A Validation and Exploration of the Collins-Michalski Theory of Plausible Reasoning

D. Boehm-Davis

K. Dontas

R. S. Michalski

George Mason University

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Abstract

Collins & Michalski (1989) developed a descriptive theory pof plausible reasoning that provides a formal framework, a language, and a computational model for describing human plausible reasoning process. This currentresearch was designed to validate the structural aspects of the theory and to examine the impact of world knowledge on the inference process. People were asked to make inferences about one of two domains: one where the subjects may have had prior knowledge that could be brought to bear on the inference process and one where they coud not have such knowledge. The inferences generated were analyzed within the framework of the model. The results suggested that the structural aspects of the original Collins & Michalski model were acequate to account for most of the reasoning patterns observed in the protocols. Further the results suggest that people rely heavily on their personal background knowledge when reasoning about a domain with which they are familiar.

A Validation and Exploration of the Collins-Michalski Theory of Plausible Reasoning

Unlike in formal logic, premises for reasoning in real-life situations are typically incomplete, uncertain, imprecise or indirectly relevant. Yet, humans have a remarkable ability to reason and derive useful conclusions from such imperfect premises. For example, people can find a desired place in a newly visited city from a combination of sketchy directions from a passer-by, imprecise information in a map, and general knowledge of city organization. They are able to integrate various bits and pieces of information from different sources, resolve contradictions if they occur, and derive the most likely conclusion.

Collins and Michalski (1989) developed a core theory of plausible reasoning that provides a formal framework, a language and a computational model for describing human plausible reasoning processes. It is a descriptive theory that tries to characterize observable aspects of human reasoning, in contrast to normative theories, which treat reasoning as a formal mathematical theory (e.g., Smets et al., 1989). The normative theories are strongly anchored in formal logic, and include probabilistic reasoning (Pearl, 1988; Nilsson, 1986), non-monotonic reasoning (McCarthy, 1980), default reasoning (Reiter, 1980), fuzzy logic (Zadeh, 1965), and multiple-valued logic (Lukasiewicz, 1967). The primary objective of these theories is to investigate parametric aspects of reasoning, i.e., to develop methods for determining the certainty of conclusions on the basis of the certainty of the premises, without investigating the meaning of the premises. In contrast, the proposed theory attempts to investigate semantic aspects of reasoning, and combine them with parametric aspects. The latter are captured by a collection of different parameters that have influence on the certainty of reasoning, such as typicality, frequency, dominance, dependency, etc. The theory includes a variety of inference patterns that do not occur in formal logic-based theories.

The present research has two primary objectives. First, the research was designed to validate the structural aspects of the theory and to determine what enhancements or extensions

might be needed to account for the data. Second, the experiments were designed to examine the impact of world knowledge on the inference process. The Collins-Michalski theory was initially developed using inferences that people made about specific domains with a well specified, small knowledge base where the participants had no special knowledge about the domain within which they made the inferences (e.g., reasoning about weather patterns in a geographical domain; Collins, 1978). In the current study, people were asked to make inferences about a domain where they may have some prior knowledge that could be brought to bear on the inference process.

An Overview of the Theory

Collins & Michalski (1989) offer a framework for characterizing recurrent patterns in human reasoning. These patterns have been captured in a model that contains a set of primitives, operators, and basic inference rules that are applied to knowledge residing in a hierarchical representation system. The primitives enable the specification of knowledge components. The operators allow specification of transformations that can be applied to the basic components in the process of plausible inference.

Insert Figure 1 about here

Primitives

Primitives include arguments, descriptors, terms, and referents, which are represented as nodes of *type* (is-a) hierarchy or *part* hierarchy (Figure 1). The hierarchies are dynamic, in the sense that they are growing and changing with experience. Arguments and referents stand for entities (objects, processes, ideas, etc.) in a statement. The same entity may serve as an argument in one statement and as a referent in another. Descriptors are attributes, functions or relations that are used to describe entities. A term is defined as a descriptor applied to one or more arguments; the evaluation of that term to a value constitutes a referent.

Insert Figure 2 about here

For example, Figure 2 presents an example of possible descriptors, terms and referents that could be applied to the arguments carnation, GMU, Cornell, and population as well as the notation used to represent them. Possible descriptors are attributes, such as color, functions such as distance, and relations, such as greater than or between. Thus, for example, the descriptor color applied to the argument carnation forms the term "color(carnation)".

Terms are formed by applying descriptors to one or more arguments. They have a special significance, because many reasoning tasks can be viewed as evaluating terms. Evaluation of a term may take place by following the trace connecting the descriptor and the argument(s), by instantiating a general rule (mutual implication or term dependency), or by one or more plausible statement transforms, such as those described below.

Referents are the result of an evaluation of a term, where a descriptor is applied to an argument. Thus, the referent formed from the term "color(carnation)" is "red".

An argument can be any node of a hierarchy, a referent can be any node except for the root node, and a descriptor can be any node except for the leaf node. Arguments, descriptors, and referents are used in the construction of simple statements, term dependencies and mutual implications. Simple statements are used to represent facts and properties of the objects in the knowledge-base. Mutual implications and term dependencies constitute more complex knowledge, which play the basic role in generating plausible inferences. Examples of each of these can be seen in Figure 3.

Insert Figure 3 about here

Simple statements, term dependencies, and mutual implications are represented as traces linking nodes in different hierarchies. The traces are annotated by a set of parameters (denoted

below by π) influencing the strength of the belief in the reasoning process. The parameters represent the frequency of usage, reliability of the source of information, dominance and typicality of a subset within a set, the consistency of the trace with other parts of the knowledge base, the strength of forward and backward implication or term dependency, etc. (Collins and Michalski, 1989).

One of the major assumptions of the theory is that plausible inferences correspond to "small perturbations" of the traces. For example, Figure 1 shows a trace representing the statement "The vertebrates of UK include fish and birds". This can be used as a base statement for generating inferences "The vertebrates of *Europe* include fish and birds" (a deductive generalization), or that "The vertebrates of *Sussex* (a part of UK) include fish and birds" (an inductive specialization).

Operators and Basic Inference Rules

The theory defines eight basic operators (transforms) on a simple statement. These transforms are viewed as forms of plausible inference. A transform is done by "perturbing" the argument or referent in a trace spanning one or more hierarchies. As mentioned above, the plausibility of the resulting statement is dependent on the type of perturbation. It also depends on the parameters associated with the base statement. The transforms are classified into two groups. In the first group, transforms modify the argument, whereas in the second group, they modify the referents. The modification is done by generalizing, specializing, similizing, or dissimilizing. For simplicity, the certainty parameters are omitted in the following examples. To describe the transforms, we use the following notation.

Generalization of a node "a" in a hierarchy to another node "a' " in context "CTX" is denoted

a' GEN a in CTX(d(a'))

where d(a') denotes descriptors relevant to a' in the given context. For example, a mammal is a generalization (GEN) of felines in the context (CTX) of mammals and their physical features.

Specialization of a node "a" in a hierarchy to another node "a'" in the context "CTX" is denoted

a' SPEC a in CTX(d(a'))

For example, a cat is a specialization (SPEC) of felines in the context (CTX) of felines and their general properties.

The fact that a node "a" in a hierarchy is similar to another node "a' " in the context "CTX" is denoted

a' SIM a in CTX(d(a'))

For example, tigers are similar (SIM) to cats in the context (CTX) of physical features of felines.

The fact that a node "a" in a hierarchy is dissimilar from another node "a' " in the context "CTX" is denoted

a' DIS a in CTX(d(a'))

For example, tigers are dissimilar (DIS) from cats in CTX of size of felines.

Before we formally describe the eight transforms, Figure 4 gives an example of each transform as applied to the base statement: "Flowers of England include daffodils and roses." A simple statement can be a seed for four different type of inferences: generalizing, specializing, similizing and dissimilizing transforms. Each type can be applied either to an argument or a referent, thus we have a total of eight transforms.

Insert Figure 4 about here

Generalizing Argument (GEN A). The generalizing argument extends the applicability of a descriptor-referent pair from an argument to its ancestor. The confidence in the generalized statement is less than in the base statement (Michalski and Zemankova, 1989). The validity of the transform essentially depends on the predictability of the descriptor value from a general node to a specific node, the typicality of the more specialized argument within the more generalized node, and the multiplicity of arguments. The predictability of the descriptor value is proportional to the

uniformity of the referent among specialized nodes. In the examples given below, formal ways of using and combining various parameters are not addressed.

Figure 5 provides the general form and specific examples of the four basic transforms. In the example for the generalizing argument, the base statement says that "*the performance of Unisys in 1988 was good.*" *Unisys* is represented in the hierarchy of companies and the node corresponding to *computer_companies* is its ancestor. The typicality of *Unisys* within *computer_companies* is high. There is also a term dependency which states that *business_type* of a company is relevant to the *performance* of a company. Using all this information, we can generalize the base statements to infer that it is likely that "*the performance of computer_companies in 1988 was good.* "

Insert Figure 5 about here

Specializing Argument (SPEC A). In contrast to the generalizing argument transform, the specializing argument transform restricts the scope of a descriptor-value. If the descriptor-value were to be inherited from a generalized node to the specialized node without exceptions, the inference would be deductive and certain. The statement "*mammals have four legs* " would imply that the *kitty cat* (who is a mammal) *has four legs*. The formalization of the specialization transform goes beyond a mere deductive inference and attempts to look for exceptions by validating the inference after ascertaining that the inheritance of the descriptor value is justified.

For example, in the process of assigning "*four legs*" to a whale, the reasoning process would look at the context of "*habitat*", which has a close functional connection to legs (by means of locomotion). It would see that a whale is not a typical mammal with respect to habitat, and therefore the conclusion that "*a whale* (which is a mammal) *has four legs* " would be blocked. A similar analysis would hold for a *bat* which is a mammal, but is atypical with respect to the means of locomotion and habitat among mammals. Notice that such relations between two or more descriptors can be used in multiple ways.

For example, it can be easily deduced that "*a tiger* , which is a mammal, *has four legs.*" However we cannot infer that "*a tiger has claws,*" since the rule that "*mammals have claws*" is too weak. However, such an inference can be strengthened by noting that "a *tiger is a hunting animal.*" Since there is a close functional relationship between claws and hunting activity, one might deduce that "*a tiger has claws.*" Note that the same line of reasoning would allow an inference that "*an eagle*, which is a bird of prey, *has claws*," on the same grounds of functional association, though *eagle* and *tiger* are otherwise far removed in the type hierarchy of animals than *tiger* and *cow*.

The strength of the inference depends on the background knowledge as to the alternative means of hunting. There is a need to combine not just one, but several lines of reasoning, as is clear from a parallel example that "the *tigers have sharp teeth*" but "the *eagles have no teeth at all!!*" The further one is away from the base statements, the more one has to look for alternative explanations and new evidence.

In the above example, we have a base statement that "*the major religion in South American countries is Roman_Catholicism.*" *Brazil* appears as a lower level node (descendant) of *South America* in the part hierarchy of places. There is a term dependency stating that *religion* of a country is related to the *geographical location* of the country (countries in the same geographical proximity tend to have similar religious background). From this it can be concluded that "*the major religion in Brazil is Roman_Catholicism.*"

Similizing Argument (SIM A). The similizing argument is a statement transform which depends on the similarity between two arguments rather than ancestor-descendant relation between them. Because potentially all the nodes in the hierarchy can be used as similar nodes, all the nodes in the hierarchy would need to be examined in order to find the best match. This makes the transform a computationally unattractive means of answering queries unless a good similar argument is known beforehand. This transform is valuable in verifying inferences by other lines of reasoning.

This example uses the similarity between argument to deduce that "*the economic_state of Hong_Kong is strong.*" The inference is based on the information that "*the economic_state of Singapore is excellent*", that *Hong_Kong* is very similar to *Singapore* in the feature space of economy_type, tax, resources, communication, and that feature space is relevant to the economic_state of a country.

Dissimilizing Argument (DIS-A). The dissimilizing argument transform depends on the dissimilarity between two arguments. The transform depends on the assumption that if some context is relevant to the descriptor, then two arguments which are dissimilar in the context will likely have different descriptor-value (referent). This transform can be used to eliminate one or more contending hypotheses. It can also be used to increase certainty of a conclusion by showing that alternative hypotheses are not plausible.

This example uses the dissimilarity between arguments to deduce that "*a cow is not a carnivorous animal*". The inference is based on the premises that *cow* and *tiger* differ with regard to having or not having *sharp teeth* and *claws*, and that these properties are important for carnivorous animals.

Method

Subjects

The subjects were eight individuals solicited from within the George Mason University community.

Materials

A table composed of 13 countries and attributes characterizing those countries was designed for use in this study. For each country, the descriptors, such as the type of government, type of press, the literacy rate, the type of work force, major religions, trading partners, major industry, per capita income, and the relations with the United States were determined from published literature. Eighteen of the country attribute values were replaced with question marks. These attribute values were the characteristics that the subjects were asked to infer in the experiment. A second version of the table was created in which the country names were replaced with three

letter non-sense names (e.g., ABC, DEF). Subjects who received this table were not told that the rows in the table represented actual countries. The table (shown with both sets of labels) can be seen in Figure 6.

Insert Figure 6 about here

Design

The design of the study was a two-factor mixed design. The between-subjects factor manipulated whether the subjects were given the actual names of the countries used in the matrix or the nonsense names. Questions (represented by the 18 cells within the table which were left blank) was the within-subjects variable.

Procedure

The participants were provided with a copy of one of the two versions of the table (four participants received table with the actual country names, the other four received a table with the nonsense names). The nature of the table was explained to the participants. They were then asked to generate plausible entries for each of the cells which contained a question mark. Thus, they were asked to make a plausible inference for each of 18 cells in the table. In collecting the protocols, the subjects were briefly told the purpose of the experiment. No specific time limit was set to answer the questions. The subjects typically took about an hour to answer the 18 questions. They were asked to verbalize their thought processes and the reasons for their conclusions as they completed their task. Verbal protocols were recorded and transcribed for analysis.

Results

Validation of the Theory

The first objective of this research was to validate the structural aspects of the theory and to determine if any modifications or extensions appeared necessary in order to characterize the observed inferences.

The 144 protocols (eight participants answering each of 18 questions) were analyzed to determine the inference rules being used. For example, Figure 7 provides the protocol from one participant's response and illustrates the analysis (both verbal and formal) for that protocol. In the example, RS means a reasoning step, PBK means personal background knowledge, GBK indicates given background knowledge (i.e. given in the table), MI indicates inference from mutual implication, and M Recall means memory recall (i.e., that the info was drawn directly from personal knowledge presumed stored in memory.)

Insert Figure 7 about here

The number of times each basic inference rule was used was tabulated, and can be seen in Figure 8, categorized by whether or not the participant knew the actual country names. In addition, counts were made of the inferences based solely on the information contained in the table (GBK), the number of inferences based on personal background knowledge (PBK), and the number of statements made directly as a recall from memory (M-Recall).

Insert Figure 8 about here

The set of protocols generally emphasized simple reasoning patterns involving reasoning by the application of one or more mutual implications. The protocols also relied heavily on the use of personal rules. In many cases, these ruls reflected what might be called "Facts"; that is, the rules were ones that most people would argue are true. For example, in response to the question "What is the type of govenment in DEF (Angola)?", one subject stated "press is state--comminist government", stating that a state-controlled press generally indicates a communist government.

In other cases, however, the personal rules appear to have no factual basis. For example, in response to the same question cited above, another subject responded :Angola, I would say

that it is a comunist. I hear about it in the news so much." In this case, there seems to be little objective basis for the ule being invoked, that is, that being on news imples that a country has a communist goverment.

Reasoning patterns involving constructive processes, such as discovery of dependencies or checking for consistency of personal knowledge with that available in the table, were far less frequent. However as the table suggests, some example sof each were found. For example, in response to the question "What are the major religions in GHI (Brazil)?", one subject responded "God, I am surprises so many are Roman Catholic, Um, sounds good for that one too, but I don't eally know. Is there a connection? I'd go with Roman Catholic for GHI" , because it seems there is a kind of pattern for Roman Catholics. Cause ~~their~~'s there's for GHI & VWX they are basically teh same forces, and almost the same industries. Trading partners are about the same. Same with YZA so that is why I picked Roman Catholic". The first sentences of this protocol suggest that this subject did note cinsistencies in the table and made a geeralization from it. The latter part of the protocol suggests that the subject also noted teh similarities among the countries in the table and confirmed the earlier generalization based on a similarity transform.

Another use of the information in the table can be seen in response of one subject to the question, "What are the major religions in JKL?"--

S: The government is parliamentary democracy, it is probably like England or something but I don't know what are the major religions there. I'd say something like Roman Catholic or Protestant, I'll just say Protestant, oh, Anglican, that is what it is.

I: Why Anglican?

S: Because that's the major religion in England. That's what I think that is. Oh, industry, steel, probably not. I don't know enough about exports, I never did well in this class. Now I am going to take a world geography course just so I can do well on this thing. I said Roman Catholic, just because Roman Catholic is highest in terms of numbers in religion besides eastern as far as free countries.

In this protocol, the subject initially concludes that the country's erligion is Anglican based n teh hypothesis that the country's identity is England. However, the subject then disconfirms the hypothesis by noting that steel is given as a major industry in the table.

There were also a few patterns in teh protocols that could not be captured easily by the existing theory. For example, in response to the question "What is the major industry in Iran?", one subject produced the following response: "Iran. Major industries. You know, I have no idea. When we stopped, when we closed diplomatic relations with Iran uh, in when were the hostages taken? 81? 80? Um, our press was naturally very limited. What appears in our press, if at all, photographs from Iran are from foreign press. We know so very little, and what we see is always these, they're just crazy, these crazy Moslems. Let me put it this way, we only see or hear about radical fundamentalists. Um, again, I imagine Iran has been historically an agricultural based society. Uh, however, to finance his revolution and got to imagine his, Khomeini's, war with Iraq, he's been forced to industrialize to a point. Now that the war has ended with Iraq they'll probably be able to convert those weapons, those material factories into more consumer goods." This protocol contains temporal information, a structural component not contained in the current theory.

Another pattern not contained in the current model is needed to capture one subject's response to the question, "What is the litaracy rate in MNO?"-- "Type of government is communist, the type of press is state, industry and service produce textile that suggests sort of a blue collar workforce. Probably the literacy rate is low because those type of countries like to keep their people oppressed. Also the income is low which suggests little education so they'd have higher learning power." In order to capture this protocol formally, a rule is needed which says that if an agent wants to achieve a given result (R), and if the agent knows that doing something(X) helps R, then the agent will do X.

Impact of World Knowledge on the Inference Process

The second objective of this study was to examine the impact of world knowledge on the inference process. Specifically, we were interested in determining whether a participant's knowledge of the domain would change the inference process. The data suggest that domain knowledge does change the process. This can be seen both in subjective and objective analyses of the protocols. Participants aware of the country names tended to state their conclusions first, often as a direct memory recall, followed by one or more lines of reasoning designed to confirm the original statement. For example, the response to the question "What are the major religions in Canada?" (seen in Figure 7) shows that the subject starts with a recall of information in the form of a statement and then goes on to offer supporting documentation. A similar pattern can be seen in Figure 9, which shows a protocol produced in response to the question "What is the type of work-force in Vietnam?".

This pattern contrasts sharply with that shown by subjects who were not informed of the actual country names. Figures 10 and 11 show the responses to the same questions discussed above for subjects who were not aware of the actual country name. In these protocols, there is much more reliance on the information presented in the table.

Insert Figures 10 and 11 about here

These results can be clearly seen in the more objective data (summarized in Figure 8). It was clear that, overall, participants who were informed of the actual country names relied much less heavily on inferences drawn from the material presented and much more heavily on information retrieved from memory. Chi squared analyses showed that the number of inferences based on information given in the table (GBK) was much lower when participants were aware of the actual country names ($\chi^2(1) = 59$, $p < .01$); on the other hand, the number of statements drawn directly from memory was much greater for participants ($\chi^2(1) = 42$, $p < .01$). The number of personal rules used to support the conclusions was the same for the two groups of participants ($\chi^2(1) = 2$,

$p > .05$). While no formal analyses of the data were carried out due to the small number of responses in each category, an examination of Figure 8 also suggests that the use of particular statement transforms follows a similar pattern for both groups of participants.

Conclusions

The results of this study suggest that the structural aspects of the theory developed by Colins & Michalski were adequate to account for most of the reasoning patterns observed in the protocols. These protocols suggest that people always attempt to build a consistent, plausible scenario to explain their conclusions based on beliefs and personal background knowledge (PBK). In developing this scenario, people follow several lines of reasoning and the individual lines are weighted and compared. If different lines lead to different conclusions with a similar weight, a subject does not express any opinion ("I do not know").

Further, the protocols suggest that people rely heavily on their personal background knowledge in developing plausible inferences. Subjects in both the groups relied heavily on personal rules, even when objective standards would suggest that these rules were invalid.

The results also suggest that when people have preexisting knowledge about a domain, they will rely more heavily on that data, even to the point of ignoring newly presented information. Finally, the data support the theory's contention that hierarchies, term dependencies and mutual implications are very important components of the process of plausible reasoning. In the present study, the question of how people learn these components was not addressed. Further research needs to be done to find a computational model of how people create conceptual hierarchies, and discover implications and dependencies. The theory also needs to be related to existing methodologies, and extended to include temporal reasoning, spatial reasoning, reasoning under time and resource constraints (e.g., related to the variable precision logic, as described by Winston and Michalski, 1986), as well as meta-knowledge reasoning.

In conclusion, the experiments have demonstrated that the theory provides an adequate mechanism for representing reasoning for the class of tasks investigated. The theory offers new tools for knowledge representation, and has a potential for applications in a variety of fields, such as decision making and analysis, diagnosis (medical, agricultural or technical), goal

recognition, intelligent tutoring, object and scene recognition, planning, autonomous robotics, estimating costs and labor in design, document retrieval systems, etc.

Authors Notes

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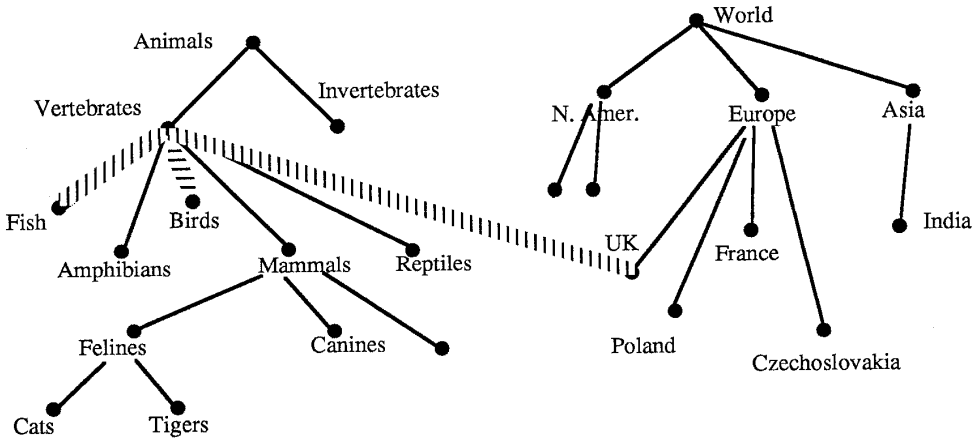

Type hierarchy **Part hierarchy**

Figure 1: Example Hierarchies and a Trace

Primitive	General Notation	Type of Primitive	Example	Specific Notation
Argument	a_i	-	carnation	a
		-	GMU	a_2
		-	Cornell	a_3
		-	population(VA)	a_4
		-	population(DC)	a_5
Descriptor	d_i	attrributes	color	d_1
		functions	distance	d_2
		relations	greater than	d_3
Terms	$d_j(a_i, a_{i+1},..)$	-	color(carnation)	$d_1(a_1)$
		-	distance(GMU, Cornell)	$d_2(a_2, a_3)$
		-	greater-than(pop(VA), pop(DC))	$d_3(a_4, a_5)$
Referents	r_i	-	red	$r_i = d_1(a_1)$
		-	400-miles	$r_2 = d_2(a_2, a_3)$
		-	true	$r_3 = d_3(a_4, a_5)$

Figure 2

Simple Statements (SS):

$$d(a_1) = r_1 : \pi$$

Examples:

Density(aluminum) = 2.7: π
Age(John) = 55: π
Likes(Robert, Mary) = very_much: π

Term Dependency

$$d_1(a_1) \text{ <---> } d_2(a_1) : \pi$$

Example: Assets(firm) <---> Credit_rating(firm): π

Mutual Implications (MI):

$$SS_i \text{ <==> } SS_j : \pi$$

Example: Latitude(place) = north <==> Temp(place) = cold: π

Figure 3: Examples of Simple Statements, Term Dependencies and Mutual Implications

BASE STATEMENT:		Flower-type(England)	= {daffodils, roses, ..}
GEN-A	(*Generalizing Argument*)	Flower-type(Europe)	= {daffodils, roses,..}
SPEC-A	(*Specializing Argument*)	Flower-type(Surrey)	= {daffodils, roses,..}
SIM-A	(*Similizing Argument*)	Flower-type(Holland)	= {daffodils, roses,..}
DIS-A	(*Dissimilizing Argument*)	Flower-type(Brazil)	≠ {daffodils, roses,..}
GEN-R	(*Generalizing Referent*)	Flower-type(England)	= {temperate flowers}
SPEC-R	(*Specializing Referent*)	Flower-type(England)	= {yellow roses}
SIM-R	(*Similizing Referent*)	Flower-type(England)	= {peonies, ..}
DIS-R	(*Dissimilizing Referent*)	Flower-type(England)	≠ {bougainvillea, ..}

Figure 4: Examples of Statement Transforms

ARGUMENT TRANSFORM	GENERAL FORM	EXAMPLE
Generalizing	Descriptor(Argument$_1$) = Referent Argument$_2$ GEN Argument$_1$ in CTX Descriptor <--> CTX --- Descriptor(Argument$_2$) = Referent	Performance (Unisys, 1988) = good Computer_companies GEN Unisys in CTX(Business_type) Performance <--> Business_type: --- Performance(Computer_companies, 1988) = good
Specializing	Descriptor(Argument$_1$) = Referent Argument$_2$ SPEC Argument$_1$ in CTX Descriptor <--> CTX --- Descriptor(Argument$_2$) = Referent	Major_religion(So_Amer_Cntries) = {Roman_Catholic, ..} Brazil SPEC So_Amer_Cntries in CTX(Geo_location) Major_religion <--> Geo_location --- Major_religion(Brazil) = {Roman_Catholic,..}
Similizing	Descriptor(Argument$_1$) = Referent Argument$_2$ SIM Argument$_1$ in CTX Descriptor <--> CTX --- Descriptor(Argument$_2$) = Referent	Economic_state(Singapore) = Excellent Hong Kong SIM Singapore in CTX(Economy_type, Tax, Latitude, Resources, Communication, ..) Economic_state <--> CTX --- Economic_state(Hong Kong) = Excellent
Dissimilizing	Descriptor(Argument$_1$) = Referent Argument$_2$ DIS Argument$_1$ in CTX Descriptor <--> CTX --- Descriptor(Argument$_2$) ≠ Referent	Carnivorous(Tiger) = yes Tiger DIS Cow in CTX(sharp_teeth, claws, ..) Carnivorous<--> CTX --- Carnivorous(Cow) ≠ yes

Figure 5

Figure 6
Country Database

Country	*Govt. Type*	*Press*	*Literacy Rate*	*Work Force*	*Major Religions*	*Trading Partners*	*Major Industry*	*P Capita Income*	*Relations with US*
Afghanistan ABC	communist	?4	very low	agric rural	Sunni Moslem Shiite Moslem	? 11	textiles	v. low	hostile
Angola DEF	?1	state	med low	agric	R. Catholic	USA	cotton goods fishmeal,alcoho	?15	strained
Brazil GHI	democratic republic	private	med high	services agric industry	?9	USA Japan Neth'lnd	steel, autos chemicals	low	?16
Canada JKL	parliament democracy	private	very high	industry services	?10	USA	steel	high	normal
Cuba MNO	communist	state	?6	industry services	R. Catholic none	? 12	textiles wood products	low	hostile
Egypt PQR	democratic republic	mixed	medium	agric sevices	Sunni Moslem	USA, W.Germ Israel	?13	v. low	normal
Iran STU	theocracy	state	medium	agric industry	Shiite Moslem	W.Ger Japan, Italy	?14	low	hostile
Italy VWX	?2	mixed	high	services industry agric	R. Catholic	W.Germ. France USA	steel, autos shoes	medium	normal
Mexico YZA		private	med high	services agric manufac	R. Catholic	USA Japan Spain	steel chemicals	med low	normal
Peru BCD	?3	?5	med high	services agric industry	R. Catholic	USA W.Germ Japan	fishmeal steel	low	normal
Poland EFG	communist	mixed	very high	?7	R. Catholic	USSR Czech E&W Ger	shipbuilding	low	?17
Vietnam HIJ	communist	state	med high	?8	Buddhist Confucian Christian animist	USSR Japan H.Kong	food processing textiles	v. low	?18

Question 10B: WHAT ARE THE MAJOR RELIGIONS IN CANADA?

Subject

Canada. Um, well, Canada is split between the French speaking sector, as well as English speaking sector, which given those two warring factions and how that conflict rather manifests itself in the language debate. Should the official language be French or should it be English. Um, given how language is so closely tied to religion, I imagine that it's probably Protestant versus Catholic, as well. Although that is not an issue that surfaces so much, that's my thought. So it's probably two religions.

Formal analysis

RS1
Lang(people(Canada)) = {French, English,..} — M Recall

RS2
Lang(people(Country)) <--> Maj_religion(people(Country)) — PBK

RS3
Lang(people(Canada)) = {French, ...} <==> Maj_religion(people(Canada)) = {R. Cath,..} — PBK
Lang(people(Canada)) = {French,..} — PBK

Maj_religion(people(Canada)) = {R Cath, ..} — MI

RS4
Lang(people(Canada))={ English, } <==> Maj_religion(people(Canada))={Prot,.. } — PBK
Lang(people(Canada)) = {English,..} — PBK

Maj_religion(people(Canada)) = {Prot, ..} — MI

Conclude: Maj_religion(Canada) = {R. Cath, Prot,..},

Figure 7: Example Protocol

Transforms	Country names unknown	Country names known
Gen-A	0	0
Spec-A	1	7
Sim-A	11	2
Dis-A	8	0
Gen-R	0	2
Spec-R	1	2
Sim-R	0	2
Dis-R	0	1
MI based	112	82
MD based	1	3
Source of Knowledge		
M Recall	0	42
GBK	149	43
PBK	168	170

Figure 8

Question 10A: WHAT ARE THE MAJOR RELIGIONS IN JKL (CANADA)?

Subject

S: Parliamentary democracy, literacy rate very high, industry services. I would say, uh, for the religion would be the same thing- Roman Catholic.
I: Ok.
S: And my reason being is that it is basically very similar to other one.
I: Yeah, OK.

(Note: The other one refers to the following dialog from Q9)
S: Democratic republic. I'd go with um, religion here I would go with Roman Catholic as the major religion. Uh, steel, autos, chemicals.
I: What about the religion being Catholic? How did you get that answer?
S: Well they could read, and you know, the literacy rate is ..
I: Oh, the literacy rate is high?
S: Yeah, and you know, big trade, big industry being steel, autos, chemicals, you know, a lot of working class people.

Formal analysis

RS1

Literacy_rate(Country) = high <==> Religion(Country) = {R_Catholic, .,.}	PBK
Literacy_rate(JKL) = high	GBK
Religion(JKL) = {R_Catholic, ..}	MI

RS2

Work_force(Cntry) = {service, industry} <==> Working_class(Cntry) = large	PBK
Working_class(Country) = large <==> Religion(Country) = {R_Catholic,..}	PBK
Major_industry(Cntry) = {steel} <==> Work_force(Cntry) = {industry}	PBK
Major_industry(JKL) = {steel}	GBK
Work_force(JKL) = {industry}	GBK
Religion(JKL) = {R_Catholic,..}	MI

Conclude
Religion(JKL) = {R_Catholic,..}

Figure 9

Question 8B: WHAT IS THE TYPE OF WORK FORCE IN VIETNAM?

Subject

Vietnam. Work force. I think it is primarily agricultural. It is way behind Pacific Rim, the development of the rest of the Pacific Rim countries because of the Vietnam war. And the continuing state of, it is very poor. The refugees, there was a mass exodus of refugees, a brain drain, if you will, during the war, after the war, continuing still. Therefore that does not leave a lot of room to revolutionize, to modernize what little industry you might have, that might have survived the war. Uh, I think it is primarily agricultural.

Verbal analysis

The subject starts with a weak recall that the type of work force in Vietnam is primarily agricultural. Then the subject offers justifications. Development of Vietnam has lagged behind its neighbors in the Pacific Rim area due to war. The economic status of Pacific Rim countries is high and Vietnam's economic situation is worse than theirs. Therefore, the economic status of Vietnam is likely to be poor. If a country has undergone recent war, if its economic status is not sound, if there are refugees from the country, then the development of the country is slow. Such a situation existed in Vietnam, therefore, its development is slow.

If a country is trying to modernize, then it will change its industry from agricultural to modern industry. This change is slow if the development of the country is slow in general, therefore change from agricultural to modern industry is slow in case of Vietnam. If there is no modern industry, then there is no large scale industrial force, therefore, the work force of Vietnam is not industrial but agricultural, therefore, the subject infers that the labor force of Vietnam is predominantly agricultural, which is consistent with the earlier recall.

Formal analysis

RS1

Labor_force(Vietnam) = {agric, ..}	M Recall

RS2

Mil_stat(Cntry)=war <==> Econ_stat(Cntry) < Econ_stat(Nbors(Cntry))	PBK
Mil_status(Vietnam) = war	PBK
Nbors(Vietnam) = Pacific_Rim_cntries	PBK

Econ_stat(Vietnam) < Econ_status(Pacific_rim_cntries)	MI

RS3

Econ_stat(Pacific_Rim_cntries) = high	PBK-Implicit
Econ_stat(Vietnam) < Econ_stat(Pacific_Rim_cntries)	RS2

Econ_stat(Vietnam) = not high	MI

RS4

Mil_stat(Cntry) = at_war <==> Xodus(Cntry) = high & Brain_drain(Cntry) = high	PBK
Mil_stat(Vietnam) = at_war	GBK

Xodus(Vietnam) = high & Brain_drain(Vietnam)= high	MI

RS5

Xodus(Cntry) = high & Brain_drain(Cntry)= high <==> Develop(Cntry) = slow — PBK
Xodus(Vietnam) = high & Brain_drain(Vietnam)= high — RS4

Develop(Vietnam) = slow — MI

RS6
Tendency(Cntry) = modernize <==> Changeto(Agric, mod-ind) — PBK
Develop(Cntry) = slow <==> Change(agric, mod-ind) = slow — PBK
Develop(Vietnam) = slow — RS5

Changeto(agric, mod-ind) = slow

RS7
Change(agric, mod-ind) = slow — RS6
Industry(Vietnam) = {agric, ..} — GBK
Industry(Cntry) = {agric, ..} <==> Lab_force(Cntry) = {agric, ..} — GPK

Lab_force(Vietnam) = {agric, ..} — MI

Conclude Lab_force(Vietnam) = {agric, ..}

Figure 10

Question 8A: WHAT IS THE TYPE OF LABOR FORCE FOR HIJ (VIETNAM)?

Subject

S: The last column. HIJ. Communist state, medium high, agricultural services. I'd go with agricultural services, the reason being that their major industry is food processing and that is related to agriculture.

Formal analysis

RS1

Maj_indst(Ctry) = {food proc,..} <==> Maj_indst(Ctry) = {agric,..}	PBK
Maj_indust(Ctry) = {agric,..} <==> Lab_force(Ctry) = {agric,..}	PBK
Maj_indust(HIJ) = {food_proc,..}	GBK

Labor_force(HIJ) = {agric,services,..}	MI

Conclude

Labor_force(HIJ) = {agric,services,..}

Figure 11