Cognitive Computing for Augmented Human Intelligence: Papers from the AAAI-14 Workshop

On the Nature of Composable Properties

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Abstract

On the premise that access to natural language meaning, the result of a hybrid human-computer effort, belongs in cognitive computing, the paper explores the nature of such composable properties as SIZE or TASTE. Each is associated with a number of component properties, and every value of a composable property, as expressed by natural language expressions, such as *large* or *small* for SIZE or *tasty*, *salty* or *sweetish* for TASTE stands, in fact, for a combination of component properties, each with its own value (range). To emulate human understanding of composable properties, the computer must analyze them as having a varying number of component properties, each with its own specified value. Thus, *large animal* should be understood as an animal with a high value on at least one, salient component property and not necessarily (but quite possibly) on all. Because none of the component properties is actually explicitly mentioned, the computer understanding of the composable property SIZE is a step in the direction of machine understanding of implicit meaning, which is the holy grail of deep meaning analysis and the ultimate goal of this strand of research.

Introduction to Property Composability

The paper deals with an important semantic phenomenon that needs a more adequate representation in order to be understood and manipulated by computer correctly. It is based on the premise that access to natural language meaning is an important component of cognitive computing (cf. Taylor and Raskin 2013) and that, applied to a richer knowledge base, the powerful algorithms for big data will lead to higher precision in applications. The paper is based on limited data, and the human subject experiment is an initial exploration but the proposed treatment of composable properties and its computational implementation scales up to apply to hundreds of such properties in big data.

The Need for Understanding/Representing Property Composability Correctly

The following two brief dialogs seem to be perfectly acceptable:

How large an animal is the crocodile?—It is very long.
How did your entree taste?—It was very salty.

In both cases, the questions are answered perfectly adequately, positively in the first dialog and negatively, in the second. Yet, they are not answered directly but rather by a special inference. The first question was about size but the answer was about length; in the second question, it is taste and saltiness, respectively. The second speaker in each dialogue substitutes the property in the question with a different property, since we know that they are somehow related. The question is, how they are related so that such substitution is possible?

In the terminology we are introducing[1], composable properties SIZE and TASTE, are replaced above with their component properties, LENGTH and SALTINESS, respectively. For the computer to be able to make the necessary inferences, it must understand the composable/component relationship and process the dialogs appropriately, as indeed do humans. The nature of this relationship and its computational treatment constitute the main thrust of this paper.

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Not a Simple Inheritance

Composable properties are routinely treated as a case of subsumption, as in the IS-A relation, and our main point here is that it is not so. Thus, if VEHICLE is the ontological parent of CAR, TRUCK, MOTORCYCLE, BUS, etc., one is much more comfortable with the sentence *A car is a vehicle* than with *Length is a size*[2]. LENGTH is more like an aspect, a part of SIZE though certainly not in any strict mereological sense[3]. LENGTH clearly pertains to SIZE—more clearly, a dimension, a component of SIZE, although, again, not in the mereological sense of it. CAR does not pertain to VEHICLE, nor is its dimension—it is one.

Moreover, here are linguistic criteria that can be used to

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[1] A note on the notation: we use SMALL CAPS for conceptual entities and *italics* for natural language expressions.

[2] Space constraints do not allow us to demonstrate that the components of such a composable property as size fail formal condition of is-a-hood, as defined by Guarino and Welty (2000)

determine whether a relation is an IS-A relation (see also fn. 2). It is possible to say, *The worm is a long animal but not particularly large.* but not *He arrived in a car but not in a vehicle*. The former excludes one dimension of size, thus indicating that the largeness comes from one, which is the case here, or both of the remaining components of size. The mere mention of a component property brings to the fore the other two as well, without ever mentioning either.

No Fixed Number of Components

The composable property SIZE has the three dimensions that would be known to all cognitively competent humans; TASTE is not that much different with its five. INTERESTING and COMFORTABLE are not that lucky: besides the plasticity/salience variability, their lists of components are not as readily established and can be added on by circumstances.

Background on Composabilty

While composability has been largely underresearched, several adjacent disciplines have considered somewhat related phenomena. Thus, the notion of 'plasticity' in the philosophy of language (Marx 1983, Lahav 1989, Katz 1972) comes the closest: each noun influences the meaning of the adjective: *good book, good man, good car* all mean different things. The discipline focused on other aspects of this phenomena, but the composability of good provides a adequate alternative explanation.

Underlaid by First Order Logic, both philosophy of language and knowledge representation, as well as formal semantics, set up properties as functions/predicates, mostly on one argument, such as RED(X), INTERESTING(y), COMFORTABLE(Z), so that if X = HOUSE, Y = BOOK, and Z = CHAIR, the representations of *red house, interesting book*, and *comfortable chair* will, of course, be, respectively, RED(HOUSE), INTERESTING(BOOK), and COMFORTABLE(CHAIR)—see, however, the property OPPOSITE(X, Y) that requires two arguments, as do some others.

In none of these disciplines, the meaning relations among properties have not received much attention: thus, in the knowledge representation account in Sowa (2000: 469), the term 'property' occurs only once on the indicated page. Similarly, descriptive logic, preferring the term 'role' to 'property,' mentions 'subroperty-of' and 'role hierarchy' (see Baader et al. 2007, Rudolph 2011), but does not appear to have devoted much expert to their exploration. In Baader et al. 2007, a formal mechanism for role construction, the potentially iterative creation of complex roles from basic ones is outlined, but its application is not explicated, and it appears unlikely that it aims at composable properties.

OWL, whose one specific version, OWL-DL, illustrates subproperties with the property hasMother being a subproperty of the property hasParent and provides it with some axiomatics but this is the closest it comes to composable properties, focusing instead on such general logical features of properties as equivalence, inverseness, functionality, transitivity and symmetry.

Ontological Semantics (Nirenburg and Raskin 2004) and its successor, Ontological Semantic Technology (Raskin et al. 2010, Taylor et al. 2010, Hempelmann et al. 2010) have a property-rich ontology as their centerpiece. Similarly to OWL, however, from which it otherwise differs in many crucial respects, it treats SIZE as the parent of HEIGHT, LENGTH, and WIDTH, its three 'subproperties' in OWL's terminology. However, as we have argued above, the nature of inheritance in a case like that is very different from the real parent-child ontological relationship, and a typical IS-A confusion results from that as per the definitive analysis of the IS-A property in formal ontology (Guarino 2000—see also fn. 2): thus, the direct inheritance will lead to a false inference X is large → X is long (or wide, or deep) and its reverse.

To reiterate, the main thrust of this paper is not a mere extension of formalism, which is always possible, but rather to enable the adequate computer understanding of the usage of composable properties, mimicking human understanding and ability to manipulate such properties, and the correct type of inheritance is essential for that.

Composable Properties: Towards Mathematicalization

Definition

We will define a composable property, such as SIZE or TASTE, as a function F that has other functions, H and G, as F's components. Thus, H and G may correspond to WIDTH and LENGTH in the case of SIZE, and to SWEETNESS and BITTERNESS in the case of TASTE. In real life, there will be more than two component functions, even in these two examples as it would be reasonable to include at least HEIGHT for SIZE, and SOURNESS, SALTINESS and UMAMI for TASTE. However, the 2 component functions are easily extendable to n functions.

Consider functions $F: D \rightarrow R_F$; $H: D \rightarrow R_H$; $G: D \rightarrow R_G$, where transformations T exist such that $T_H(R_H) = R_F$ and $T_G(R_G) = R_F$. We will define a relation ⌘ on H and G, such that $H(x)⌘G(x) = w_H * T_H(H(x)) + w_G * T_G(G(x))$, for $w_j > \alpha$, where *w* is the weight and α is a threshold of saliency or importance. We will call a function F composible when there are H, G such that F = H⌘G. We will refer to H and G as components of F. We will also generalize ⌘ to any number of components H of F: $⌘(H_i) = \{\sum_i w_i * T_i(H_i(x)) \mid H_i : D \rightarrow R_{H_i} ; T_i(R_{H_i}) = R_F\}$.

The proposed treatment of composable properties is envisioned as a dynamic operation where some of the components may or may not exist as salient in the mind of individuals. It means then, that the hardcoded traditional type inference rules would not reflect the individual worldviews.

What Happens to SIZE and TASTE

As stated in the introduction, we are interested in applying the notion of composability to properties like SIZE and TASTE.

SIZE. Any physical entity that has SIZE belongs to the domain of SIZE, LENGTH, WIDTH, and HEIGHT. If for some reason, such a physical entity does not have one of the components, then, again, the weight coefficient *w* for this component becomes 0. Since we know how to handle such cases, we will, in this section, consider only cases that have all of these component properties because such cases are the most interesting ones.

We will also assume that the range of SIZE R_{SIZE} = {small, medium, large} and that any hedging that needs to be done (very, a little, etc.) can be done similar to equations in Zadeh 1972 (see also the "prequel" and "sequel" in Lakoff 1971 and Yager 1982). With the same assumption, the range of length R_{LENGTH} = {short, ave-length, long}; the range of width R_{WIDTH} = {narrow, ave-width, wide}; and the range of height is R_{HEIGHT} ={short, ave-height, tall}.

The transformation functions from the component property range values to those of the composable property's range values are defined as follows:

T_{LENGTH}(short) = small
T_{LENGTH}(ave-length) = medium
T_{LENGTH}(long) = large
T_{WIDTH}(narrow)=small
T_{WIDTH}(ave-width)=medium
T_{WIDTH}(wide)=large
T_{HEIGHT}(short)=small
T_{HEIGHT} (ave-height)=medium
T_{HEIGHT} (tall)=large

Finally, we need to know the weights w for each component property. While their individual coefficients are possible to obtain, we will use commonly used perceptions for generic calculations. The coefficients do not have to be precise but should correspond to the human perception of the relative importance of each property for the object that is defined by them.

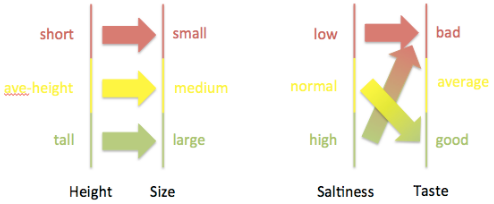

Figure 1: Transformation functions' example

TASTE. TASTE follows a slightly different pattern because the transformation functions are not as straightforwardly mathematical—see Fig. 1. For example, the high quantity of SALTINESS, typically, does not result in a high range of TASTE but rather decreases its value: a different pattern than what happens in SIZE and its component properties.

Nevertheless, other than the somewhat unintuitive shifts in the transformation functions, the foundations of the composability don't change. Thus, provided that the four other taste component properties are within a normal range, and not increasing the weight coefficient above α, and weight of the SALTINESS property is 1, a salty entree will be treated as:

TASTE(entrée) = w_{SALT} * T_{SALT}(SALTINESS(high)) = bad

Testing Human Perception of SIZE and TASTE as Composable Properties

We wanted to check whether the intuition behind the formula holds for human perception. With this in mind, we conducted an experiment on Amazon's Mechanical Turk, where 50 English-speaking participants were asked questions about their perception of size and taste. The participants were presented with the words for eight animals. With some animals, there were component properties that were obviously prominent/salient, such as length in *snake*; other animals did not have any features that were more salient than others, such as *cat*; and yet other animals fluctuated between those two extremes.

To experiment with taste, similar considerations were taken into effect, resulting in the words for 7 food objects. Some of the selected objects did not have a clear common value of attributes. For example, *apple*, one of the food object words that was presented, can be sweet or sour—thus individual considerations should be given to the responses of this object.

In order to evaluate the values of the component properties, the participants were presented with a sliding bar (from 0 to 100) and asked to select an appropriate value. The same question was asked for the composable properties. In order to evaluate the importance or salience of the component properties, participants were asked to identify those properties that are more important than others when they think about an object in question. They were also asked if the overall property is more important than one of the features or not, as these are the cases that can result in the mismatched question/answers such as *what size/long* pair that we saw above in our example with a crocodile. These last two questions had a text box response, and the participants could write anything they wanted to. These boxes served a secondary purpose as well: it was possible to identify, from their answers, if the participants were paying attention to the questions.

The average answers for SIZE and TASTE are shown in Tables 1 and 2 respectively. Salient properties for each object are indicated in boldface. When a component property is more important than a composable property, it is underlined.

Table 1: SIZE indication

animal	***length***	***width***	***height***	***size***
snake	**64**	24	26	54
elephant	62	**65**	**67**	79
crocodile	**63**	43	25	60
giraffe	46	35	**81**	77
cat	**35**	**25**	**27**	37
mouse	**24**	**18**	**16**	25
camel	45	37	**60**	62
worm	**40**	18	19	34

Table 2: TASTE indication

food	***bitter***	***sweet***	***sour***	***salt***	***umami***	***taste***
cake	14	**76**	13	15	22	80
meat	**18**	**17**	**20**	**36**	**32**	68
lemon	31	20	**58**	25	20	54
carrot	18	**50**	18	19	23	67
herring	**18**	17	20	**32**	25	39
apple	20	**68**	25	14	18	79
salmon (smoked)	**18**	**18**	17	**29**	23	46

Table 1 indicates that our treatment of composable properties corresponds with their human perceptions. Table 2 is more interesting to analyze. The first cursory look at the results, for each food object described, appears to indicate that the transformation function is different if we use the unmodified formula as introduced in the section above. Upon deeper analysis, however, the transformation functions of the expected tastes turn out to be roughly identical to the transformations of SIZE: high SWEETNESS is good, or rather, expected in *cake*; high SOURNESS is expected in *lemon*; and so on with the list of examples. The transformation functions of TASTE, then, reflect the difference of what is expected (and illustrated in Table 2) from what is actually received in a dish.

Conclusion

In this paper, we presented a case for a new representation of a special class of properties that we called 'composable.' Such properties consist of component properties, so closely and intuitively associated with them that a question about the value of a composable property can be appropriately and felicitously answered with a statement about the value of a component property, and vice versa. The class is populated with such simple properties as SIZE, whose most obvious components are HEIGHT, LENGTH, and WIDTH//DEPTH; as a somewhat more complexly organized TASTE, and in fact, as many other properties, which—while clearly composable—have component properties that are harder to identify and whose number may be unspecified.

We see this phenomenon as providing a relatively easy insight into implicit meaning, the computer understanding of which, emulating human easy access, is a theoretical and practical challenge. The lack of access to the so-called 'deep meaning' critically limits the accuracy of text analytical applications of all kinds (see DARPA 2012).

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