A Natural Cure for the Pet Fish Problem: Feature Emergence as Classificatory Composition

Chris Thornton
Informatics
University of Sussex
Brighton
BN1 9QH
UK
c.thornton@sussex.ac.uk

Abstract

Where do emergent features come from? This has long been an intriging puzzle. The concept of pet fish illustrates the difficulty. Most people expect pet fish to live in bowls, even though this is not something either pets or fish normally do. The inference that pet fish have the feature of living in bowls cannot be explained purely in terms of the constituents themselves. The feature seems to emerge. The present paper aims to explain this effect using notions of classificatory composition. Adjoined concept references are taken to construct classifications rather than combinations; a pet fish is taken to be a fish classified as a pet rather than a combination of a pet a fish. It is also shown that, where concepts have a compositional representation, feature emergence can be accounted for in terms of compositional accommodation.

Introduction

The concept of pet fish is one of the best known examples of a conceptual combination that produces difficult to explain 'emergent features.' People expect pet fish to live in bowls, even though this is not expected of either pets or fish (Murphy, 1988). The feature lives-in-bowls somehow leaps into existence when the concepts pet and fish are combined. But how and why? The effect seems to be something to do with the way the combination is explained. But giving a precise and general account is not straightforward (Rosch, 2011). This is the so-called Pet Fish problem, also known as the Guppy problem (Osherson and Smith, 1981)

Simple cases of concept combination are dealt with relatively easily. Let's say we combine the concept brown with the concept cow to form the concept, brown cow. Linguistically, the effect is to apply an adjective to a noun. In conceptual terms, the process is said to involve attachment of a modifier concept (brown) to a head concept (cow). Various explanations can then be set out. Assuming a schematic, slot/filler type of representation, the effect can be seen as one in which the modifier concept brown becomes the new filler for the color slot in the cow representation (cf. Hampton, 2011).

Simple explanations of this sort run into problems quite quickly, however. One relates to typicality effects. Consider the concept of a road bridge. For residents of the UK, a highly typical case of a road bridge is the Forth Road Bridge in Scotland. Unfortunately, this entity is unlikely to be considered typical of either roads or bridges, on which basis there is a mystery about how the combination acquires typicality attributions not given to either constituent. This is known as the conjunction effect (Smith and Osherson, 1984).

Schematic theories of representation (Rumelhart and Ortony, 1977; Rumelhart, 1980) seem to offer a way of dealing with such problems. Let's say an apple concept is represented by a schema with slots for color and size. The fact that apples are typically green may be captured by placing a high typicality value on green as a color value (Murphy, 2002, p. 447). If constructing the concept of a red apple has the effect of placing red into the color slot of the apple schema, while also giving it a high typicality value, the expected typicality effect is reproduced. A red apple is then modeled as more typical of the concept red apple than it is of the concept red, or the concept apple. This approach to typicality values is at the heart of the selective modification proposal of Smith and Osherson (1984; Smith et al., 1988).[1]

The immediate difficulty with this idea is that it depends on there being a suitably modifiable slot in the head schema (Machery, 2009). In many cases, this seems to be ruled out. Consider Murphy's example of a 'party dog'. A plausible idea is that a party dog is a dog that does tricks. It is much less plausible that a dog schema will have a does-tricks slot, however. Combinations in which the head concept seems to lack any usefully modifiable slot abound. As Murphy notes, it is simply 'not the case that an adjective can automatically pick out a single dimension to modify' (Murphy, 2002, p. 450).

The general difficulty is the way in which concept combination goes beyond what can plausibly be conjured from constituent representations. The concept of pet fish is the classic illustration but 'Harvard-educated carpenter' is also revealing. People described as instances of this concept are likely to be seen as non-materialistic (Kunda et al., 1990). This seems to involve reasoning with relations that have nothing to do with the constituent concepts. Kunda et al., describe the process as the development of a 'causal narrative.' A simpler ex-

[1] In fact, the selective modification model involves modification of both typicality 'votes' and dimension diagnosticities, the latter being required to explain reverse conjunction effects.

ample is 'big dog'. This entity seems to have features that cannot be explained in terms of representations for the concept big and the concept dog. A big dog is presumably small in relation to a house, for example. Any theory that models the combinational process purely in terms of constituent representations cannot explain such effects.

Explaining how concept-combination goes beyond processing of constituent representations is thus a key part of most proposals. In the concept specialization model of (Cohen and Murphy, 1984; Murphy, 1988) the process is understood to involve placing a representation of the modifier concept into a slot selected on the basis of background knowledge. This is then interpreted and elaborated taking 'outside knowledge' into account (Murphy, 1988, p. 533).[2] The model allows scope for emergence of features through explanation. It has also been extended by Wisniewski to incorporate mechanisms of property-mapping, concept hybridization and relation-linking (Wisniewski, 1997; Wisniewski and Love, 1998).

Other proposals envisage ways in which processes of reasoning might directly mediate the combinational process. In Thagard's Amalgam theory (Thagard, 1984) application of procedural rules regulates slot/value selection in ways that promote an interpretation that reconciles 'the conflicting expectations contained in the candidate concepts' (Thagard, 1984, p. 4). Hampton's composite prototype model (Hampton, 1987, 1988, 1991) also deems combination to involve processes of reasoning, although here the process is based on theory-driven relations connecting slots of the original representations. Another proposal is the CARIN model of Gagne and Shoben (1997; Gagne, 2000; Gagne and Shoben, 2002). Here, the key idea is that combinational processes access a small library of fundamental thematic relations, including Cause, Has, About, Make, For, Use and Located-at. The model envisages combination to involve constructing an integrated slot/filler representation based around one or more of these foundational relations.

A variety of combinatorial mechanisms are proposed in the literature, then. Each has its pros and cons from the explanatory point of view (Ran and Duimerang, 2009; Murphy, 2002). The present paper aims to add a new explanatory proposal but does not hypothesise any new form of combinatorial mechanism. Rather it aims to explain featural effects in terms of the compositional properties that concepts *inherently* possess. It aims to show the sense in which feature emergence is a natural outcome of conceptual compositionality.

The hypothesis, more specifically, is that feature emergence can be explained in terms of natural concept composition. Conceptual structure assembled by this process has the distinguishing feature of being held together purely by the classificatory properties of concepts in the structure. There is no superimposed, compositional framework. The features which emerge from combining two concepts, it is argued, can be explained as the constructs that grow out of extending a natural compositional structure to accommodate constituent representations. However, it is to emphasized that the examples set out are intended to illustrate possible mechanisms. They are not intended to be realistic models of cognitive structure. The proposal is set out in two main sections. The section immediately to follow introduces the idea of natural concept composition. The second section shows how this type of conceptual structure can be a way of explaining cases of feature emergence.

Natural concept composition

Although the classificatory functions of concepts are normally viewed as applying to non-conceptual entities, they can also be seen as applying to concepts themselves. A fork concept is the means of classifying something as a fork. A plastic concept is the means of classifying something as plastic. But some forks are plastic, on which basis the plastic concept can also be a way of classifying the fork *concept*. What is picked out is the extensional intersection—the set of all plastic forks. This is just the extension of the concept of plastic forks. Where extensions intersect in this way, the effect of using one concept to cross-classify another can thus be a new concept: it is the concept whose extension is the intersection arising. Cross-classification of one concept by another has the potential to yield an implied concept, with an extension that is derived by intersection.

The more complex case of this is where we have a concept that classifies an n-tuple of entities (i.e., a relation). For example, let's say we have a male-celebrity concept, a female-celebrity concept and a married-couple concept. There is the potential for a male and female celebrity to be classified as a married couple. The married-couple concept is a potential classification of an n-tuple comprising the male-celebrity and female-celebrity concepts, then. The result is a celebrity-couple concept, whose extension is the set of couples made up of a male and a female celebrity.

Classifications of this type exist whenever the extension of the classifying concept contains at least one of the possible permutations of instances. To formalize this, we have to work in terms of cartesian products. A cross-classification exists if the extension of the classifying concept intersects the cartesian product of the extensions of constituents in the classified n-tuple.[3] Provided we allow singleton n-tuples, this deals with all cases, since the

[2] As Ran and Duimerang note, a problem with this is that the nature of outside knowledge is 'not clearly defined and is treated as a kind of black box in which the cognitive mechanisms that guide its function are unknown' (Ran and Duimerang, 2009, p. 57).

[3] The statement that two sets intersect is taken to mean that they have a non-empty intersection.

cartesian product of a single set is just the set itself.

A general rule can be stated accordingly.

- *Cross-classification rule*: concept x classifies some n-tuple of concepts (not including x) if the cartesian product formed from their extensions intersects the extension of x.

It is then possible to define the situation where a set of concepts gives rise to an implied concept by means of classificatory composition.

- *Composition rule*: if within some set of concepts there is a valid cross-classification that gives rise to an extension that is new for the set, this composition is an implied concept.

The idea of 'compositional completion' can then be set out. A set of concepts may be said to be compositionally complete just in case it has no implied concepts. This either means all of them have already been added, or there were none to begin with. The compositional completion of a set of concepts is the set of implied concepts given rise to, then. The composition rule specifically requires that an extension be new for the original set of concepts. This accommodates the possibility of having two or more implied concepts with the same extension.

Notice the rules allow for cumulative effects: the identification of one implied concept can give rise to another. The result in such cases is a compositional structure of two levels—one classification inside another. There is no limit on the number of times this can happen, and thus no limit on the structural complexity that may emerge. The compositional completion of a set of concepts may comprise conceptual structures of arbitrary compositional complexity. These structures have the distinguishing feature of being held together purely by the classificatory properties of the concepts they contain. There is no superimposed, compositional formalism. For this reason, the process is called natural concept composition.

Couples example

The dynamics of natural concept composition can be illustrated by extending the celebrity-couples example. Let's say we start with a set of five concepts defined as follows.

male-celebrity = {Brad, David, George}
female-celebrity = {Ange, Posh, Rita}
pets = {Fido, Twinkle, Rover}
couples = {⟨Brad Ange⟩, ⟨David Posh⟩, ⟨Fido Qi⟩}
pet-owners = {⟨Brad Ange Fido⟩, ⟨Jo Sam Rover⟩}

These definitions should be self-explanatory. The extension of the male-celebrity concept is defined to be {Brad, David, George}. The extension of the couples concept is {⟨Brad Ange⟩, ⟨David Posh⟩, ⟨Fido Qi⟩}, and so on. All elements of extensions are understood to be n-tuples, but where $n = 1$, the angle brackets are omitted.

Examination of the definitions reveals that initially there is just one compositional implication. The extensional cartesian product of male-celebrity and female-celebrity intersects the extension of the couples concept, with the intersection being {⟨Brad Ange⟩, ⟨David Posh⟩}. The classification of ⟨male-celebrity female-celebrity⟩ by the couples concept is an implication of the set, then. For purpose of notating this, the convention used here is to enclose the classifying concept and its constituents in square brackets, with the classifying concept placed first. The implied construction is thus written

[couples male-celebrity female-celebrity]

The concept is that of a celebrity couple: it is referred to as the celebrity-couple concept below. The extensional definition is {⟨Brad Ange⟩, ⟨David Posh⟩}.

Once this implied concept has been identified, there is a knock-on effect resulting from the ability of the pet-owners concept to classify a composite of celebrity-couple and pets. The cartesian product derived from this includes ⟨Brad Ange Fido⟩, which is within the extension of pet-owners. A second implied concept then exists, in which the initial construction plays the role of a constituent. This is a structure of two levels:

[pet-owners
    [couples male-celebrity female-celebrity]
    pets]

The implied concept is that of a celebrity-couple classified as pet owners. In other words, it is the concept of a pet-owning celebrity-couple. This is the final implication in the present case. The compositional completion of this set comprises just two concepts, then.

Feature emergence

The second part of the proposal can now be set out. The hypothesis is that feature emergence results from natural concept composition. Viewing concept combination as classificatory composition has the effect of making feature emergence an expected outcome. Where a feature is seen to emerge as a result of combining two concepts, the process can be modeled in terms of compositional conceptions brought into existence by activating compositional representations.

In the simplest cases, concept combination can be explained purely in terms of schematic representation, and the ways in which activating one schema modifies another. Such accounts are straightforwardly translated into the present framework. From the compositional point of view, a slot/filler schema is a construction in which the classifying concept is that of combination, and each constituent is a one-level construction in which a filler value classifies a slot value. An apple schema has something like the following form, then.

[combination [green color] [round shape]]

Any account in which concepts are deemed to be combined by means of schema modification can then be expressed in terms of conceptual integration. Taking the concept of red to have the form [red color], an integration of the apple and red concepts would produce this conception of a red apple, for example.

[combination [red color] [round shape]]

This is the sense in which compositional processes can model schema-updates.[4] But notice the classificatory viewpoint that is imposed. On the assumption of the combination being represented compositionally, a red apple is an apple that is classified as red. It is not a red thing that is also an apple.

Combinations of more relevance to the Pet Fish problem are ones which yield emergent features via inferential explanation. The account in the case of 'pet fish' has already been noted: people expect pet fish to live in bowls (even though this is not the usual behavior of either pets or fish) because this is a way of explaining how fish can be both kept, and kept alive (cf. Murphy, 1988). The process is seen to involve the construction of an inferential explanation in which living in bowls is inferred to be the only way of meeting the requirement for fish to be kept in water.

The procedure for translating an explanatory process into a compositional one involves treating each inferential step as a conception. Inferences involving a schematic idea are seen as combinatorial conceptions (i.e., classifications based on the concept of combination). Inferences involving a categorical idea are seen as unifying conceptions (i.e., classifications based on the concept of unity). The process of connecting one inference to another is conceptual construction. Such connections are established by making one conception a constituent of another.

The explanatory process prompted by 'pet fish' integrates the schematic inference that fish need to live in water with the schematic inference that pets are kept in enclosures. Assume the construction of the pet conception is

[combination [habitat enclosure] [role amusement]],

[4]Most of the subtleties of schema-update proposals are ignored, here. Conjunction and reverse-conjunction effects (Smith et al., 1988) are potentially explained, however, assuming typicality attributions are increased by conceptual specificity, and decreased by conceptual contradiction. This has the effect of making red apples more typical, and brown apples less typical of the red apple conception than either apples or red things taken separately.

The corresponding conception of fish is

[combination [habitat water] [activity swimming]].

The two schematic inferences are then straightforwardly accomplished—they result directly from activating the constituent representations. Their integration, on the other hand, requires a combining conception. Given the understanding that a pet fish is a fish classified as a pet, this must impose the habitat classification from the pet conception on the habitat classification in the fish conception. The construct obtained is then

[combination
[habitat [enclosure water]]
[role amusement]
[activity swimming]].

On the assumption that [habitat [enclosure water]] constructs a conception of a habitat containing water, something akin to the lives-in-bowls feature is reproduced.

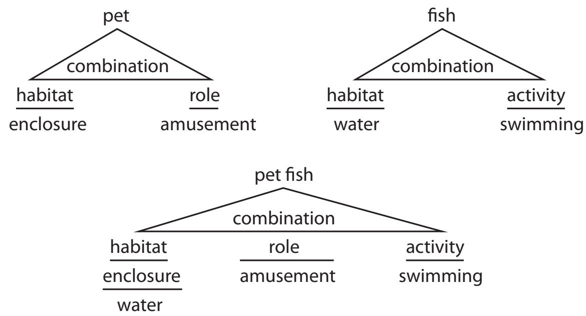

Figure 1: 'Pet fish'.

This compositional story is set out schematically in Figure 1. In this diagram, triangles represent conceptions: the name of the conception appears at the apex, with the classifying concept placed above the lower edge, and the classified constituents below it. Where we have a classification with a single constituent, a stack arrangement is used. The classifying conception is placed immediately above the classified constituent, with a line between them.

More complex cases of feature emergence give rise to more complex interpretations. But the principles of translation remain the same. Consider the case of 'Harvard-educated carpenter'. The emergent feature in this case relates to an attitude: Harvard-educated carpenters are inferred to be 'non-materialistic' (Kunda et al., 1990). The combination of high earning power and modest remuneration in a single individual is taken to imply that the individual must have a care-less attitude to money. The feature that emerges is a known classification of a combination of features. But these features are *inferred* rather than given.

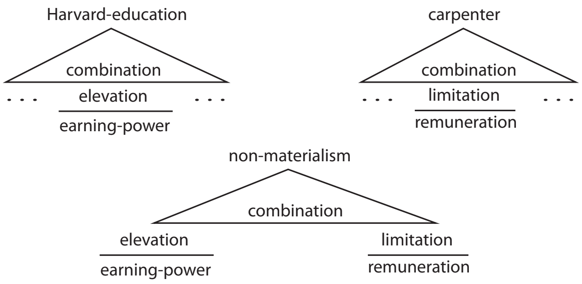

Figure 2: ‘Harvard-educated carpenter’.

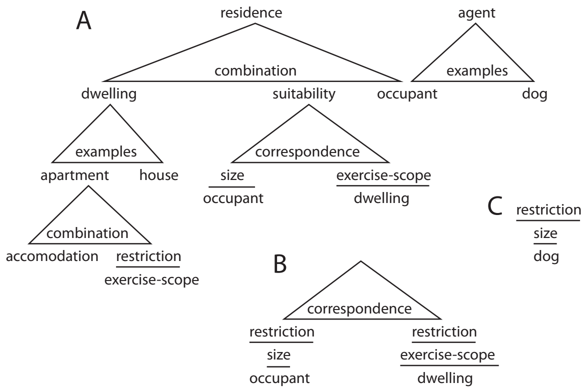

Figure 3: ‘Apartment dog’.

Modeled as natural concept composition, the explanatory process has the form depicted in Figure 2. The inference that a Harvard education produces high earning power comes from activating the relevant compositional representation (which incorporates the conception [elevation earning-power]). The inference that a carpenter is likely to have limited remuneration is produced in a similar same way, by activating the relevant compositional conception. An attitude of non-materialism is then inferred by means of an existing combinatorial conception for non-materialism based on these particular constituents. Again, the interpretation enforces a classificatory understanding. A Harvard-educated carpenter is not taken to be a combination of a carpenter and a Harvard education. It is seen to be the classification of a carpenter as Harvard-educated.

More complex still is the idea of an apartment dog. This phrase is found to suggest the idea of a dog that is small, even though this is not normally a property of either apartments or dogs (Murphy, 1988). The complication is the involvement of an intermediate idea. An apartment dog is not seen to be a dog classified as an apartment, let alone a dog that is also an apartment. It is expected to be a dog that *lives* in an apartment. Part of the explanatory process entails the idea of a particular type of agent residing in a particular type of dwelling.

The inferential steps in the explanation are seen to be essentially as follows (cf. Murphy, 2002). There is the categorical inference that apartments are types of dwelling, and the categorical inference that dogs and occupants are both types of agent. There are also three schematic inferences: the inference that apartments offer limited scope for exercise, the inference that dwellings have residents that are suitable, and the inference that suitability of an occupant for a dwelling requires correspondence between the occupant's size and exercise requirement. The structure labeled A in Figure 3 shows these five steps as compositional conceptions. The concepts utilized for classification include that of combination, of unity, and of correspondence.

Given this model, the conclusion that apartment dogs are small can be seen to result from an interaction between two conceptual processes. Reference to an apartment activates a dwelling conception in which exercise-scope is classified as restricted. A conception of residence is then realized, incorporating a suitability conception that classifies the size of the occupant as corresponding to the (restricted) exercise-scope of the dwelling. The only way of integrating the conception activated by the dog reference is then by inferring the dog to be the occupant in the residence conception. There is then an implicit classification (via the suitability conception) of the size of the dog as corresponding to the exercise-scope of the dwelling. A restriction is inferred to apply to the size of the dog. Emergence of the infered feature of smallness is obtained by means of a sequence of interacting, compositional constructions.

Modeling concept combination in this way has the advantage of parsimony. Notions of schematic representation and explanatory inference are collapsed to the idea of compositional conceptualization. The approach can deal with simple cases involving direct transfer of features as well as more complex cases involving explanation. But it cannot be emphasized too strongly that the examples set out are not intended to be realistic models of human cognition. It is *not* claimed that these particular conceptions are the ones people use. Given a free choice of what concepts are given, and no restriction on the number of constructive levels that can be brought into play, there are infinitely many ways in which any conception can be constructed. The examples set out are purely illustrative of the way in which feature emergence *might* result from classificatory composition.

Conclusion

Adjoined concept references are normally viewed as constructing combinations. The phrase ‘toy vehicle’ is considered to combine the concepts toy and vehicle, the phrase ‘pet fish’ is considered to combine pet and fish, and the phrase ‘apartment dog’ is considered to combine apartment and dog. Hence the name of the area of study. But as the present paper shows, these phrases can also be seen as classifications. A 'toy vehicle' can be a vehicle classified as a toy, a pet fish can be a fish classified as a pet, and an apartment dog can be a dog classified as living in an apartment. This leads to a new way of explaining feature emergence. On the assumption that concepts are represented as classificatory compositions (rather than as one-leveled schemata), explanatory feature emergence can be seen to grow out of compositional conceptualization. This avoids the need to think in terms of dedicated mechanisms of combination and explanation. The phenomenon is seen to result from activation of naturally constructed, compositional representations.

References

Cohen, B. and Murphy, G. L. (1984). Models of concepts. *Cognitive Science*, *8* (pp. 27-58).

Gagne, C. L. and Shoben, E. (1997). Influence of thematic relations on the comprehension of modifier-noun combinations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23* (pp. 71-87).

Gagne, C. L. and Shoben, E. (2002). Priming relations in ambiguous nounnoun combinations. *Memory Cognition*, *30* (pp. 637646).

Gagne, C. L. (2000). Relation-based versus property-based combinations: a test of the CARIN theory and dual-process theory of conceptual combination. *Journal of Memory and Language*, *42* (pp. 365-389).

Hampton, J. A. (1987). Inheritance of attributes in natural concept conjunctions. *Memory and Cognition*, *15*, No. 1 (pp. 55-71).

Hampton, J. A. (1988). Overextension of conjunctive concepts: evidence for a unitary model of concept typicality and class inclusion. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *14* (pp. 12-32).

Hampton, J. A. (1991). The combination of prototype concepts. In Schwanenflugel (Ed.), *The Psychology of Word Meanings*. Hillsdale, N.J: Lawrence Erlbaum Associates

Hampton, J. (2011). Conceptual combination and fuzzy logic. In Belohlavek and Klir (Eds.), *Concepts and Fuzzy Logic* (pp. 209-232). MIT Press

Kunda, Z., Miller, D. T. and Claire, T. (1990). Combining social concepts: the role of causal reasoning. *Cognitive Science*, *14* (pp. 551-577).

Machery, E. (2009). *Doing without Concepts*. Oxford: Oxford University Press

Murphy, G. L. (1988). Comprehending complex concepts. *Cognitive Science*, *12* (pp. 529-562).

Murphy, G. L. (2002). *The Big Book of Concepts*. London, England: The MIT Press

Osherson, D. N. and Smith, E. E. (1981). On the adequacy of prototype theory as a theory of concepts. *Cognition: International Journal of Cognitive Psychology*, *9* (pp. 35-58).

Ran, B. and Duimerang, P. R. (2009). Conceptual combination: models, theories, and controversies (chapter 2). In Weingarten and Penat (Eds.), *Cognitive Psychology Research Developments*. Nova Science Publishers, Inc

Rosch, E. H. (2011). "slow lettuce": categories, concepts, fuzzy sets and logical deduction (chapter 4). In Belohlavek and Klir (Eds.), *Concepts and Fuzzy Logic* (pp. 89-120). MIT Press

Rumelhart, D. E. and Ortony, A. (1977). The representation of knowledge in memory. In Anderson, Spiro and Montaque (Eds.), *Schooling and the Acquisition of Knowledge*. Hillsdale, NJ: Erlbaum

Rumelhart, D. E. (1980). Schemata: the building blocks of cognition. In Spiro, Bruce and Brewer (Eds.), *Theoretical Issues in Reading Comprehension*. Hillsdale, NJ: Erlbaum

Smith, E. E. and Osherson, D. N. (1984). *Categories and Concepts*. Cambridge, MA: Harvard University Press

Smith, E. E., Osherson, D. N., Rips, L. J. and Keane, M. (1988). Combining prototypes: a selective modification model. *Cognitive Science*, *12* (pp. 485-527).

Thagard, P. (1984). Conceptual combination and scientific discovery. In Asquith and Kitcher (Eds.), *PSA 1984 vol. 1* (pp. 3-12). East Lansing: Philosophy of Science Association

Wisniewski, E. J. and Love, B. C. (1998). Relations versus properties in conceptual combination. *Journal of Memory and Language*, *38* (pp. 177-202).

Wisniewski, E. J. (1997). When concepts combine. *Psychonomic Bulletin Review*, *4* (pp. 167-183).