delim $$ **The Two Frame Problems**

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Abstract

We argue that there are not one, and not many, but rather *two* frame problems. One frame problem is simply a computational one, the other conceptual. We argue that reasoning in the commonsense world necessarily involves the conceptual problem. This is closely linked to (and even subsumed by) the familiar qualification problem in philosophy which, in turn, is related to the problem of natural and artifactual kinds.

I. Introduction Descriptions and explanations of ‘‘the frame problem’’ seem to be as numerous and as varied as those of Artificial Intelligence (AI) itself. We argue, however, that there are essentially two different frame problems. One pertains to a mathematically precise world, and the other to the less precise commonsense world. This distinction seems not to have been examined before, and appears to be the source of some confusion in discussions of the frame problem. Dealing with the first type of frame problem is similar to devising clever heuristics to search through the state space of a problem. On the other hand, the real-world frame problem is related to the problem of ‘‘kinds’’, a philosophical problem that needs to be considered in designing intelligent robots that interact with the world. To be more specific, we believe that this latter frame problem exists because of another: the natural and artifactual *kinds problem*. If this is the case, programs that are expected to guide a robot through a rich environment might reasonably be based on the lessons the kinds problem can teach us. In section II we survey some of the published definitions of ‘‘the frame problem’’. In sections III and IV we argue that these definitions split the problem into two: the ‘‘mathematical’’ frame problem (**MFP**) and the ‘‘commonsense’’ frame problem (**CFP**). The latter, we argue, is central to commonsense reasoning, and is in a strong sense unsolvable.

II. The Frame Problem Defined Here we review a number of definitions of ‘‘the frame problem’’[1] [2]We note that the expression ‘‘frame problem’’ first appeared in [McCarthy and Hayes 1969]. Apparently the term was intended to reflect the sequence of pictures – like frames on a film-strip – of some domain represented by their situation calculus. There is often confusion due to Minsky’s use of the word ‘‘frame’’ in [Minsky 1975]; a (Minsky-)frame is perhaps best seen as a suggestion for a data structure containing the inheritance features of a particular (natural or artifactual) kind, which we discuss in section IV below. found in the literature. Different definitions of the frame problem focus on its different aspects. To facilitate our discussion we will isolate these characteristics and group the definitions accordingly.

One characteristic that often appears is that of determining what *does not change*; another is that there is an impractically (but not impossibly) large number of axioms (qualifications) needed:

> If we had a number of actions to be performed in sequence we would have quite a number of conditions to write down that certain actions do not change the values of certain fluents [properties]. In fact with n actions and m fluents, we might have to write down mn such conditions. [McCarthy and Hayes 1969]

> The frame problem arises in the representation of dynamic worlds. The problem stems from the need to represent those aspects of the world which remain invariant under certain state changes. In a first order representation of such worlds, it is necessary to explicitly represent all of the invariants under all state changes. The problem is that in general a vast number of such axioms will be required, so there is a major difficulty in even articulating a deductively adequate set of frame axioms for a given world. A solution to the frame problem is a representation of the world coupled with appropriate rules of inference such that the frame axioms are neither explicitly represented nor explicitly used in reasoning about the world. [Reiter 1980]

Conversely, some have emphasized the determination of what *does* change:

> Since we base our actions on what we currently believe, we must continually update our current set of beliefs. The problem of describing and performing this updating efficiently is sometimes called the frame problem. [Doyle 1979]

This has been specifically linked to real-world complexity as the source of the problem:

> The frame problem arises in attempts to formalise problem-solving processes involving interactions with a complex world. It concerns the difficulty of keeping track of the consequences of the performance of an action in, or more generally of the making of some alteration to, a representation of the world. The frame problem can be briefly stated as the problem of finding adequate collections of laws of motion. [Hayes 1971]

Some have pointed to the difficulty in defining the complexities in commonsense situations, suggesting that there may be no fully adequate characterization allowing for precise determination of how things interact.

> A situation can rarely be fully defined by a single data structure; not only its explicit characteristics, but also the ways in which it was derived from or is related to other situations, can be important problem-solving considerations. The frame problem is the problem of maintaining an appropriate informational context, or frame of reference, at each stage during problem-solving processes. [Raphael 1976]

McCarthy [1977] uses the cannibals and missionaries problem to explain his view of the frame problem. He likens the frame problem to the qualification problem[3] [4]We take the ‘‘qualification problem’’ (as in McCarthy [1980]) to be that of describing an entity sufficiently well to be able to pin down its behavior. This then is a slightly broader problem than the frame problem. Nevertheless, we feel there are two qualification problems which are analogous to our two frame problems: one for mathematical domains and one for commonsense domains. Furthermore, our comments regarding **MFP** and **CFP** apply also to the respective qualification problems. , and in fact says that the former is probably reducible to the latter. (This view is also expressed by Hayes [1971].)

> The "qualification problem" immediately arose in representing general common sense knowledge. In order to fully represent the conditions for successful performance of an action, an impractical and implausible number of qualifications would have to be included in the sentences expressing them. For example the successful use of a boat to cross a river requires, if the boat is a rowboat, that the oars and rowlocks be present and unbroken, and that they fit each other. Many other qualifications can be added, making the rules for using the rowboat almost impossible to apply, and yet anyone will still be able to think of additional requirements not yet stated. [McCarthy 1980]

Despite their apparent variety, these definitions fall into two natural categories: those emphasizing the computational difficulties in dealing with a large (but clear-cut) set of conditions, and those emphasizing the underlying lack of precisely specified circumstances and characteristics of real-world objects. While this is not stated in such sharply contrasting fashion in the literature, we will argue that it is in fact at the heart of the various approaches to "the frame problem." In fact, McCarthy's statement above straddles our two categories. It suggests both "too many" and also "can't be done – no end in sight". We think these are essentially different, and discuss this in the following sections. The other differences, especially what does not change as opposed to what does change, are not significant. Indeed, what does change is the complement of what does not, and so these are really dual problems, equally solvable or unsolvable.

III. The Mathematical Frame Problem (MFP) Consider again the definition given by [McCarthy and Hayes 1969], particularly their contention that there can be up to *nm* needed frame axioms given *n* actions and *m* properties. Given a mathematically precise world, this can indeed be the situation. In fact, it can easily be shown that the potential upper bound on the number of blocks world frame axioms can even be much greater than *nm*: it is exponential, roughly on the order of m!n. This is a severe computational difficulty for deciding what has and has not changed as state transformations occur. Note that the situations in which this kind of counting of actions and properties is possible characterize the so-called *blocks world* problems. Blocks world problems make many simplifying assumptions, and are not real-world (commonsense) problems. They are instead precisely defined ideal situations in which blocks and other entities *by definition* do what the axioms say. Similarly, we can think of a chess-playing program as another victim of exponential computation. Consider, for example, a chess program that incorporates a WINS predicate.

That is, WINS (s,x) means that player x can win from board state s. Clearly, WINS (s,a) is decidable, but this is not enough. We would like a smart program to always know whether it can or cannot win from some position. Thus, if WINS($s sub 0$,a) is true, where $s sub 0$ is the state of the board at the beginning of the game, we would like our program to never move to a board position t such that WINS(t,a) is false. Of course too much time will be required for this to be practical, and so much effort has been spent on finding heuristics to shorten the search. We grant that there is a difference between the above two examples. Whereas the blocks world is stifled by too many axioms, the chess program is not. In fact it is rather easy to write the one rule necessary to decide the WINS predicate (though not easy to calculate its truth or falsity). Nevertheless we still believe that, in essence, it is the same culprit that is at work in both of these cases: time (and space) intractability. That does not mean these problems are inherently or conceptually without formally correct solutions; solutions do indeed exist, but they are not ones that (in general) can be found in reasonable time. So heuristics are called for; their job being to solve the **MFP** in specific domains. We mention that approaches to "solving" the computational frame problem [STRIPS (add and delete lists), McCarthy-Hayes' state space (frame axioms), and Hayes' causality (what is not affected stays the same)] do not really solve it so much as present representational schemes for expressing it. That this is possible at all characterizes this version of the frame problem. We now turn to the other type of frame problem.

IV. The Commonsense Frame Problem (CFP) The second principal view of the frame problem seems to be based on the notion that it might not even be *possible* to axiomatize any significant portion of the real world in which a smart program might have to exist. That is, formally correct solutions to the problems that fall under the rubric of the **CFP** *do not exist*. In support of this idea we remind the reader of McCarthy's [1977] view above, part of which indicates that the complexity and ill-definability of the real world is what causes the qualification problem and the frame problem to be a problem at all. This has been stated in an even stronger form by Hayes [private communication], namely, that "there is *no* set of axioms" that correctly characterizes the trajectories of commonsense objects. He gives the example of a teacup on a saucer; if the saucer is lifted, will the cup rise with it? This depends on not merely *many* factors (Is the saucer tilted? Is a string tied to the cup handle? Is the cup metallic and pulled aside by a magnet?) as in the **MFP**, but a literal infinitude, forever beyond precise specification. What is going on here? Why should things be so complicated that they *cannot* be specified correctly, even in principle? Clearly the answer is that commonsense reasoning deals with ill-defined concepts. That is, the everyday world seems populated by things that fall into categories, but these categories on closer inspection defy precise characterization. Philosophers have been interested in the problem of ‘‘kinds’’ for some time. This is the problem of analyzing the apparent phenomenon that the world consists in large part of certain ‘‘natural’’ and ‘‘artifactual’’ classes of things, such as planets, rocks, living things, noises, pains, clouds, stars, leopards, and so on. One thorny problem that arises in this effort is the fact that it is notoriously difficult to pin down precisely just what constitutes a particular class. That is, there is no firm agreement on just which things are or are not clouds. How small can a ‘‘cloud’’ be, for instance, before it no longer is a cloud? Or, how ‘‘alive’’ must a living thing be (e.g., a virus)? Kinds seem to have extremely rough boundaries. Thus the entire commonsense world seems populated with categories of things that we find immensely useful to think about in planning our daily getting around, and yet which defy precise definition. Since we think in terms of categories that are in large measure ill-defined, then the formulation of rules governing their behavior is necessarily error-prone, and hence, we have the qualification problem. We think ‘‘birds fly’’ and yet, of course, not all birds fly. The class of birds, even of flying birds, is ill-defined. Thus keeping track of how things behave is, in principle, impossible, unless we settle for approximate answers and occasional outright mistakes. This in fact is what default reasoning is all about. Too many things can go wrong for us to take them all into account, not simply because of sheer numbers, but even more because of ill-defined concepts. There simply is no final word on what makes a bird. Zoologists notwithstanding, a bird can fail to have feathers (it may be too young, or diseased, or genetically impaired). The offspring of feathered birds may (by some fluke event) fail to have feathers and yet be perfectly able to bear fertile young. We suggest that the answer to McCarthy’s conjecture that the frame problem is reducible to the qualification problem, is yes: that, in fact, the determination of the appropriate qualifications for a given phenomenon in a given circumstance amounts to deciding what its ‘‘kind’’ is in that circumstance (a car, a metallic thing, a vehicle, a physical object, a heavy thing, etc). This ‘‘kind’’ then determines the inheritances that allow the question of its trajectory to be settled. The qualification problem, then, can be seen as arising from the fact that we are dealing with classifications of things into categories that do not correspond precisely to what happens: inherited properties are not necessarily correct, and thus these inherited values are better seen as defaults. Here it is not time and space that are the enemy of a smart program, but rather the unavailability of sufficient precise (mathematical) concepts to define the world of commonsense. Approaches to dealing with the natural kinds frame problem include the following: circumscription (McCarthy [1980]), defaults (McDermott and Doyle [1980], Reiter [1980]), real-time reasoning (Drapkin, Miller, and Perlis [1986]). These also (at least at present) do not *solve* this version of the frame problem, so much as allow mechanisms for expressing the problem. However, unlike the computational frame problem, these mechanisms are not formally correct. They depend on constructs that can have no unassailable formulation; hence they must be viewed as approximations.

V. Discussion Taking the frame problem to be that of keeping track of what changes (and what does not change), we see that it involves first describing the type of entities and their behavioral properties in the domain in question. Thus solving the frame problem necessarily depends upon solving the qualification problem which, in turn, depends upon solving the kinds problem. In a mathematical domain, there are formally correct solutions to all of the problems, but they bring with them expense in time and space. On the other hand, in the commonsense domain, there exists no precise solution to the kinds problem and thus no precise solution to either the qualification problem or the **CFP**, so that other methods are needed. We believe that real-time reasoning models (see Elgot-Drapkin, Miller, Perlis [1986] and Drapkin and Perlis [1986]) are a key to this problem.

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