Concept Construction as Constraint Relaxation: Working Note 3

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1 Introduction

Anyone who's tried building a knowledge-base soon observes the following phenomenon: almost everything you write down is false. By this we mean that for almost every axiom[1], there exist special cases when it does not hold. For example "Cars have four wheels." and "Birds fly." are typically but not universally true statements. As a result, we require some mechanism to allow such statements to be dropped or 'relaxed' in the face of strong evidence to the contrary. This is particularly the case when we construct novel concepts as combinations of old ones: often, typical properties of the old concepts will no longer make sense for the new composition.

Before discussing this issue further, we note that it differs from the problem of *terminological errors* which Guha's context mechanism in CYC sought to address [Blair et al., 1992]. Guha was similarly concerned that when a knowledge engineer wrote `bird` $\Rightarrow$ `flies` it might sometimes be false, but for a different reason: Not because only 95% of living birds fly, but because the knowledge engineer had failed to state the assumption that `bird` meant "living bird" (say). This can be viewed as a terminological error, as the knowledge engineer had written `bird` when he/she meant `living-bird`. Guha was concerned that the knowledge engineer hadn't correctly expressed what he/she meant, whereas we are concerned that, even if the engineer did express what he/she meant as an axiom, it is only true in a probabilistic sense. Guha was concerned with making assumptions explicit, whereas we are concerned that axioms over-state most common-sense 'facts'.

2 Concept Construction as Constraint Relaxation

2.1 An Illustration of The Problem

Given many axioms are not universally true (in the world), it may be necessary to ignore or 'over-ride' them if substantial evidence contradicts them. This requirement has become particularly apparent in our goal to construct novel concepts (such as the `RocketBus`, described earlier in Working Note 1) through composition of old concepts. Typically, the new, composed concept is not simply the union of axioms about its components, but also requires dropping some of the axioms from the old components.

[1](or rule or frame: we consider these terms synonymous in this note.)

As a toy example for illustration purposes, consider the composed concept of a `lava_kayak`, namely a kayak which travels through hot lava rather than water. Our KB may contain the following axioms about kayaks (and related concepts):

1. "Kayaks are made of plastic."
2. "Kayaks travel through water."
3. "Speed of a vehicle is $\propto$ 1 / the viscosity of the medium moved through."
4. "Melt temp of the vehicle's material $\geq$ than temp of the medium moved through."

and also:

5. "Water has low temperature and low viscosity."
6. "Plastic has average melting temperature."

For normal kayaks, applying these axioms we get a concept description:

```
kayak(made_of => plastic(melt_temp => lo),
      speed => hi,
      travels_thru => water(density => lo,temp => lo))
```

However, if we ask about a `lava_kayak` ie. we assert

7. "Lava kayaks travel through lava."
8. "Lava has high temperature and high viscosity."

then we start to hit contradictions in the KB:

- Axioms 7 and 2 directly contradict.
- Axioms 1, 4, 7 and 8 contradict (the lava kayak can't made of plastic, or else it'll melt)

2.2 The Task viewed as Constraint Relaxation

In order to properly describe `lava_kayak`, we need some mechanism to allow axioms to be dropped if necessary. A simple algorithm is to try applying each axiom in turn to the new concept, and just ignore it if it causes a contradiction. This leads to the first description of `lava_kayak` shown in Figure 1. However, the resulting description is not particularly intuitive (we've retained the kayak being made of plastic, and dropped the law of physics saying it would melt). A more plausible description is the second one given in Figure 1, where we drop the axiom that the `lava_kayak` is made of plastic instead. This illustrates that, as well as being able to drop axioms, we need to express some preference about which axioms to drop. For example, laws of physics and definitions should be preferrable to keep than axioms stating typical properties of concepts.

A description of `lava_kayak`, formed by selecting a consistent subset of axioms:

Axiom	**Ok?**
1. `"Kayaks are made of plastic."`	$\surd$
2. `"Kayaks travel through water."`	× (contradicts 7)
3. `"Speed inversely proportional to viscosity."`	$\surd$
4. `"Melting temp of material ≥ temp of medium."`	× (contradicts 1)

Resulting description:

```
lava_kayak(made_of => plastic(melt_temp => lo),
           speed => lo,
           travels_thru => lava(density => hi,temp => hi)
```

An alternative description, formed by selecting a different, consistent subset of axioms:

Axiom	**Ok?**
1. `"Kayaks are made of plastic."`	× (contradicts 4)
2. `"Kayaks travel through water."`	× (contradicts 7)
3. `"Speed inversely proportional to viscosity."`	$\surd$
4. `"Melting temp of material ≥ temp of medium."`	$\surd$

Resulting description:

```
lava_kayak(made_of => thing(melt_temp => hi),
           speed => lo,
           travels_thru => lava(density => hi,temp => hi)
```

Figure 1: Alternative ways of relaxing constraints on `lava_kayak` concept.

Generalizing from this example, we can view concept composition as a standard constraint relaxation problem:

Given:

- A KB of axioms (plus some measure of confidence associated with each)
- A specification of a target concept (ie. the definitional properties of a new concept such as `lava_kayak(travels_thru=>lava)`

Find:

- The 'most coherent' description of the target concept, ie. the best description constructable from a subset of axioms in the KB.

The most coherent description is the one in which all, or (if impossible) as many as possible, axioms were applied; or, to be more sophisticated, we can weight some axioms more than others. An evaluation function defining coherence which we've been experimenting with is: penalize a concept for every axiom which could apply but leads to a contradiction (ie. with the axiom formulated an if...then... rule, penalize if the conditions are satisfied but the conclusions are contradictory). We can assign different penalties with different axioms (eg. laws and definitions have high penalties, axioms about associated properties have low penalties). The most coherent concept is then the one which accrues a minimum overall penalty.

This task can be viewed as constraint relaxation, as the axioms represent constraints, and the task is to find the minimal ignoring or 'relaxation' of these constraints.

3 Significance, Implications and Problems

There are two particularly important points to make about concept construction as constraint relaxation as described in the previous Section.

3.1 Decomposable Concepts

First, we emphasise the importance of viewing a concept description as a composition of components. Rather than writing down a description of `kayak` per se, we described it as the combination of six axioms (Section 2). This composed description provides us with the 'seams' by which we can break up the concept again – we can selectively drop and add axioms into the description. As we've described, the ability to break up concepts is important for automatically formulating new concept descriptions. This contrasts with the approach of trying to override particular slot-values in a description – an approach which is problematic as the dependencies between slot-values remains hidden. In short: a concept is better thought of as a composition of axioms/constraints, rather than a collection of values. Axioms, not slots, provide the proper dimensions of a concept, as axioms properly isolate and encapsulate individual phenomena of the world. As in software engineering, this encapsulation is essential for concept reuse.

3.2 Searching for General Coherence rather than a Specific Answer

Second, forming a 'coherent' concept description seems an important part of question-answering, and shows up the limitations of standard inference techniques such as backward-chaining. Consider the question:

```
"What material is a lava_kayak made of?"
```

A backward-chaining algorithm will simply answer `plastic`, as a rule applies (Axiom 1, Section 2), and not realize the contradictions that this answer implies (eg. the lava kayak will melt). This rather myopic response is caused by the algorithm never looking beyond the first information it hits which could produce an answer. To produce a more common-sense answer (eg. "Something which withstands high temperatures.") it seems necessary to go beyond the immediate confines of a specific question and form a coherent 'picture' of the concept of interest.

In fact, building a coherent picture from initial facts is what most expert systems already do. Mycin's inference engine (for example) doesn't simply backward chain to find an answer, but also asks for and elaborates on other information (through the use of its context mechanism). Mycin's reasoning can be seen as searching for a most coherent model of the patient being diagnosed. This view of expert system reasoning – as *searching for a coherent, problem-specific model at run-time* rather than "applying rules" – has been eloquently articulated by Clancey [Clancey, 1992]. As he argues, this view underlies almost all problem-solving, either implicitly or explicitly (more often implicitly, unfortunately). It is hence not surprising that we too need to adopt this view for concept construction.

3.3 Coherence and Belief Revision

Our notion of coherence in Section 2.2 is similar, but not quite the same, as coherence theories of belief revision [Rao and Foo, 1989a]. Rao and Foo define "maximizing coherence" as retaining as many consistent beliefs as possible during a state change [Rao and Foo, 1989b]; similarly, we are attempting to minimize the (weighted) number of axioms which are not applied to a concept description. However, two differences are also worth noting: First, we have not yet addressed the issue of belief *revision*; instead, we have only addressed the construction of an initial set of 'beliefs' about a new concept. Second, if a rule's application is inconsistent, we do not retract the rule or its preconditions (as typically happens in belief revision systems), but instead reject the rule only for the *particular instance* which led to a contradiction. This can be viewed as a conservative type of rule modification: $f(X) \rightarrow g(X)$ becomes $f(X) \wedge X \neq x_i \rightarrow g(X)$, given that $f(x_i)$ and $\neg g(x_i)$ is known. We have not addressed the issue of when to make more significant changes to the KB, eg. reject a rule in its entirity.

3.4 The Problem of Constraining Inference

This, however, itself raises a new issue: how much elaboration of a concept should be performed, and how can the process be controlled? It seems clear that we want to do more than just answer a question (eg. backward chaining), but also less than completely elaborating every single detail of the concept of interest.

One heuristic method might be to use a depth-limit on the concept description being constructed. In other words, if we sketch the concept description as a conceptual graph, then we only apply axioms that apply to nodes within one (say) arc of the concept of interest, as illustrated in Figure 2. Later, a particular question may prompt the 'focal point' in the graph to shift from the original concept to some sub-concept of it, at which point the graph is further elaborated by applying axioms to nodes within the depth-bounded proximity of this new focal point (Figure 3).

A second method of limiting the pool of axioms available is to use some context mechanism (as already discussed in Working Note 2). Axioms are grouped according to the class of information they provide information about (eg. spatial properties, physical properties, functional properties) and then only axioms from relevant context(s) are considered.

4 Concluding Remarks

To summarize:

- Considering concepts as a superposition of axioms provides us the 'seams' by which a concept description can be pulled apart.
- Axioms (rather than slots) properly encapsulate individual phenomena about the world.
- Given many axioms are not universally true, concept composition can be viewed as a constraint relaxation problem, in which some minimal dropping of axioms is searched for in order to produce the most coherent description of a new concept.
- Forming a coherent concept description is an important sub-task of question answering (as happens in most expert systems).
- The issue of controlling elaboration of a concept is still an open problem.

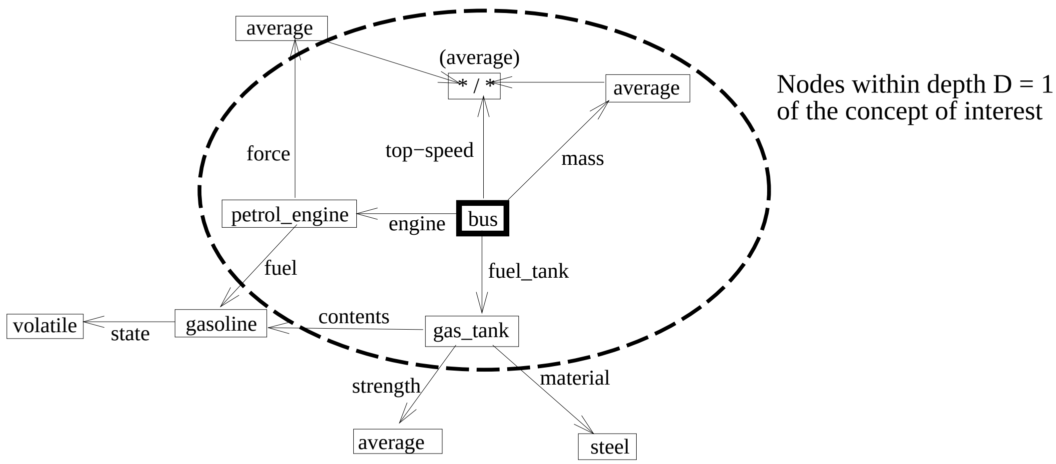

Figure 2: Elaboration of nodes up to distance 1 from a concept of interest.

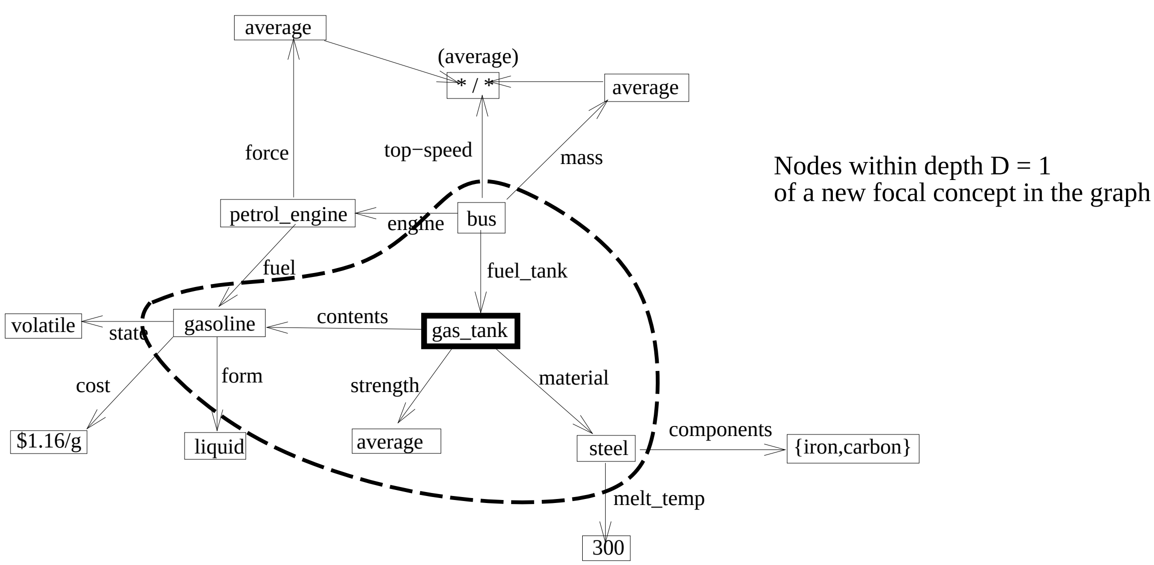

Figure 3: Further elaboration, as the focal point in the graph changes.

References

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