

Chapter 2

CONCEPTUAL COMBINATION: MODELS, THEORIES, AND CONTROVERSIES

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ABSTRACT

This paper provides a comprehensive and critical review of the major theories and models of conceptual combination, by highlighting agreements and controversies in the literature, and identifying future directions for research. The review summarizes the basic arguments of ten major models and then presents an analytical framework to compare and contrast these models along four dimensions: (1) the causal role of schemata in the model; (2) the role of cognitive harmony or consistency in the model; (3) the pragmatic orientation in the model; and (4) the explanatory scope of the model. The review identifies areas of agreement and disagreement among the various models and theories and calls for a synthesis theory to address various theoretical weaknesses and empirical gaps in the current explanations.

1. INTRODUCTION

Conceptual combination refers to the cognitive process by which people use two or more concepts to construct a new conceptual entity that a single concept is insufficient to describe. Researchers agree that the ability to combine concepts plays a fundamental role in diverse cognitive processes such as learning, communication, language comprehension, the composition of thoughts, and the expansion and structuring of knowledge.

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In the last thirty years, there has been a very strong interest in the cognitive mechanisms involved in combining concepts in cognitive psychology and related fields such as linguistics, artificial intelligence, and philosophy. Many models and theories of conceptual combination have been proposed, among which ten models are of particular significance: Fuzzy Set Theory (Zadeh 1965, 1976, 1982; Osherson and Smith 1981, 1982); the Selective Modification Model (Smith, Osherson 1984; Smith, Osherson, Rips and Keane, 1988); Amalgam Theory (Thagard, 1984); the Concept Specialization Model (Cohen & Murphy, 1984; Murphy, 1988, 1990, 2002); the Composite Prototype Model (Hampton 1987, 1988, 1989, 1990, 1991); the Dual-Process Model (Wisniewski, 1997a, 1997b, 1999; Wisniewski & Love, 1998), the Constraint Model (Costello & Keane, 2000, 2001), the Competition Among Relations in Nominals (CARIN) Model (Gagné, 2000, 2001; Gagné & Shoben, 1997), Coherence Theory (Thagard 1989; 1997), and the Interactive Property Attribution Model (Estes and Glucksberg, 2000; Choi, Oh, Yi & Shin, 2007). This paper will critically review these ten models by identifying areas of agreement and disagreement among them, and various theoretical weaknesses and empirical gaps in the current explanations that might be addressed by a future synthesis theory.

The paper is organized as follows. In the next section each of the ten models will be briefly described and evaluated. Then an analytical framework will be proposed to summarize agreements and controversies among the models. Questionable assumptions and issues in the current theorizing will also be critically examined in the context of a discussion of future directions for conceptual combination research.

2. CURRENT MODELS OF CONCEPTUAL COMBINATION

In this section, we will briefly summarize ten significance models of conceptual combination. The ten models can be sorted into two groups. In the first group, each model was proposed as a logical extension or modification of previous models: Fuzzy Set Theory, Selective Modification Model, Concept Specialization Model, Dual-Process Model, and Interactive Property Attribution Model. Our review will trace the development of these models, focusing on how each addresses earlier theoretical weaknesses. In the second group, the remaining five models each focus on particular aspects of the conceptual combination process: Amalgam Theory, Coherence Theory, Composite Prototype Model, Constraint Model, and CARIN Model. Our review will examine the specific aspects that are emphasized by each model in this group.

2.1. Conceptual Combination as the Intersection of Fuzzy Sets

The earliest attempt to describe the phenomenon of conceptual combination was conducted by mathematicians known as fuzzy set theorists. This attempt generated a formalized explanation of how humans combine smaller conceptual units into more complex ones (Osherson and Smith 1981, 1982; Zadeh 1965, 1976, 1982). The model is based on the idea of referential semantics in which the meaning of a concept represented by a word equates to the extensional set of things denoted by the word. For example, the meaning of the concept

bird refers to the set of all birds. When two concepts are combined, the resulting concept is then the intersection of the two extensional sets. Thus, if X and Y are the extensional sets of concepts x and y respectively, the conceptual combination xy is understood as the intersection of the set X and the set Y , that is the set of things that are both X and Y . For example, the meaning of *pet fish* is the intersection of *pet* and *fish*, i.e., the set of things that are both pet and fish. More formally, in classic set theory, the conceptual combination XY is defined as follows: (Let X, Y be sets) the intersection of X and Y (denoted $X \cap Y$) is the set $\{z : z \in X, z \in Y\}$. In fuzzy set theory, the intersection of two fuzzy sets A and B with respective membership functions $f_A(x)$ and $f_B(x)$ is a fuzzy set C , whose membership function is related to those of A and B by $f_C(x) = \text{Min} [f_A(x), f_B(x)]$, $x \in X$. (Zadeh 1965).

As a formal logic model of conceptual representation, fuzzy set theory provides a strong tool to describe and analyze phenomena such as conceptual combination. The description is clear, logical, and parsimonious. However, as a description of conceptual structure, fuzzy set theory was strongly criticized by psychologists. The major criticisms could be summarized as follows.

The first criticism relates to whether set theory is an appropriate theory of concept representation. For example, the applicability of set theory in concept representation is limited. Osherson and Smith pointed out that the extensional view of concepts “is best suited to ‘kind’ notions (such as *dog*, *tree* and *animal*), to ‘artifact’ notions (like *tool* and *clothing*), and to simple descriptive notions (like *triangular* and *red*) where the extensional sets are easier to define. More difficult to describe are intentional or intricate concepts such as *belief*, *desire*, and *justice*” (Osherson and Smith, 1981 p.38). The diversity of different kinds of concepts imposes difficulties on how set theory formally describes their structure, and whenever non-kind concepts are combined, the intersection of sets is difficult to describe or formalize. Based on this observation, Murphy argued that “(i)t is very difficult to interpret (set theory) as a psychological theory at all. Even if all *pet fish* fall into the intersection of pets and fish, this does not tell us what people do with their concepts *pet* and *fish* in order to create a new concept” (Murphy 1988, p.531). To be considered a psychological model, set theory should provide an intensional explanation of how or why people combine concepts.

The second criticism relates to what are known as conjunction effects. Fuzzy set theory will lead to a contradiction in its calculation whenever an object is more prototypical of a conjunction set than of its constituent sets (Osherson and Smith, 1981). For example, it can be shown empirically that a guppy is more prototypical of the conjunctive concept *pet fish* than it is of either *pet* or *fish*. That is, $C_{\text{pet fish}}(\text{guppy}) > C_{\text{pet}}(\text{guppy})$ or $C_{\text{fish}}(\text{guppy})$. However, the intersection of the fuzzy sets is defined as: $(\forall x \in F) (C_{\text{pet fish}}(\text{guppy})) = \min (C_{\text{pet}}(\text{guppy}), C_{\text{fish}}(\text{guppy}))$ which implies: $C_{\text{pet fish}}(\text{guppy}) < C_{\text{pet}}(\text{guppy})$ or $C_{\text{fish}}(\text{guppy})$. In other words, “it is possible, contrary to fuzzy-set theory, for the characteristicness of an instantiation of a conjunctive concept to be greater than either of the characteristicnesses of its constituent simple concepts” (Jones, 1982 p.284). This apparent contradiction suggests that set intersection is insufficient to describe the conceptual combination process.

The third criticism relates to concepts that are not intersective. For example, Murphy (1988) noted that set intersection does not account for the meaning of combinations like *apartment dog*, which does not correspond to the intersection of the sets *apartments* and *dogs*. Moreover, nonpredicating adjectives, when combined with nouns, do not produce meaningful intersections. “The interpretation of atomic engineer as someone who runs equipment to make

atomic energy is not the intersection of atomic things (whatever they are) and engineers. the intersection of the two sets does not define the combined concept” (Murphy, 2002 p.445).

A final criticism is related to the symmetric property of set intersection which contradicts our intuitive understanding of the meaning of many conceptual combinations. Set theory presumes that noun-noun combinations are symmetric (i.e., true conjunctives), because $X \cap Y$ is equal to $Y \cap X$. However, our intuitive understanding of the combination XY usually has very different meaning than its YX counterpart. For example, “a desk lamp is a kind of lamp, but a lamp desk is a kind of desk” (Murphy, 2002 p.445).

2.2. Selective Modification Model

The weaknesses of using fuzzy set theory to explain conceptual combination led to an alternative explanation: the selective modification model proposed by Smith, Osherson and colleagues (Smith, Osherson 1984; Smith, Osherson, Rips and Keane, 1988). This model consists of two arguments describing how concepts are mentally represented and how these mental representations are combined. The model assumes that concepts are represented by Attribute-*value* pairs. For example, *apple* may be represented by Color-*red*, Shape-*round*, Taste-*sweet* etc. Each attribute is associated with a certain weight, or “diagnosticity,” which is an empirically-determined numerical value that indicates “how useful the attribute is in discriminating instances of the concept from instances of contrasting concepts” (Smith et al. 1988 p.487). Each value is also associated with a certain weight to indicate its relative salience. For instance, *red* might be more salient than *round* in the *apple* concept, as determined by “votes” for the value by experimental subjects. Despite different terminology, attribute-value pairs essentially correspond to slots (or dimensions) and features in a schematic concept representation (Rumelhart & Ortony, 1977; Rumelhart, 1980).

The model further proposes that the meaning of an adjective-noun combination results from a process of “adjective modification” in which, the adjective modifies the noun: “Each attribute in the adjective concept selects the corresponding attribute in the noun concept; then, for each selected attribute in the noun, there is an increase in the salience (or votes) of the value given in the adjective, as well as an increase in the diagnosticity of the attribute. Consider shrivelled apple as an example. Presumably shrivelled contains attributes pertaining to shape and texture; accordingly, it would select these attributes in the apple prototype, boost their diagnosticities, and shift their votes away from round and smooth and toward irregular and bumpy” (Smith, et al. 1988 p.492).

Selective modification is regarded as the first psychological model of conceptual combination. The main contribution of this model is that it highlighted important aspects of conceptual combination, including typicality effects (i.e., that the typicality of a combination is not a simple function of the typicality of component concepts) and the conjunction effect (i.e., when an item is well described by a conceptual combination, it is usually more typical of that concept than of the two components). However, the model suffers from two major drawbacks. First, the scope of the model is limited to only one kind of conceptual combination, namely predicating adjective-noun phrases such as *red apple* or *long vegetable*. The model does not explain other types of combinations such as nonpredicating adjective-noun combinations like *atomic engineer* (Murphy, 2002) or noun-noun combinations like *telephone television*.

Second, the process of conceptual combination described by this model is problematic. As discussed by Murphy: “The main problem with this theory that later writers have criticized is its assumptions about modification. Consider the way modification works for the concept *red apple*. The adjective *red* finds its match in the schema: There is a feature with the same name. That feature now gets all the votes, and its dimension gets a higher diagnosticity rating. However, there are more complex cases that aren’t so easily accommodated. It has been argued that sometimes, the exact feature would not be present in the concept already, and yet people can figure out how to modify it. Indeed, there may not be an obvious dimension for the modifier to affect. Furthermore, sometimes more than one dimension is altered. Thus, the modification process itself has been argued to be much more complex than Smith et al. let on” (Murphy, 2002 pp.449-450).

2.3. Concept Specialization Model

Murphy and Cohen proposed the concept specialization model to address weaknesses of the selective modification model (Cohen & Murphy, 1984; Murphy, 1988, 1990, 2002). Similar to the previous model, the concept specialization model assumes a schematic representation of concepts where nouns are represented as schemata with slots (dimensions) and fillers (values for each dimension). Based on this representation, “conceptual combination is a process in which a head noun concept (is) specialized by one or more of its slots being filled by the modifying concept” (Murphy, 2002 p.453). In this process, “knowledge is involved in choosing the best-fitting slot” (Murphy, 2002 p.453). For example, to understand the combination *apartment dog*, the modifier *apartment* is used to fill some slot in the head concept *dog*. What dimension or slot of *dog* is picked by the modifier *apartment*? Our background knowledge will guide us to choose the slot of *dog* that makes the most sense with *apartment* as the filler. In this case, *apartment* is classified as a type of Habitat and so fills the Habitat slot in the head concept *dog*. This provides the interpretation of “a dog that lives in an apartment”. Beyond this slot-filling process, the model proposes that further interpretation and elaboration occurs in which we use our background knowledge to expand our initial interpretation. This process seeks to make an interpretation more coherent and complete by retrieving information from our background world knowledge that is relevant to the interpretation. For example, people might elaborate that an apartment dog is cleaner, smaller and quieter than other dogs. This elaboration generates a rich conceptual combination with emergent features that were not part of the original concepts.

As an extension of the selective modification model, concept specialization can account for more complex combinations. As Murphy explained: “one way to relate these two models is to think of the feature weighting model (selective modification model) as a simpler version or subset of the specialization model. That is, the specialization model is very similar in the way it deals with simple features, but it adds another layer of conceptual operations – the elaboration based on world knowledge” (Murphy 1988 p.535). However, later researchers noted two major issues in this model’s explanation.

First, the concept specialization model can account for limited types of interpretations (Costello & Keane, 2000; Wisniewski & Gentner, 1991). The model can only account for conceptual combinations where the head and modifier concepts are linked by some kind of thematic relation, but ignores the possibility of property-based interpretation. Wisniewski &

Markman (1993) used the example *robin hawk* to illustrate. *Robin hawk* could be interpreted as “a hawk that preys on robins”, by filling the Preys slot in the schema representation of *hawk* with the modifier name. The meaning generated this way explains the thematic relation between *hawk* and *robin*. However, it does not allow for properties of the modifier to be transferred into the head representation. This means that an interpretation such as “a hawk with a red breast” cannot be explained by this model.

Second, the process of concept specialization is worth further scrutiny. The model suggests that people attempt to place the modifier into the best fitting slot in the head noun’s schema. However, beyond a metaphorical description, the mechanisms involved in cognitively “filling a slot” are not specified in the model. Intuitively, it is not the whole modifier concept that fills the slot in the head concept. For example, the meaning of *apartment dog* does not result from the whole concept of *apartment* filling the Habitat slot of *dog*, but only certain aspects of *apartment*. The concept of *apartment* has its own rich and complex schematic structure, potentially including dimensions related to rent, size, storey, apartment number, landlord, etc. None of these dimensions would be relevant to the Habitat slot of the concept *dog*, but what happens to them in the slot filling process is not clear.

2.4. Dual-Process Model

Wisniewski (1997a, 1997b, 1998, 1999) proposed the dual-process model as a successor to address some of the weaknesses in the concept specialization model and to account for a wider range of empirical data. The model assumes that concepts are represented by a schematic structure, and proposes three general types of conceptual combination: property-based, relation-based, and hybrid interpretations. “*Relation-linking* interpretations involve a relation between the referents of the modifier and head concepts. For example, people sometimes interpret *robin snake* as ‘a snake that *eats* robins’. In *property* interpretations, people assert that one or more properties of the modifier concept apply in some way to the head concept, as in ‘snake with a *red underbelly*’, for *robin snake*. A third, less frequent type of interpretation is *hybridization*. These interpretations refer to a combination of the constituents (e.g., a *robin canary* is ‘a bird that is a cross between the two – half robin and half canary’) or to a conjunction of the constituents (e.g., a *musician painter* could refer to someone who is both a musician and a painter)” (Wisniewski 1997b. pp.168-169). The dual process model proposes that these different interpretations arise from two different cognitive processes: relational combinations result from integration (also known as scenario creation), while property-based combinations result from comparison and construction (hybridization may be considered as both).

In a process similar to Fillmore’s (1968, 1976, 1982) case and frame grammar, scenario creation generates a relation-based interpretation, “...creating a plausible scenario involving the constituents of the combination. ... For example, a plausible interpretation of *truck soap* is ‘soap for cleaning a truck’, because *truck* can be bound to the *recipient* role of *cleaning* (i.e., the thing being cleaned), while *soap* to the *instrument* role (what is used to do the cleaning)” (Wisniewski, 1997b. p.174).

Property-based interpretations start from comparing commonalities and differences between the head and modifier concepts along comparable dimensions, and selecting a property from the modifier to apply to the head. When multiple differences are found, several

factors regulate the choice of the best property to be transferred to the head concept, including the communicative context, the salience of the property, cue and category validity, and plausibility. After comparison, the selected property is used to construct a new version of that property for the combined concept. “The new property must bear enough resemblance to its source in the modifier so that people can determine how the modifier contributes to the meaning of the combination... at the same time, the construction of the new property must not alter the head noun concept in such a way that it destroys its integrity” (Wisniewski 1997b, p.176). For example, “in interpreting *fork spoon*, people could begin by aligning the *handle* of *fork* with the *handle* of *spoon*, and the *end* of *fork* with the *end* of *spoon* and note an important difference: forks have prongs on their ends but spoons have ‘little bowls’ on their ends... the comparison process identifies where in the representation of *spoon* the property ‘has prong’ can be incorporated (on the *end* of *spoon*). However, there is a conflict between mentally connecting this property to the *end* of *spoon* and staying within the referential scope of *spoon*... People can resolve this conflict by mentally attaching the prongs to the end of the little bowl and shortening them or by mentally attaching the prongs to the top of the spoon” (Wisniewski, 1997b. pp.176 - 177).

The dual-process model extends the concept specialization model by providing an explanation of different types of interpretations, by accounting for processes involved in property-based conceptual combinations, and by synthesizing schema based theories of conceptual combination into one model. However, critics of the dual-process model have argued that it lacks a detailed explanation of the underlying cognitive mechanisms involved. For example, Costello and Keane (2006) noted that “the elaboration or construction process ... is clearly a very complex process that is, as yet, unspecified” (p.334). Similarly, Murphy (2002) pointed out that “what is not yet known is the online process by which one of these interpretations is constructed / selected. The feature-mapping process involves comparing the two concepts, identifying a feature of the modifier that could be plausibly transferred over to the head noun, and carrying out that transfer. The slot-filling process involves seeing whether there is a relation available in the head noun that the entire modifier could fill, and then constructing that relation. Furthermore, both of these are complicated by the possibility of construal (e.g., interpreting *skunk* as referring to a bad smell), which allows many more ways of possibly relating the concepts. How all these alternatives are considered (or if they aren't, how they are ruled out) is at this point not clear” (pp.458 - 459).

2.5. Interactive Property Attribution Model

The interactive property attribution model was proposed by Estes and Glucksberg (2000) as an extension of Wisniewski's dual process model. Specifically, this model provides an explanation of property-based interpretation by suggesting that it is not similarity between component concepts, but feature interactions between the head and modifier, that guide property-based interpretations. By assuming a schematic representation of component concepts, the model proposes that “the modifier and the head play different, but equally important, roles: The head provides relevant dimensions, whereas the modifier provides candidate properties for attribution. For example, in the combination *shark lawyer*, the head concept *lawyer* provides relevant dimensions for attribution (e.g., TEMPERAMENT, COMPETENCE, COST, etc.), and the modifier *shark* provides salient candidate properties

(e.g., “predatory,” “aggressive,” and “vicious”) that can be attributed. ... (In the interactive property attribution model ..., instead of exhaustively aligning the dimensions and comparing the features of the two concepts, people align the relevant dimensions of the head with salient properties of the modifier” (Estes and Glucksberg 2000, pp. 29 - 30).

The interactive property attribution model made two important extensions beyond previous models. First, it proposes that the head and modifier do not need to exhaust their complete list of dimensions for comparison and alignment as suggested by dual-process model; instead, only certain dimensions of the head concept are activated which are relevant to salient properties of the modifier. The second extension is the observation that relevance and salience of dimensions and features are context-dependent, rather than context-independent as assumed by most previous models. That is to say, “a salient feature of a modifier may increase or even introduce the relevance of a dimension in the head concept, and vice versa. For instance, NUMBER OF LEGS is not a particularly relevant dimension of *table*, since almost all tables have four legs. However, that dimension becomes relevant in the combination *octopus table*, when interpreted as a table with eight legs” (Estes and Glucksberg 2000, pp. 30).

The preceding five models of conceptual combination have been reviewed chronologically according to their first appearance in the literature, because each can be regarded as an extension or replacement of previous models, which addresses prior limitations and offers increasing explanatory power. The remaining five models to be reviewed were proposed over a similar time-frame, and emphasized particular aspects of the conceptual combination process, but were not proposed as explicit extensions of previous models.

2.6. Amalgam Theory

Thagard (1984) proposed a theory of conceptual combination within the context of philosophical investigations on the phenomenon of scientific concept development. It is “a theory of how new concepts can arise, not by abstraction from experience or by definition, but by conceptual combination. Such combination produces a new concept as a non-linear, non-definitional amalgam of existing concepts” (Thagard, 1984 p.3). The basic claim of amalgam theory is that “conceptual combination requires mechanisms for reconciling the conflicting expectations contained in the candidate concepts” (Thagard, 1984 p.4).

Using formalized language, this theory assumes a schematic representation of concepts (the paper adopted the term “frame” from Minsky 1975) with slots and values (i.e., each concept has slots C_i with values $C_{i,1} \dots C_{i,n}$), and proposes that a new concept C_3 is formed from initial concepts C_1 and C_2 by selecting from $C_{1,j}$ and $C_{2,k}$, a subset of slots $C_{3,m}$ for combined concept C_3 . Thagard proposed six procedural rules to regulate the process of slots and value selection. For example, “a concept concerning a kind of physical object which has a value for size is also likely to have a value for weight. Conceptual combination should preserve such linkages” (p.7). Other rules propose that if a slot is chosen by conceptual combination, the value of the slot will depend on the adjectival concept, the variability of the concept, specific examples of the combination, or the representativeness of given instances of the combination. Specifically, the theory proposed that when we try to reconcile conflicting slots, we tend to favor those that contribute to desired problem solutions. For example,

“suppose that in forming the combined concept of a Canadian violinist you notice that your friend the Canadian violinist prefers hamburgers to classical French cuisine. In order to explain this preference, you may add the default expectation about Canadians to your frame for Canadian violinist, overruling the expectation derived from the frame for violinists” (Thagard, 1984 p.9). To reconcile the conflicting preference of food by *Canadian violinist*, we favor the connotation that “Canadians usually prefer hamburgers” to resolve the conflict that was brought in by *Canadian* and *violinist* (who supposedly prefer classical French cuisine).

Amalgam theory was the first model to suggest that conceptual combination is a kind of problem solving process of reconciling conflicting expectations contained in the candidate concepts. This general line of thinking is consistent with Thagard’s (1997) later theorizing of coherence on this problem (to be discussed below). The six procedural rules specify how features of the candidate concepts and empirically observed instances are reconciled into a non-conflicting set for the new, combined concept. However, how these rules might be implemented cognitively is not specified by the theory. Further, the theory emphasizes the importance of specific examples in resolving the conflicting expectations contained in our component concept schema. For example, four of the six rules are example-driven procedures, in which empirical observations influence the meaning of a combination. However, some conceptual combinations do not have ready-made examples, especially novel combinations such as triangular basketball or tasty computer. How conflicting expectations are reconciled for such novel combinations needs more theoretical exploration.

2.7. Composite Prototype Model

Hampton proposed the composite prototype model (Hampton 1987, 1988, 1989, 1990, 1991) at about the same time as Murphy proposed the concept specialization model. The model assumes that concepts are represented schematically as sets of attributes connected by theory-driven relations. For example, we might know that birds have wings and can fly (attributes) and that having wings is an enabling condition for flight. Attributes are assumed to have a quantitative “degree of definingness” called Importance[‡]. “At the top end of the scale of attribute importance there may be some attributes which are so important as to be necessary for category membership. For example HAS GILLS may be treated as a necessary attribute of FISH” (Hampton 1991 p.106).

Based on these assumptions, Hampton proposed that “a conjunctive concept is then represented semantically by a composite prototype... which is formed as the union of the sets of attributes from both ‘parent’ (constituent) concepts. Thus initially the concept PET FISH will have all the attributes of both PET and FISH prototypes” (p.107). The combined set of attributes is then modified based on a necessity constraint, which specifies that a necessary attribute of one constituent concept will also be a necessary attribute for the conjunctive. For example, if has gills is necessary for fish, then it will also be necessary for pet fish. For non-necessary attributes, their importance is determined as a monotonic positive function of

‡ The notion of importance has been proposed as definingness (Smith, Shoben, and Rips, 1974), cue validity (Murphy, 1982), diagnosticity (Smith & Osherson 1984) or centrality (Barsalou & Billman, 1989). It reflects the relative likelihood of an item belonging to a category given that it does or does not have the particular attribute.

importance for each constituent concept and attributes with low average importance will be dropped from the conjunctive set.

After forming the set of attributes for a conceptual combination, a consistency checking procedure is applied, and “(w)here there are incompatible attributes, a choice has to be made to delete certain attributes” (p.107). The consistency constraint incorporates several rules. When a non-necessary attribute of a constituent concept has a conflict with the necessary attribute of the other constituent concept, it will not be used by the conjunctive. “For example, if PETS typically breathe air, but this is inconsistent with living underwater, which itself is necessary for the concept FISH, then breathing air will not be possible for PET FISH” (p.108). When the conflict is between two necessary attributes of two constituents, then the conjunction is an empty set - a “logical impossibility” (p.108). “When the conflict involves two non-necessary attributes, then the choice of which to delete will depend on their relative importance, on the overall consistency that can be achieved with respect to the other inherited attributes, and on the context in which the phrase is being used” (p.108).

The composite prototype model contributes by proposing the necessity and consistency constraints, which exhibit a strong pragmatic orientation. This model is applicable to both novel and mundane combinations. As Hampton (1991) explained, “the proposed model could be applied to the conjunction of well-defined concepts with a core of common element defining features, with the desired results. The necessity constraint would ensure that all defining features of each concept remain critical for the conjunctive concept, and the consistency constraint would ensure the correct identification of nonoverlapping sets. Well-defined concepts would therefore require no different treatment in the model” (p.108).

It is notable that this model bears some similarity to fuzzy set theory, in that the union of the attribute sets of constituent concepts corresponds closely with the intersection of the extensional sets denoted by each constituent concept. Hampton’s model can, therefore, be viewed as a kind of extension of fuzzy set theory by suggesting cognitive processes involved in the intersection of extensional sets. It also bears similarity to Wisniewski’s hybridization interpretation whereby the meaning of a conceptual combination is taken to be a hybrid of the constituent concepts.

2.8. Constraint Model

The constraint model was proposed by artificial intelligence scholars Costello and Keane (1997a, 1997b, 1998, 2000, 2001). This model focuses on the efficiency of the conceptual combination process based on pragmatic principles, which have been implemented as a computational model called C3. The following will focus on the theoretical model and ignore technical details associated with its computational implementation.

Similar to other models, the constraint model assumes that concepts are represented in a schematic structure. When people understand a novel combination, they construct a combined concept to represent that combination. In the process of combining, people assume that everyone involved in the communication follows the cooperative principle as theorized by Grice (1975). “Three constraints ... follow from this assumption. By following these constraints the listener can construct the correct concept as intended by the speaker” (Costello 2004). The first constraint is called plausibility. Because it is assumed that everyone in the communication is cooperating, the intended combined concept should be something the

listener already somewhat knows. Thus the listener assumes that the new combined concept must describe something plausible which is similar to things the listener has seen before. The second constraint is called diagnosticity. Because the speaker is assumed to be cooperating, the intended combined concept is one best identified by the two words in the phrase (otherwise the speaker would have selected other words). Thus the listener knows that the new combined concept must contain some properties which are best identified by (that is, are diagnostic of) each word in the phrase. The third constraint is called informativeness. Because the speaker is cooperating, the intended combination is one for which both words in the phrase are necessary (otherwise the speaker would have used fewer words). Thus the new combined concept must be more informative than either of the constituent words. Costello illustrated his idea with the example of *shovel bird* understood as “a bird that has a flat, wide beak like a shovel, for digging worms” (2004). In this case, the listener constructs an understanding with the diagnostic properties of *shovel* (flat, wide, and used for digging) that is something plausible (bird digging worms) and informative (flat, wide beak).

The constraint model contributes by emphasizing pragmatic principles and addressing the possibility of multiple interpretations for novel combinations and how different interpretations are selected. For this reason Costello (2004) describes the model as a pragmatics of conceptual combination. Theoretically, however, it is notable that Grice discussed cooperation in communication in relation to four cooperative principles (quality, quantity, relevance, and manner), to explain how listeners could arrive at a speaker’s meaning and why speakers could mean more than they said. Grice argued that it is a violation of the cooperative principles that produces extra meaning not contained in what is said. Although the constraint model borrows the general idea of cooperation, the proposed plausibility, diagnosticity, and informativeness constraints do not correspond directly to Grice’s four cooperative principles. Thus, whereas many communicative and pragmatic constraints may influence human cognition, why these particular three are emphasized by Costello & Keane is not clear.

2.9. Coherence Theory

Thagard (1997) proposed a coherence theory of conceptual combination following the basic line of thinking in his 1984 paper that conceptual combination involves solving a problem by reconciling conflicting expectations contained in the candidate concepts. The basic argument of coherence theory is that elements in a conceptual system (concepts, propositions, parts of images, goals, actions etc.) can cohere (i.e., fit together) or incohere (i.e., resist fitting together; Thagard, 1989, 1997, 1998). If two elements cohere, there is a positive constraint between them. Otherwise, there is a negative constraint between them. “A positive constraint between two elements can be satisfied either by accepting both of the elements or by rejecting both of the elements. A negative constraint between two elements can be satisfied only by accepting one element and rejecting the other. The coherence problem consists of dividing a set of elements into accepted and rejected sets in a way that satisfies the most constraints” (Thagard & Verbeurgt 1998 pp.2-3). Conceptual combination is therefore viewed as an “instance of coherence conceived of as maximization of constraint satisfaction” which “requires us to apply some concepts to a situation and withhold other concepts in such a way as to maximize the overall satisfaction of the constraints determined

by the positive and negative associations between the concepts” (Thagard 1997). In practice, Thagard models such problems by constructing a constraint network with elements of all possible inferences of the head and modifier concepts. He then uses certain connectionist algorithms to propagate association weights in a way that maximizes coherence by accepting some elements and rejecting others. The output is “an interpretation of the relation between the head and modifier, as well as a collection of inferences about the object denoted by the head as characterized by the modifier. If the most coherent interpretation is nevertheless not very coherent, then move to other mechanisms such as analogy and explanation that produce incoherence-driven conceptual combinations” (Thagard 1997).

Thagard (1997) used racial stereotypes associated with the conceptual combination *well-dressed black* to illustrate. He suggested that people confronted with this combination might activate a network of associated concepts such as *aggressive* or *poor ghetto inhabitant* for *black*; and *businessman*, *not poor* and *not aggressive* for *well-dressed*. The positive constraints in this network include the associations that ghetto blacks are aggressive, while negative constraints include the negative association that ghetto blacks tend not to be businessmen. Apparently, this is not a coherent network. To understand the meaning of this combination, we need to come up with the most coherent interpretation, which best satisfies the constraints. A connectionist algorithm is used to maximize coherence by rejecting *aggressiveness*, resulting in the interpretation of *well-dressed black* as “a black businessman who is not an aggressive ghetto black”.

Different from his earlier amalgam theory, Thagard’s coherence theory does not depend on schematic concept representation and uses connectionist logic to achieve coherence rather than a system of logical rules. Perhaps the most important contribution of this theory to the field of conceptual combination is the explicit orientation toward coherence and consistency in a cognitive network. The basic assumption is that a conceptual network tends to evolve toward a more stable and harmonious state through “the maximal satisfaction of multiple positive and negative constraints that is achieved by some parallel constraint satisfaction algorithms” (Thagard & Verbeurgt 1998 p.1). As such, coherence theory exhibits a basic assumption of goodness-of-fit or harmony as emphasized by Gestalt psychology. However, as explained by Thagard (1997), the current coherence-driven constraint-satisfying model has difficulties explaining non-predicting combinations such as *apartment dog* and incoherence-driven novel combinations like *web potato* where meaning may be motivated not by coherence but by the failure to find coherence. Finally, the connectionist algorithms used in coherence theory are not a direct reflection of mental activity, but a simulated approximation of the mind.

2.10. CARIN Model

The Competition Among Relations In Nominals (CARIN) theory (Gagné, 2000, 2001; Gagné & Shoben, 1997, 2002) provides a model of conceptual combination that uses our prior experience of the kinds of thematic relations that words have in compounds to predict what interpretations people will produce, and what compounds people will find easiest to understand. In linguistics, thematic relations between two words in a compound have often been examined by developing taxonomies of relations required for interpreting combinations (Kay & Zimmer, 1976; Gleitman & Gleitman, 1970; Downing 1977; Levi, 1978). For

example, Levi (1978) identified 15 thematic relations (such as Cause, Has, Make, For, Is, Use, About, etc.) to classify the meanings of many familiar compounds.

Unlike models which use a feature based schematic representation of concepts, the CARIN model assumes a kind of schematic representation of the relations between concepts. That is to say, it assumes a slot-type structure where slots are not features of the concept but of the kinds of thematic relations it can have with other concepts. The internal feature representation of concepts is largely irrelevant in this model, where the goal of conceptual combination is to fit compounds into existing relational templates. Specifically, the model argues that people possess distributional knowledge based on their experience of how often particular relations are used with particular concepts, corresponding with variable relation strengths for concepts. These relations “compete for the interpretation of the combined concept and ... the difficulty of interpretation is a function of the relative strength of the selected relation. ... Interpretations are easier if the required relation is of high strength than if the thematic relation is of low strength. Other things being equal, it is easier to arrive at the correct interpretation for *mountain stream* than it is for *mountain magazine* because the Locative relation has a greater strength relation than does the About relation” (Gagné & Shoben, 1997 p.81). Thus combinations involving typical thematic relations will be easier to understand than those involving atypical relations.

The CARIN model proposes a linguistic taxonomy of 16 thematic relations between component words, including Cause, Has, Make, For, Is, Use, Located, etc. By paying attention to the kinds of thematic relations that words assume and adding weights to these relations, the model predicts the priority between different thematic relations when constructing an interpretation for a compound. The model differentiates between the roles of the head and modifier concepts and, unlike other models which primarily emphasize the head concept, CARIN places most emphasis on the modifier by suggesting that it selects a thematic relation for the compound during the combination process. It is easy to conclude, however, that the 16 relations proposed in the model are too abstract to capture the variety of meaningful interpretations that can arise in conceptual combinations. For example, the combinations *birthday cake* and *bravery medal* share the For relation between their components. However, treating these as the same relation overlooks crucial differences between the interpretations of For in these two combinations: a birthday cake is a cake *used for the purpose of* celebrating birthday while a bravery medal is a medal rewarded *because of* bravery. The relations denoted by simple words such as Make or For imply very complex meanings corresponding to complex conceptual structures. Using this complex conceptual structure to link two concepts will inevitably result in a rather vague interpretation. In general, each of the 16 proposed relations is itself a category of diverse relational meanings, which lacks the precision to account for particular interpretations of conceptual combinations.

3. AGREEMENTS AND CONTROVERSIES – AN ANALYTICAL FRAMEWORK

The preceding review demonstrates that conceptual combination research has produced a variety of theories with different emphases and terminology. As such it is impossible to

compare and contrast every aspect of the literature in this paper. However, we will use a relatively coherent analytical framework to summarize the major issues related to conceptual combination and to provide a basis on which to compare and contrast the models and theories in an integrative way. The framework consists of four dimensions reflecting major characteristics of the various models: (1) the causal role of schemata in the model; (2) the role of cognitive harmony or consistency in the model; (3) the pragmatic orientation of the model; and (4) the explanatory scope of the model. In addition to using the framework to summarize major characteristics of the models, we will also provide a critical analysis and challenge some of the fundamental assumptions related to these four dimensions. Table 1 summarizes major characteristics of the ten models in relation to our framework.

3.1 The Causal Role of Schemata

Perhaps the most prominent aspect of the conceptual combination literature is that most models rely on schema theory in two ways. First, most models assume a schematic representation of conceptual structure. Except for fuzzy set theory and coherence theory, all of the current models assume a schematic representation of noun concepts as dimension-value pairs. Although the CARIN model emphasizes thematic relations between the two constituent concepts, if thematic relations are understood as a kind of dimension reflecting how concepts connect with one another, then there is not too much difference between feature-based schema models and thematic relation models. Second, schemata play a causal role in the cognitive mechanisms proposed by many of the models, where conceptual combination is understood in terms of certain cognitive operations that take place along dimensions in the schema. For example, the selective modification, concept specialization, dual process, CARIN, and interactive property attribution models all propose cognitive processes related to the idea of slot-filling, where a modifier, or some aspect of a modifier, fills a slot in the head concept schema. Schemata play a different causal role in the composite prototype model, which proposed mechanisms of composing a schema to represent the conceptual combination from the union of the prototypical attributes of both component concepts, based on necessity, importance, and consistency constraints. Only the constraint model appears to assume a schematic concept representation, which plays no obvious causal role in the operation of its three proposed constraint mechanisms (plausibility, diagnosticity, and informativeness).

Despite their fundamental roles in current theories of conceptual combination, several questions could be raised about the nature of schemata and the workings of associated cognitive processes such as slot filling. The causal role of schemata in current theories of conceptual combination is based on several problematic assumptions: 1. Schema represents our fundamental conceptual structure, independent of communicative context; 2. Pre-existing schema dimensions and values are necessary, sufficient, and exhaustive for cognitive processing; 3. The weights associated with a schema's dimensions and values are absolute and will carry over to any cognitive processing task. There are issues related to each of these assumptions.

The first assumption, that schema represents our fundamental conceptual structure, deals with the nature of schema as either intrinsic to our cognition or retrospectively imposed. Schema theory describes "how knowledge is represented and about how that representation facilitates the use of the knowledge in particular ways" (Rumelhart 1980 p. 34). Schema

theory assumes a logical structure to organize knowledge in the human mind, in which features are organized at a lower conceptual level relative to the super-ordinate dimensions. This structure seems to match our intuitive experience: when we think about a concept, we may feel that it is logically related to other concepts in a manner similar to the dimensions or values proposed by schema theory. For example, we may know that apples are typically red and that red is a color, so the concepts *apple*, *red*, and *color* have a logical relationship that could be described by an *apple* schema consisting of a dimension/slot *color* with value *red*. However, the fact that we understand these concepts as being logically related to one another does not necessarily imply that our minds represent them in such an organized manner in permanent memory. It is possible that our minds represent knowledge in less structured ways and that logical structure is imposed after the fact, as part of online processes of thinking about these concepts and the logical relations between them. Hierarchical concept taxonomies serve situation-specific purposes or goals, suggesting that they may be created or activated online in response to communicative context, rather than permanently stored in memory. *Red* might be a subordinate concept within an *apple* schema if we are selecting fruit at the supermarket, but *apples* might be subordinate to *red* if we are classifying objects based on color, and *red* might be irrelevant to *apple* if we are thinking metaphorically about New York City.

The second assumption that a schema's pre-existing set of dimensions and values are necessary, sufficient, and exhaustive for cognitive processing is quite problematic. The fact that we can quite easily make sense of novel combinations counters such a view. For example, the novel combination *smart apple* has the same structure as the more mundane *red apple*, but it is hard to imagine that our schematic knowledge of *apple* would include an intrinsic dimension/slot for *intelligence* with different values in *smartness*. How many dimensions are needed to account for all of the possible knowledge that we have regarding a concept and for all potential conceptual combinations? How would we know whether a limited number of dimensions such as *color*, *shape*, *texture*, etc. would be capable of representing our complete knowledge of the concept *apple*? What about social concepts such as *country* and *suicide*, or abstract concepts like *love* and *hate*? How should we determine a necessary, sufficient, and exhaustive set of slots/dimensions for these kinds of concepts? Apparently, certain extra dimensions or associations must be activated and constructed online in the process of conceptual combination, rather than being stored in memory independent of context.

By the same token, many schema dimensions may be eliminated or filtered out in the process of conceptual combination. It was observed earlier that the specific cognitive mechanisms involved in filling a slot are not specified by any of the current models of conceptual combination. The example of *apartment dog* was used to illustrate that the modifier concept *apartment* is at least as complex in structure as the head concept *dog*, including potential dimensions related to rent, size, storey, apartment number, landlord, etc., yet most of these are irrelevant to the meaning of this combination. Thus, if *apartment* fills a *habitat* slot in *dog*, is it the entire complex modifier concept that fills the slot? Or is much of this conceptual structure filtered out during the combination process, and if so, how does this filtering process work? In general, most current models place primary emphasis on the structure of the head noun schema and overlook both the potential complexity of the modifier schema structure and theoretical difficulties associated with the slot filling process.

The third assumption, that the weights associated with dimensions and values in a schema are absolute and will carry over to any cognitive processing task, deals with the way that the importance, saliency and diagnosticity of an attribute are evaluated in various models of conceptual combination. In some of the models, the importance and diagnosticity of an attribute are evaluated within the concept itself and treated as an absolute value. Thus, if certain attributes are most central for category membership, they will be assigned a higher weight which will be carried over to the combination. However, when combining concepts, the importance of an attribute is not just related to individual concepts alone. The weight of an attribute seems to vary in relation to the context in which the concept is used. In other words, diagnostic and important features of a concept depend on the set of other concepts that are salient at the time of use and should not be evaluated just within a single concept. For example, when the meaning of the novel combination *chocolate computer* is understood as “a chocolate shaped like a computer”, most of the attributes of *computer* are dropped regardless of how important they might be for the individual concept, and the importance of the dimension *shape* increases from a low weight to the much higher value for this combination.

Based on this analysis of assumptions underlying schema-based models, we would argue that a schematic representation of conceptual structure is insufficient to account for the complexity of conceptual combination. Pre-existing schema dimensions and values cannot provide a necessary, sufficient, and exhaustive set of knowledge resources appropriate to the required cognitive processing. A different model of how conceptual information is stored and processed in the mind is needed to address the preceding limitations. In this respect, Thagard’s coherence theory may suggest a potential alternative in that its proposed cognitive mechanisms do not depend on a priori schematic conceptual structure. Instead of an overly restrictive schematic representation, a connectionist framework requires only that networks of associated concepts are activated online during cognitive processing.

3.2. The Role of Cognitive Harmony or Consistency

The second dimension of our analytical framework considers the role of cognitive harmony or consistency in conceptual combination. When we combine two previously unrelated concepts, there might be conflicting connotations, expectations, and attributes contained in the component concepts that need to be reconciled before a coherent understanding can be generated. For example, in the combination *television cellphone*, the first concept *television* might bring in the attributes of *large screen* and *a remote control*, which would conflict with attributes of the second concept *cellphone* such as *small screen* and *no remote control* respectively. Three conceptual combination models (amalgam theory, coherence theory, and composite prototype model) propose explicit consistency checking mechanisms for combining concepts with conflicting expectations to generate a meaning that is coherent, consistent and harmonious. Amalgam theory proposes six procedural mechanisms by which features from candidate concepts and instances are reconciled into a non-conflicting set for the new, combined concept. The composite prototype model proposes mechanisms that focus on how necessary attributes of head and modifier influence the meaning of the combined concept. Coherence theory proposes parallel weight propagation among elements in a conceptual network to maximize coherence. Two other models (the concept specialization and dual-process models) discuss the issue of consistency implicitly by

suggesting that world knowledge is used to construe or clean up conflicts in the combined concepts.

Consistency is discussed intuitively without an explicit operationalization in most of these models, but Hampton proposed a means of empirically estimating attribute coherence scores as part of the composite prototype model. For example, “the PET and BIRD attributes were set up as rows and columns of a two-way matrix, and ... subjects ... were instructed to take each row attribute in turn and to rate it against each column attribute using a scale from +2 meaning can occur together, to -2 meaning impossible to occur together ... For each attribute, an average coherence score was calculated, based on the mean ratings given to the attribute, averaged across subjects and across the attributes of the other concept” (Hampton, 1987, pp. 66). This is a useful contribution in that it provides a way to measure the degree of consistency empirically, rather than relying on an intuitive notion of consistency, and in the case of coherence theory could be used to validate connectionist simulation models.

Consistency and harmony issues are usually approached from the connectionism and consistency perspectives in cognitive psychology. Connectionism began in the field of artificial intelligence with the goal of understanding cognition by viewing the brain as a network of interconnected neurons (Rumelhart et al. 1986). Connectionist models consist of interconnected and distributed processing units that perform simple computations concurrently transforming inputs into outputs to neighboring units. Thagard’s coherence theory follows this connectionist tradition in terms of the basic assumptions of goodness-of-fit or harmony. The idea of harmony in connectionist approaches is also very similar to what has been historically called cognitive balance or consistency in the psychological literature. Consistency theories began in 1940s and include a group of theories that were proposed in attempts to “uncover the structural-dynamic characteristics of human cognition” (Simon & Holyoak 2002, p.283) towards consistency. “These conceptions, symmetry, consonance, balance, and simplicity, are, of course, implied in that idea with which Gestalt theory started and which always was central to it, namely, the idea of a ‘good’ figure... this model implies a number of different entities with certain properties and standing in certain relations, which make up a constellation of factors tending toward a standard (consistent) state” (Heider, 1960 p.168).

The basic assumption of these theories is that inter-related cognitive elements tend to form a stable structure, whereas inconsistent elements are associated with psychological tension and a tendency towards reestablishing stability or harmony. Conceptual combination could be understood as forming a stable structure of attributes associated with two component concepts, such that conflicting attributes associated with each concept are reconciled. Particularly in the case of novel combinations, perceived inconsistency among attributes may be associated with tension and psychological forces to reorganize the cognitive elements into a more balanced or harmonious state. For example, we might interpret *elephant fish* as “a fish with a trunk,” but nonetheless experience some residual psychological imbalance or discomfort in relation to this constructed meaning. The remaining imbalance comes from perceived inconsistency between this constructed interpretation and a larger cognitive field associated with our background knowledge of concepts associated with *elephant* and *fish*. In this circumstance, it is likely that further cognitive effort beyond the initial interpretation will be exerted to make the larger field harmonious. What cognitive mechanisms are involved in reducing discomfort and making the system of attributes coherent and harmonious? How do we empirically examine the state of harmony before and after a combination? How could the

tradition from consistency theories and connectionist models be carried over to the research of conceptual combinations so that we do not re-invent wheel when proposing explanations? Future models of conceptual combination should address these sorts of questions.

3.3. The Pragmatic Orientation

The third dimension in our framework considers the pragmatic orientation of conceptual combination models. Studying how people construct and understand a conceptual combination is largely the study of how meaning is constructed and communicated in the context of a two-word combination. There are two senses of meaning in this situation: the semantic meaning and the pragmatic meaning. Semantic meaning refers to the literal meaning or the informative intent of an expression, whereas pragmatic meaning refers to the implied meaning or the communicative intent of the expression. A nice way to think about the difference is that semantics considers “what X means”, while pragmatics considers “what a speaker means by saying X”. Five of the models reviewed (amalgam theory, concept specialization model, dual process model, constraints theory, and interactive property attribution model) consider pragmatic aspects of the communicative context in their explanation of conceptual combination, where communicators might cooperate to achieve intended meaning, use context and general knowledge to contribute to the meaning of the combination, or make sense of the combination in terms of judging the plausibility, intention, goal, and appropriateness of the combined concepts. However, the degree of emphasis and the focus on pragmatic principles varies greatly between the five models.

For example, amalgam theory proposed that there are three kinds of conceptual combinations, pure, data-driven, and goal-directed, based on the degree that context is involved. A context could consist of prospective instances of the new combined concepts, or of a goal of solving a problem by reconciling the conflicting expectations contained in the candidate concepts. The interactive property attribution model discusses only the linguistic context of the combination, involving the collocation and pairing of words in the combination, rather than a broader communicative context that might contribute to the construction of a plausible and appropriate meaning. The concept specialization model does not consider how context or communicative intent contribute to meaning, but relies heavily on the concept of “background knowledge” to explain the plausibility and appropriateness of the meaning of combinations. As a direct descendent of the concept specialization model, the dual-process model has a stronger pragmatic orientation and discusses how context, plausibility, informativeness, and definingness contribute to comparison processes and the construction of combined meaning. Costello and Keane’s (2000) constraint model explicitly proposed three pragmatic constraints that influence conceptual combination – diagnosticity, plausibility and informativeness – and implemented them in a computational simulation. However, the underlying cognitive mechanisms that might correspond to these constraints are very vague. In computer simulations, for example, Costello and Keane operationalized the informativeness constraint as the appearance of a new predicate that was not contained in the prototype of the head concept but whether similar processes might operate in the mind is unknown.

Constructing the meaning of a conceptual combination involves numerous factors, among which the communicative context is undoubtedly one of the most important. Conceptual

combination is largely a problem of communication, where someone intends to communicate a meaningful message to others with a certain context. Pragmatics provides useful tools to help conceptualize this process. However, current models that include pragmatic considerations generally lack detailed explanations of how pragmatic factors function cognitively. For example, Murphy proposed that knowledge serves two functions in the concept specialization model. “First, outside knowledge must often be consulted in order to decide which slot is the appropriate one to specialize... the second reason for consulting outside knowledge is to elaborate or clean up the concept in order to make it more coherent and complete” (Murphy 1988 p.533). However, 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. Similar observations could be made about variables such as context, appropriateness, and relevance in various models. These pragmatic factors have face validity, but the cognitive mechanisms underlying them are in need of more detailed specification.

One reason such cognitive mechanisms may be difficult to specify is an apparent assumption that pragmatic constructs such as context or knowledge require a different representation and treatment than that used for conceptual meaning. Is it possible that we could treat meaning, context, and knowledge in more or less the same way, using a common representational scheme, so that whenever we discuss the meaning of a conceptual combination, we naturally include aspects of context and knowledge in the discussion? Ideally, future models of conceptual combination need to consider how pragmatic factors could be integrated with conceptual meaning in a parsimonious fashion.

3.4. Explanatory Scope

The last dimension of our framework compares the theories of conceptual combination based on the explanatory scope of each model, referring specifically to the following four distinctions: novel vs. mundane combinations, true vs. spurious conjunctives, head vs. modifier roles, and noun-noun vs. adjective-noun combinations. With respect to the first of these distinctions, a mundane combination is the one that is commonly used in everyday language, such as *red apple*, while a novel combination is the one that rarely if ever appears in our daily language, such as *elephant fish*. It has been suggested that novel conceptual combinations are a key source of creative thought, thus several of the models focus on the cognitive processes of combining concepts in novel ways.

For the second distinction, a true conjunctive refers to a symmetric conceptual combination of two component concepts (X and Y), such that the combined concept (XY or YX) represents something that is a member of both category X and Y, regardless of component sequence. On the other hand, if XY and YX have different meanings, they are considered to be spurious conjunctives. For example, if *pet fish* has the same meaning as *fish pet* it is a true conjunctive. Two models of conceptual combination explicitly focus on true conjunctives. In fuzzy set theory the meaning of a combination is defined symmetrically as set intersection (i.e., $X \cap Y = Y \cap X$). In the composite prototype model a particular syntactic structure of “X that is also Y” is used in experiments to ensure that combinations reflected true conjunctives (e.g., “machines that are also vehicles,” “furniture that is also a household

appliance,” etc.). Most of the other theories, however, assume that XY and YX have different meanings and, therefore, focus their attention on spurious combinations.

The third distinction relates to the different roles of head and modifier concepts in contributing to the meaning of a combination. In the current literature, the head noun or head concept (sometimes simply called head) refers to the central word or concept in the combination (usually corresponding to the second word in the combination in the English language). The modifier refers to the word or concept in the combination that changes some aspect of the head (usually corresponding to the first word in the combination in English). Five of the models explicitly discuss the role of head or modifier, but they differ with respect to which concept is believed to contribute most to the combined meaning. The selective modification, concept specialization, and dual process models propose that the head concept dominates the meaning of the combination, while the CARIN model proposes that the modifier dominates by selecting thematic relations for the combination. The interactive property attribution model proposes that both head and modifier contribute equally to the meaning of the combination.

The fourth distinction is between noun-noun and adjective-noun combinations. It is interesting to note that grammatical terminology is often intermingled with cognitive terminology in the current literature. When we define conceptual combination as a combination of two (or more) concepts, we are discussing the cognitive structure of this combination. However, cognitive structure cannot be explicitly discussed without reference to the grammatical structure of words and their relations. Thus in all of the current models, a combination of two concepts equates to a combination of two words. For example, the two-word combination “elephant fish” refers to a combination of two concepts *elephant* and *fish*. Because of this, researchers frequently use grammatical terms to refer to cognitive combinations. Noun-noun combinations, such as “zebra bird,” refer to combinations of two concepts represented by nouns in the English language. Adjective-noun combinations, such as “red apple,” refer to combinations of one noun concept and one adjective concept that, arguably, refers to a feature of the object denoted by the noun. The latter are sometimes sub-categorized into predicating adjective-noun combinations (e.g., “beautiful story”) in which the combination can be re-written into a semantically correct sentence (“story is beautiful”), and non-predicating adjective-noun combinations (e.g., “atomic engineer”) in which the combination cannot be re-written into a semantically correct sentence (i.e., the sentence “engineer is atomic” is meaningless). Except for the selective modification model, most of the current models are intended to explain noun-noun combinations and only a few are adequate to explain adjective-noun combinations.

These four distinctions (novel vs. mundane combinations, true vs. spurious conjunctives, head vs. modifier, and noun-noun vs. adjective-noun) are based on current terminology used in the literature to characterize the explanatory scope of the ten models. However, it should be noted that these distinctions themselves raise certain questions of concern in relation to theorizing about the conceptual combination process.

First, the assumption of the existence of genuinely conjunctive concepts is questionable. Zadeh (1982) assumes that conjunctive concepts are distinguishable from spurious conjunctions and that fuzzy set intersection is applicable only to genuinely conjunctive concepts. Psychologically, if we artificially define concepts strictly in terms of categorical denotations, there may be genuine conjunctives representing something that is both in category X and Y. Hampton (1988) used such a strategy in experiments by directly asking

subjects to think about conjunctives like “machines that are also vehicles.” However, whenever we move to the linguistic level and use two words to denote a conceptual combination (e.g., “apartment dog”), it could be argued that the vast majority of empirically observed conceptual combinations, if not all, are really spurious conjunctives, because our intuitive understanding of the meaning of combination XY is usually very different from the meaning of YX. To repeat an earlier quote, “a desk lamp is a kind of lamp, but a lamp desk is a kind of desk” (Murphy, 2002 p.445). In the communicative context, syntactic constraints function by which one word sub-consciously functions as a logical operator X (i.e., the modifier) while the other word functions as a denotation Y (i.e., the head) such that X transforms Y into the denotation XY. Thus, when conceptual combinations are interpreted within a natural linguistic context and not defined artificially, it seems that there really are no genuine conjunctives and all combinations XY become so-called spurious conjunctives.

Another questionable implicit assumption made by most of the current models is that nouns represent concepts deserving of a rich schematic representation, while other parts-of-speech do not represent concepts and do not need to be represented by a similar cognitive structure. The earlier example of *apartment dog* showed that modifiers (*apartment*) are also rich concepts but, compared to head concepts, modifiers are treated by most theories in much simpler terms as mere slot fillers. In this example, the noun *apartment* acts as an adjective to modify the meaning of *dog*. In general, it is clear that concepts exhibit a greater variety of linguistic manifestations than just nouns, including adjectives, verbs, prepositions, adverbs, etc., which deserve an equally rich representation of their conceptual structure. If the modifier or non-noun component of a conceptual combination does more than just provide a value for a slot of the head noun concept, what might be the appropriate schematic representation of the modifier concept? How do the two schemata of the head and modifier concepts interact and influence one another in the interpretation of a conceptual combination? Future models of conceptual combination need to address these two questions.

Table 1. A summary of the ten models evaluated against the analytical framework.

	Schema		Consistency	Pragmatic orientation	Explanatory scope				
	schematic representation	schema as causal factor			reconciling conflicting expectation	context, intent, plausibility, goal, appropriateness	head - modifier	noun-noun	adjective-noun
Interactive property attribution	yes	yes	no	somewhat	yes	yes	no	novel	spurious
CARIN	yes	yes	no	no	yes	yes		both	spurious
Coherence	no	no	yes	no	no	yes	yes	both	not explicit
Constraint	yes	no	no	yes	no	yes	no	novel	spurious
Dual process	yes	yes	yes	yes	yes	yes	no	novel	spurious
Composite prototype	yes	no	yes	no	not explicit	yes	no	both	true
Concept specialization	yes	yes	somewhat	somewhat	yes	yes	yes	both	spurious
Amalgam	yes	yes	yes	yes	no	yes	yes	both	both
Selective modification	yes	yes	no	no	Yes	no	yes	both	spurious
Fuzzy set	no	no	no	no	no	yes	yes	mundane	true

4 CONCLUSION

Conceptual combination is a fundamental process of human cognition, in which people use two or more concepts to articulate and comprehend more complex meanings than a single concept can denote. Through conceptual combination we develop new ideas, communicate with one another, learn and expand our knowledge. This paper contributes to the study of conceptual combination by comprehensively and critically reviewing ten major models, which have been proposed over the last thirty years by researchers in cognitive psychology, linguistics, artificial intelligence, and philosophy. We have examined fuzzy set theory, the selective modification model, amalgam theory, the concept specialization model, the composite prototype model, the dual-process model, the constraint model, the CARIN model, coherence theory, and the interactive property attribution model. We have summarized the basic arguments of each model and critically examined their major issues and theoretical limitations. In addition, we proposed an analytical framework to compare and contrast the ten models along four dimensions: (1) the causal role of schemata in the model; (2) the role of cognitive harmony or consistency in the model; (3) the pragmatic orientation in the model; and (4) the explanatory scope of the model. We identified areas of agreement and disagreement among the various models and theories. For example, all models assume a communicative purpose for the combination and a correspondence between linguistic words and psychological concepts. Most also agree that the component concepts (modifier or head) play different roles in the conceptual combination process, and interact with one another to generate a meaning in harmony with a person's background knowledge. Different models disagree substantially on the cognitive mechanisms involved, however, and emphasize different aspects of the process.

Finally, we have offered suggestions for future research directed toward the development of a synthesis model of the conceptual combination process. A suitable theory should address the limitations and problematic assumptions of schema theory as a representation of conceptual structure in online cognitive processing. It should accommodate the requirement for cognitive consistency by specifying both the cognitive mechanisms involved in reducing inconsistency and provide empirical methods for measuring the degree of consistency before and after combination. Pragmatic considerations should be integrated with cognitive considerations, such that background knowledge and aspects of the communicative and linguistic context of conceptual combination can be represented consistently with how concepts are represented. Lastly, a complete theory of conceptual combination must account for the diversity of combinations observed empirically (including both novel and mundane), accommodate the different roles of head and modify concepts in the combination process, reflect the conceptual complexity of the full range of linguistic parts-of-speech beyond just head nouns, and account for the interaction of complex head and modify concepts and their relative contribution to meaning during the combination process.

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