref. 13) uses Material–object (configurational/invariant) and Place–area (configurational/homeomeric) only. On the other hand, UML (refs. 1, 14) seems to equate the notion of composition with all Invariant aggregates (Material–object, Place–area and Member–partnership). This definition ignores Component–integral object which Odell (ref. 6) notes to be the most common form of aggregation used in the object modelling literature. Coad and Yourdon (ref. 15) identify three meanings for aggregation: Assembly–Part, Collection–Members, Container–Contents. The last of these is really containment (see below), which is not strictly a subtype of aggregation (ref. 6).

In ref. 4, several contrasting dimensions are used for characterizing aggregations. Their orthogonal dimensions are, in part, different to those of refs. 6 and 10:

Serializable — ordered or non-ordered (non-ordered components is default) — this has no analogue in ref. 6.

Changeability — static or variable (variable is default) — this is the Invariance category of ref. 6.

Hierarchy — network or hierarchy (network is default) — this is equivalent to the notion of shared aggregation in UML but not discussed in ref. 6.

Linkage — ASSEMBLY, SUBORDINATE, PACKAGE, LIST (PACKAGE is default).

Assigning one value from each enumerated list for all four characteristics gives a definition of one of 32 possible types of aggregation. For example, Kilov and Ross (ref. 4) suggest that containment = hierarchical, subordinate, non-ordered, variable (the last two being the default values).
It should also be noted that characteristics of creation, lifetimes and visibility are not discussed in any of these sources and the characteristics of shareability only occasionally. All these topics are worthy of further detailed analysis (see, for example, ref. 12).

**OMT aggregation**

The first observation is that OMT associations are bi-directional. Secondly, OMT aggregation is “just an association with extra connotations” (ref. 8 and supported by ref. 16). The consequence of this is that OMT aggregations are bi-directional. This is problematic since it is clear from the wider literature that bi-directional aggregations are exceptions not the rule.

**Booch aggregation**

It should be noted that Booch’s (ref. 17) two types of aggregation (by-value, by-reference) are really design or implementation constructs. That they are ill-defined is really a consequence of Booch’s wide-ranging, all inclusive form of aggregation (cf. Odell’s six types) — as identified in ref. 18. A tightening up of the semantics of the word aggregation, as discussed in this section, will then lead to better design and coding rules regarding the most effective use of by-value and by-reference styles of “aggregation”.

**UML (Version 1.1) aggregation**

In UML, aggregation again relates to whole-part. A “strong” form of aggregation (called composite aggregation or composition in Version 1.1a R6) is noted as one in which a part can be only part of one composite, but that it is not invariant. This is exactly the Component–Integral object classification of ref. 6. However, on the grounds that no statement is made at all regarding the homeomorphic nature of the aggregation, one could
surmise that a Portion–object relationship might also be within this definition. Propagation semantics are implicit/assumed in V1.0 and explicit in V1.1a R6.

A second type of aggregation is then identified which is labelled as “shared aggregation” (Figure 4) in which a part could belong simultaneously to more than one aggregate. The wall of a room might be an example here which is actually a component part of two rooms simultaneously. Or an article in a journal which also appears as a book chapter i.e. it is part of a journal and part of a book simultaneously. Interestingly, the question of shared aggregation, ignored in ref. 6, is discussed in detail by ref. 12. Their modelling answer is not to create a separate meta(sub)type but to annotate the aggregation relationship with a pair of attributes to indicate exclusiveness/sharing and dependence/independence.

As can be seen from the above discussion, both Composite Aggregation and Shared Aggregation in UML are implicitly configurational. No discussion of Odell’s Member–bunch or Member–partnership is undertaken which we must assume would be modelled in UML with an association.

UML Ver 1.1 goes further to state that this means that there are now three subtypes of Association: (i) Composite aggregation, (ii) Shared aggregation (also called ordinary aggregation on page 17 of ref. 2) and (iii) ordinary (or common) Association.

**CONTAINMENT**

The separate representation of containment outside of the notion of aggregation accords with refs. 6 and 10 in which not only are six types of aggregation identified but so also are many other, different relationships which are often confused with aggregation (also noted earlier in ref. 12). One of these is containment. Odell calls it “topological inclusion”
and is NOT one of the subtypes of aggregation. Odell also notes that this (containment) should not be confused with Place–Area which is identified by Odell as one of the six useful types of aggregation. Further confusion between containment and aggregation can be readily resolved by applying the heuristic on page 71 of ref. 7. The question to be answered is “If I remove the ‘contained’ object, is the behaviour of the ‘containing’ class altered?” If the answer is yes, then the relationship is an aggregation/composition; if no, it is containment/topological inclusion.

**AGGREGATION, MEMBERSHIP AND CONTAINMENT IN OPEN**

The set of four configurational, non-homeomeric aggregation relationships in Figure 3 seem to have a mutual affinity. Certainly the invariant/variable nature of the parts to the component could be construed as merely being an additional characteristic of the relationship and not creating anything unique. Whether the material in the part(s) and the whole is the same or different also seems less than critical. OPEN (ref. 5) thus adopts these four Configurational definitions as providing its basic understanding of aggregation. Shared aggregation can be shown by an annotation (or possibly in the future by labels based on further study of the new Kolp and Pirotte ideas). This type of aggregation is labelled with the circle and plus sign as given in the *OML Reference Manual* (ref. 3).

Secondly, it seems worthwhile that the two Member relationships might be given separate consideration. We thus propose a membership relationship which might either be shown by cardinalities (multiplicities) on a regular mapping (or pair of mappings) or, since this is a pattern likely to recur, encapsulated with a new notation, proposed here: a circle with a set inclusion sign (which looks like a U on its side) (Figure 5). Portion–object is
anomalous and less clearly defined. Since it too is non-configurational, for the interim we propose it too is labelled as membership.

As noted above, topological inclusion or *containment* is not a subtype of aggregation. It is denoted in OML (ref. 19) by an annotation showing a stylized cup (a container) as in Figure 5. Containment is not recognized as a distinct relationship in UML.

In summary, OPEN supports a range of useful relationships, including:

- Aggregation, which is defined as a configurational, non-homeomeric relationship which may or may not be invariant
- Membership, which is non-configurational
- Containment, which is *not* a subtype of aggregation but an independent relationship.

It describes topological inclusion.

(These three are in fact similar to those chosen in ref. 15.)

COMN (the notation preferred by OPEN) uses

- a circle with a plus sign at the source end for aggregation
- a circle with a sideways U at the source end for membership
- a circle with a U at the source end for containment

These conclusions are summarized in Figure 6 together with an indication as to how these conclusions fit in with the evolving UML metamodel. Both fit neatly within the one hierarchy. In both UML and OML, Aggregation (which is similarly, although not obviously exactly, defined) is a special type of “association” (mapping in OML). The only reason why two separate metatypes for aggregation appear is because, in inheriting from “association” in both cases, this makes the UML Aggregation essentially bi-directional and the OML Aggregation uni-directional. There is no reason why the UML Shared
Aggregation should not be made available within OML and, conversely, that the OML Containment and Membership should not be made available within UML. Indeed, since the OMG process is still ongoing it may be that, between the writing of this article and the publication of it, more convergence will already have been achieved. We hope so.

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Figure Legends

Figure 1 Winston et al.’s (ref. 10) six meronymic relationships

Figure 2 Odell’s (ref. 6) six forms of composition or aggregation

Figure 3 Proposed seven subtypes of aggregation

Figure 4 Part hierarchy for Associations and Aggregations in UML

Figure 5 Parts hierarchy and COMN notation for Aggregation, Membership and Containment

Figure 6 Proposed hierarchy for aggregation, containment and membership encompassing those proposed in UML and those in this column for OML.