Identity-Based Change Operations for Composite Objects

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Abstract

Incorporating abstraction methods, such as aggregation and association, into information system design methodologies has improved our ability to model the real world. The semantically-higher level objects that result from these abstractions are referred to as *composite objects.* These objects play an important role in spatio-temporal knowledge representation and query formulation, although little has been done so far on formalizing operations involving these types of objects. In this investigation, the semantics associated with composite objects are explored as is the role of *object identity* for composite objects. Object identity refers to that trait which distinguishes an object from all others. The different semantics associated with creating composite objects and adding parts to composites are discussed and a set of basic identity-based change operations for composites, including separation and elimination operations, are described. Formalizing the operations relating to composite objects aids in improving current spatial data models and leads to advances in spatial-temporal query languages.

Keywords: composite objects, object identity, spatio-temporal knowledge representation

1. Introduction

Geographic information systems (GISs) are used to portray spatio-temporal phenomena found in the real world. This need to model the real world has led to the development of semantic and object-oriented data models that attempt to capture more of the meaning as well as the structure and behavior of data than traditional models (Hull and King 1987; Peckham and Maryanski 1988). In addition, it has led to incorporating appropriate abstraction mechanisms such as aggregation and association into information system design methodologies (Egenhofer and Frank 1992; Motschnig-Pitrik 1992), providing structures with which to describe phenomena and mimicking the way humans themselves utilize abstraction methods to categorize what is being perceived (Tversky and Hemenway 1984; Smith 1990).

In this paper, we examine the multi-part or *composite objects* that are formed as a result of aggregation and association. We formalize different types of operations to create these objects and operations that change them including operations to separate and eliminate composites. Understanding the relation between a composite and its parts is used regularly in human thought and language (Tversky and Hemenway 1984; Winston *et al.* 1987). For instance, knowledge about countries and their parts plays a major role in understanding the effects of war, or the landscape around us is typically described in terms of its parts, such as lawns, gardens, and woods. As such, composites are important for query formulation since without the notion of aggregated objects, significant semantics may be lost. Composite objects can also result in more efficient storage and

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retrieval (Kim *et al.* 1987). While past investigations into composite objects focused on modeling part-whole relations, little attention has been paid to describing the operations that manipulate composite objects. Sequences of composite object operations are of interest to GIS users as they form a basis for spatio-temporal reasoning at a high level of abstraction.

The methods presented in this paper are based upon a classification of alterations to composite objects through tracking changes to *object identity*. Object identity is that trait that distinguishes an object from all others (Khoshafian and Copeland 1986). Identity provides a way to represent the individuality or uniqueness of an object, independent of its attributes and values. The concept of a unique object identity has been recognized as a tool to help track changes to objects (Al-Taha and Barrera 1994; Hornsby and Egenhofer 1997), particularly in proving the existence or non-existence of an object as well as being able to track similarities or differences in objects during scenarios of change (Hornsby and Egenhofer 1997). Here, we use identity as a basis for distinguishing semantics for composite objects from single objects.

Changes to the identity of composites and their parts are described in the form of an iconic visual language, called the *Change Description Language* (Hornsby and Egenhofer 1997). It is based on an iconic representation of some of the fundamental operations on composites and their parts and is used to capture the states of these objects and identities and the transitions between different states.

The remainder of this paper is structured as follows: Section 2 describes the abstraction methods of aggregation and association. Section 3 examines the relations between composite objects and their parts. Section 4 introduces an identity-based Change Description Language. Section 5 applies this iconic language for modeling changes to composites. Section 6 illustrates an application of the Change Description Language to a scenario that involves changes to a composite. Conclusions and future research directions are presented in Section 7.

2. Abstraction Methods: Aggregation and Association

The real world is too detailed for humans to process directly, so to make sense of our world, people structure their thinking through grouping and classification to simplify until only the necessary components remain (Tversky and Hemenway 1984; Smith 1990). For similar reasons, many computing applications require a treatment of objects such that several objects are conceptualized and manipulated as a single logical entity for semantic purposes (Kim *et al.* 1987). This *abstraction* involves the emphasis of details essential to the task at hand and the suppression of all irrelevant details (Brodie 1984). In geographic information systems, abstraction methods are important to ensure the close mapping of the user's concept of object behavior onto the GIS data model (Egenhofer and Frank 1992) creating a system that is easier to use.

Aggregation is a fundamental abstraction method (Smith and Smith 1977; Kim *et al.* 1987; Schiel 1989) as it suppresses details about an object, except for those relevant to the defined task, and as such, allows a relationship between several objects that can be thought of as a higher-level composite (Smith and Smith 1977; Brodie 1984). The relation formed by aggregation is often called the *part-of* relation since aggregated instances are parts of the aggregate.

Association is another abstraction method used in databases in which the relationship between similar objects is considered as a higher level *set object* (Egenhofer and Frank 1992). With this approach, the details of the *members* of the set are suppressed, while properties of the set object are emphasized (Brodie 1984). There is a *member-of* relationship between a member object and a set object, such that the set object "lakes" is defined over the member object "Swan Lake."

In this paper, objects formed through aggregation or association are generally referred to as *composite objects*. Composite objects capture the notion that an object may be composed of other objects called *parts*, representing a hierarchy of objects.

3. Relations between Composites and their Parts

Describing the relationship between composites and their parts is relevant for GIS applications (Clementini *et al.* 1995; Tryfona and Egenhofer 1997), object-oriented databases (Kim *et al.* 1987; Kim *et al.* 1989; Mitschang 1989; Kim 1995), artificial intelligence domains (Brodie 1984), linguistics (Cruse 1979; Winston *et al.* 1987), and cognitive psychology (Tversky and Hemenway 1984). Philosophers have contributed formal theories of parts, wholes, and related concepts (Guarino *et al.* 1996). Classical mereology offers a theory of part-whole relations (Simons 1987; Casati and Varzi 1994), although recent work has suggested that mereology alone is too restrictive for a complete treatment of parts and wholes (Casati and Varzi 1994; Casati and Varzi 1997) and as such is commonly integrated with concepts from topology. Transitivity of part-of relations has also been examined to determine under what conditions does transitivity hold (Cruse 1979; Winston *et al.* 1987).

A study of relations between parts and wholes as used in linguistics resulted in a categorization of part-of or *meronymic* relations (Winston *et al.* 1987). In particular, two of these types of relations capture the semantics of aggregation and association: component-integral relations and member-collection relations. Objects that can have components represent a range of phenomena. They may be physical objects, like a building, or they may be abstract or *fiat*, representing the case when an object is created through human imagination or convention, such as the creation of counties, states, or other administrative units (Smith 1995). Components or *parts* have some structure or pattern that tie them to the wholes that they comprise and so are not haphazardly arranged (Winston *et al.* 1987). Some functional relation exists between the parts and their integral wholes. An example of this type of relation is, “Maine is part of the USA.” In addition to a functional relationship with the whole, parts may be dissimilar to themselves and to their wholes. For example, the State of Maine is different to the District of Columbia and is different from the USA itself.

Winston *et al.* (1987) also distinguish a type of relation where parts are *not* required to perform a particular function or possess a particular structure in relation to themselves or their wholes. These *member-collection* relations such as, “a tree is part of a forest” involve the concept of spatial proximity or social connection. For instance, for a tree to be part of a forest, it must be near to other trees (Markman 1982).

4. Identity-based Change Description Language

Composite objects can be represented using the *Change Description Language* (Hornsby and Egenhofer 1997) that is based upon a classification of alterations to objects through tracking changes to *object identity.* Object identity provides a way to represent the individuality or uniqueness of an object, independent of its attributes and values. In this paper, we will show that identity is very useful in tracking changes to composite objects and their parts.

The Change Description Language (CDL) is based on an iconic representation of different kinds of change and is used to depict a model of change, i.e., the states of objects with their identities and the transitions between objects. The CDL uses basic symbols to represent the primitive elements of the language. These primitive elements are: (1) non-existence and (2) object existence. The first case describes the situation in which no single object with identity is existing (Figure 1a). The second primitive, object existence, describes the case in which an identifiable single object is present (Figure 1b). Objects have been given a label to aid identification of unique identities. These symbols represent states in which single objects reside at different times. The identity concepts of existence and non-existence can be extended to other domains. For instance, in the visual domain, existence can be equated with *visible* and non-existence with *invisible.*

Figure 1: Basic symbols used for: (a) non-existing single object, and (b) existing single object.

Temporal change is represented qualitatively based on the temporal order of events, an approach to temporal reasoning that has been found to be necessary to many of the domains using GIS (Frank 1994). The change from one state of an object to the next is captured through an arrow and is referred to as a *transition* (Figure 2). Scenarios reflecting changes to object identity are developed from the left of the transition arrow to the right, where "left" corresponds to "before" and "right" to "after." Transitions are assumed to be direct, with no intermediate states being portrayed. No quantitative measures are represented with the CDL and no information on the *duration* of the length of time of a transition is assumed.

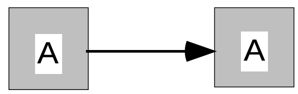


Figure 2: A transition between two states of an existing object.

A set of basic identity-based change operations is derived through systematic combinations of the primitives, capturing the semantics of creation (Figure 3a), continuation (Figure 3b), elimination (Figure 3c), and continued non-existence (Figure 3d).

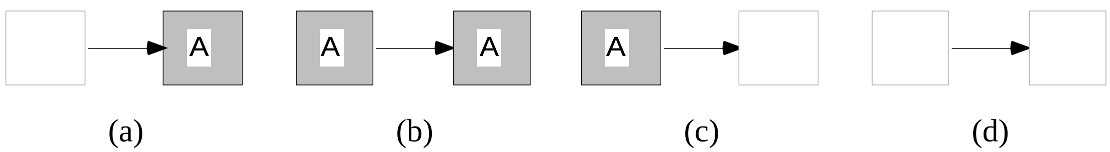


Figure 3: Identity-based change operations: (a) `create`, (b) `continue existence`, (c) `eliminate`, and (d) `continue non-existence`.

5. Representation of Composite Objects Using the Change Description Language

The CDL is extended to capture the semantics of composite objects. Physically, composite objects may be disconnected wholes like the USA or may be spatially connected like a train and its parts. However, in this paper, we do not represent spatial relations between objects and their parts with the CDL, but rather capture the semantics associated with certain basic operations on composite objects. In general, a composite object will be represented as an existing object that contains *1…n* object subparts (Figure 4).

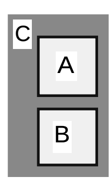


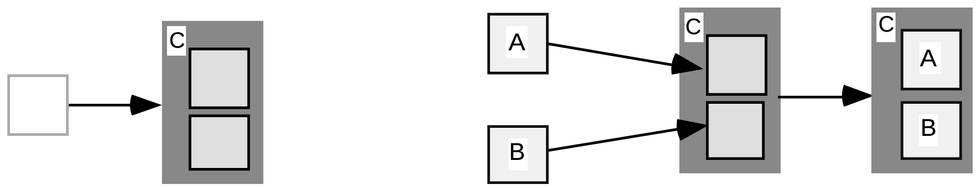
Figure 4: Composite object C with parts A and B.

A set of basic operations on composite objects is described. We show that there are rich semantics associated with operations to create and eliminate composite objects and their subparts.

5.1 Creating Composite Objects

As suggested by the work of Winston *et al.* (1987), composite objects can be grouped into at least two different categories. Consider as a first case that the identity of the composite may be dependent on the existence of the parts combined in some particular way such that the whole is created. For instance all the parts of a car laid out in a row on a garage floor do not give us a "car" as we commonly know it. The parts need to be combined in the particular way we understand for a car and then we can say that the car exists. So, some kind of rule, procedure, charter, or the like is needed in order ensure that the right *kind of* parts are combined according to some method bringing about the creation of the whole or composite object. This captures the notion that the whole is more than the sum of its parts (Casati and Varzi 1997).

The CDL can be applied to represent these semantics. A `create` operation establishes a "framework" that serves as a structure for the whole (Figure 5a). Conceptually, this framework has placeholders or "slots" into which objects can be added (Figure 5b). The number of objects that can be added depends on the pre-defined task of the composite object. These objects or *parts* have a functional or structural relation to the whole. With the addition of parts, the object can be identified as a *composite object*. Each part has a distinct identity as does its composite.



(a) (b)

Figure 5: Creation of a composite object: (a) creation of a framework C with slots and (b) population of the slots in framework C with the objects A and B.

As many composite spatial objects such as nations, states, or counties are conceptual in nature, the framework and "slots" will also be abstract. For instance, a nation may be formed from an act or charter that represents the framework. The Dominion of Canada, for instance, was formed with the British North America Act of 1867 that united the provinces of Quebec, Ontario, New Brunswick, and Nova Scotia. The provinces or parts have unique identities separate from the composite and have a functional role with respect to the whole.

Different semantics are present for the second category of composites, where pre-existing individual objects, representing parts each with their own unique identity, are combined into a semantically higher-level object (Figure 6a). In order to distinguish the composite formed as a result of this type of `create` operation from the case described above, the representation of the composite object is shown using stripes. In this case, there are no slots in a framework, rather the composite object represents a *collection* or set of pre-existing identities. A distinct identity also exists for the composite. A set of land parcels belonging to one owner, for instance, can be viewed in this way. Each land parcel has its own identity as does the whole (e.g., all the land owned by the individual). Under certain circumstances, such a composite may also be created where no object previously existed. For instance, in the visual domain, a composite object may be invisible (non-existing) and then become visible (existing).

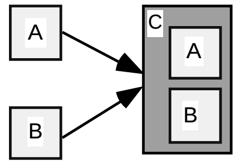


Figure 6: Objects A and B combine to form composite object C.

5.2 Adding Individual Parts to Composite Objects

In order to add new parts to a composite object that has been formed from a framework, it is first necessary to create a new slot(s) in the framework of the composite. Additional objects can then populate these slots (Figure 7). The object joining the composite is an existing object with its own identity. The composite's identity is not changed with the addition of the new part. These semantics for adding new parts can be likened to the additions to an existing plan that are necessary in order to create a new administrative unit in a region or state, or the space that must be cleared in order to add a new wing to a building.

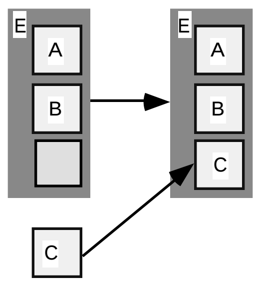


Figure 7: Adding a new part to a composite object formed by a framework. A new slot is added to an existing composite framework and a new part C populates the available slot.

With composite objects that are created as a collection, additional parts may be added to the composite as necessary without first creating a slot (Figure 8). The composite's identity remains unchanged by these additions. For example, the parcels of land belonging to a town's landowner may be referenced individually and hold unique identities, while collectively they are "Mr. Brown's land." As Mr. Brown buys more land, these parcels are added to the composite identity. Within the composite, the individual identities continue to exist.

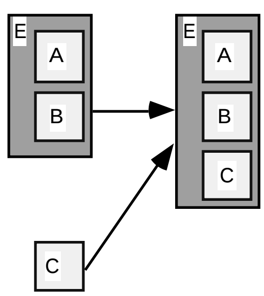


Figure 8: Part C is added to composite E.

5.3 Selecting Composite Objects and Parts

In order to perform an operation that results in a change of either a composite object or one or more subparts, it is necessary to have a `select` operator that allows for choice or selection based on some defined criteria of either the entire object or a portion of the object (Figure 9).

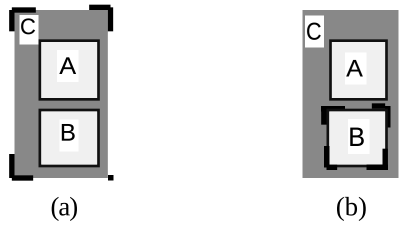


Figure 9: The `select` operator applies a selection to: (a) composite object C and (b) part B of composite C.

5.4. Eliminating Composite Objects or Their Subparts

Eliminating composite objects involves the removal of either the whole and its identity or one or more of the parts. Different semantics apply to those composites created from a framework versus those created as a collection of objects.

5.4.1 Eliminating the Composite Object

The elimination of composite objects created from a framework involves selecting the object and removing the composite with or without its part identities, according to the task. Two different outcomes are possible:

- The composite is *eliminated* and becomes a non-existing object, while the parts continue to exist (Figure 10a). For instance, the Soviet Union ceased to exist in December 1991, but its component regions, such as Russia, Georgia, and Lithuania, continue to exist as independent states.
- Both the composite object and the parts are eliminated. No existing identities remain (Figure 10b).

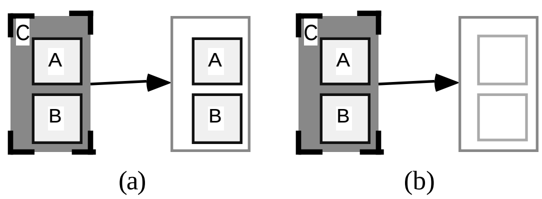


Figure 10: Elimination of a composite object created from framework: (a) composite object C is eliminated while parts continue to exist and (b) composite C and parts A and B are eliminated.

Different semantics apply to the case of a composite created as a collection of objects and are reflected in the representation with the CDL. For these situations, when a collection is eliminated, no *parts* continue to exist. Former parts become *objects* outside the composite (Figure 11a). Alternatively, the entire composite and its parts may be eliminated (Figure 11b).

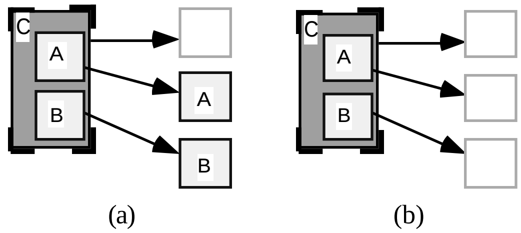


Figure 11: Elimination of a composite object created as a collection: (a) composite object C is eliminated while parts continue to exist as objects and (b) composite object C and parts A and B are eliminated.

5.4.2 Separating and Eliminating Parts of a Composite

When removing the parts of a composite object, two different semantics are involved: (1) the part is *separated* from the composite while continuing to exist, or (2) it is *eliminated*. In addition, different semantics may be associated with the composites that are formed from a framework versus those that reflect a collection of objects.

In the first case, for a composite created from a framework, the part is removed and continues to exist, capturing the semantics of a *separation* (Figure 12a). After this transition, the composite object continues to exist, but now a non-existing object appears in the "slot" for that part. For instance, when the engine is removed from a car, the place for the engine continues to exist but is empty. The second case involves a part that is eliminated from the composite and ceases to exist (Figure 12b).

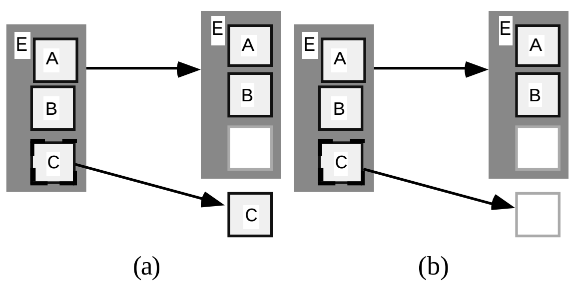
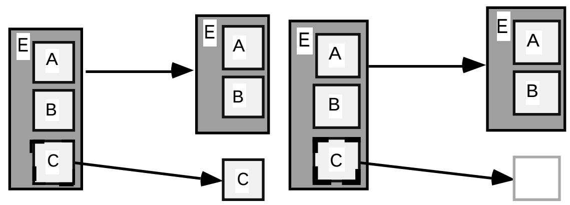


Figure 12: Removing a part from a composite: (a) removal of part C from composite object E. Both composite and separated part identity continue to exist, (b) part C is eliminated and becomes a non-existing object.

Different semantics apply to the case where identities collectively form a composite. In this case, when a part is separated from the composite, no non-existing parts appear in the composite after the transition (Figure 13a). Instead, the composite is depicted as now being composed of only the remaining existing parts. So, if Mr. Brown sells a land parcel, the composite object representing Mr. Brown's land no longer contains that parcel. Alternatively, a part can be *eliminated* upon removal from the composite (Figure 13b). In this case, the identity of the eliminated part is non-existing.



(a) (b)

Figure 13: Removal of a part from a composite formed as a collection: (a) part C continues to exist after a separation, (b) part C is eliminated from the composite E.

Additional semantics may be involved in certain cases where dependencies exist such that if all the parts of a composite are eliminated, the composite identity is also eliminated. So, for example, when all the trees in a forest are successively cut down, this destroys the forest. The forest cannot exist without the trees. In other cases, however, it may be possible for the composite identity to continue to exist after separation or elimination of the parts.

6. Example of Change Involving Composites: Tracking a Convoy of Vehicles

Suppose we have a birds-eye view of four vehicles (Figure 14a) that form a convoy (Figure 14b). Another vehicle joins the convoy (Figure 14c), and then a vehicle leaves the convoy (Figure 14d). Now consider another change in events, as the convoy disappears from view when the road winds through a forest (Figure 14e) and then partially emerges from the forest (Figure 14f).

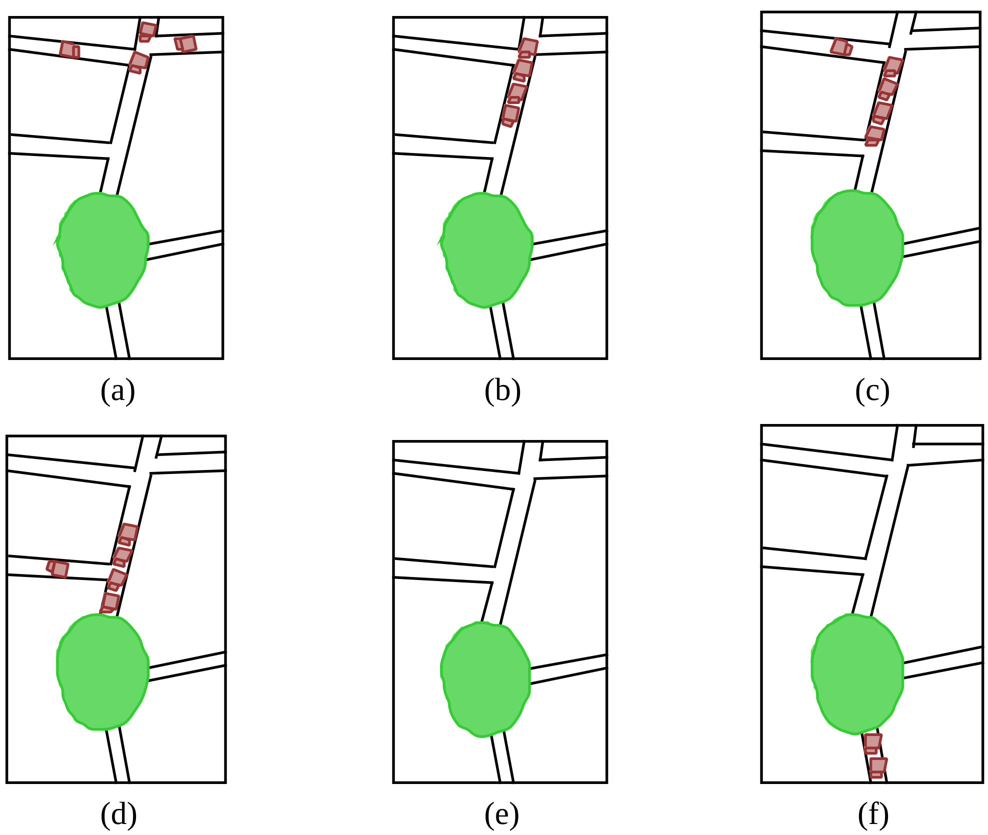


Figure 14: Tracking a convoy: (a) vehicles are visible on the roads, (b) vehicles form a convoy, (c) another vehicle joins the convoy, (d) a vehicle leaves the convoy, (e) the convoy has entered the forest and no vehicles are visible, and (f) two vehicles are visible.

In this example, the visibility of the vehicles and convoy can be likened to the identity concepts of existing and non-existing in the visual domain (Equation 1a and 1b).

visible ≡ existing in the visual domain (1a)

invisible ≡ non-existingin the visual domain (1b)

This scenario can be represented with the CDL. First, a set of individual vehicles with separate identities (Figure 15a) collect to form a convoy (Figure 15b). The addition of a vehicle to the convoy can be modeled (Figure 15c), as can the removal of a vehicle from the convoy (Figure 15d). In the latter case, since the composite is viewed as a collection of vehicles, the composite only contains the existing (visible) objects as parts after the transition.

When the convoy disappears from view as the road winds through a forest, the composite and the parts are now non-existing objects (Figure 15e). When it partially emerges from the forest, such that two vehicles are visible, there is a `create` of the composite object "convoy" (the same identity is created again) (Figure 15f). The composite identity is now existing—even without the creation of *all* the parts—as the viewer recognizes the convoy as being "the same" as earlier. The two vehicle identities that are recognized are also re-created and become parts of the composite once again.

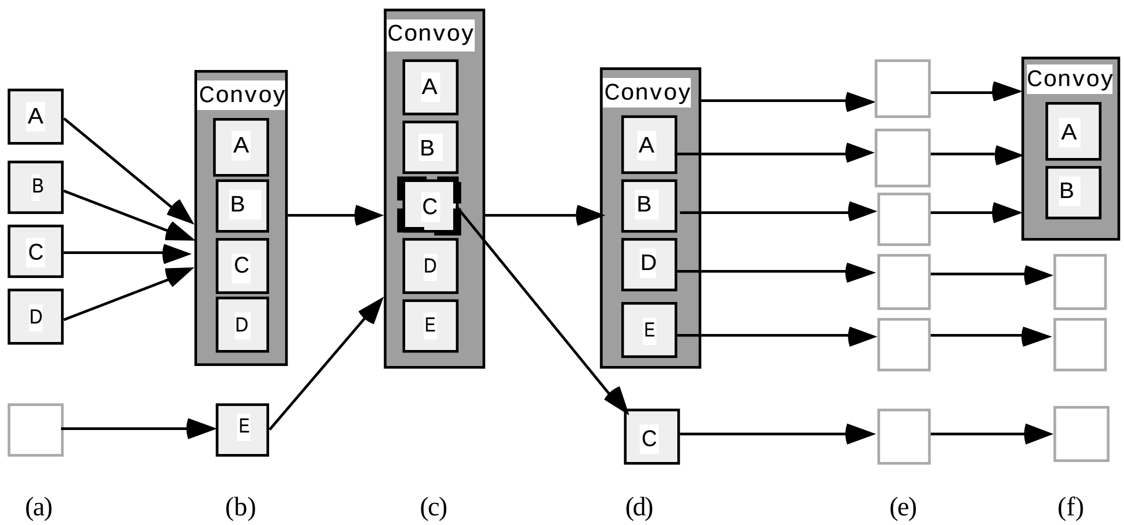


Figure 15: Composite object Convoy: (a) four existing objects represent separate vehicles that are visible (b) creation of a composite object representing the convoy, (c) an existing object is added to the composite, (d) a part C is separated from the composite, (d) the composite and all parts become non-existing, and (e) the composite and two parts, A and B, are created again.

The use of identities in this example captures the semantics of "a convoy" as well as the individual objects (vehicles) that make up the composite. It allows us to track the composite object and its parts as well as single objects during periods of existence and non-existence.

7. Conclusions and Future Work

This paper has described operations on composite objects with special emphasis on the semantics associated with composites. Composite objects often play an important role in spatio-temporal reasoning tasks yet few operations exist that are specific to these objects. This paper has shown that there are at least two different categories of composite objects, reflecting the different ways in which composite objects are created. These in turn affect how additional parts can be added to a composite or how parts are removed. Operations on composite objects have been described including: selection, elimination, and separation. The role of object identity as applied to composites and their parts is shown to be particularly useful from the perspective of tracking existence and non-existence of composites and their parts during scenarios of change.

Future work will consider further the semantic differences between composite objects—those created via a framework and those formed as a collection of objects. Also dependencies between a composite and its parts will be explored Parts of a composite object can exist independently of the whole, or they may be dependent on the existence of the composite (Kim *et al.* 1989). Additionally, relationships between parts and composites may be referred to as exclusive or shared (Halper *et al.* 1992). An *exclusive* relationship describes the situation where a part can belong to one whole, for instance, a school cannot belong to more than one school administrative district. A *shared* part relationship captures the semantics that a part may belong to more than one whole.

Future research is also needed on the importance of type to composite objects. For instance, composites may be restricted in the *kind of* parts of which they can be comprised. Operations on composites that allow for more or less detail to be shown need also to be formalized.

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