Chapter 6

A methodology for modeling context

6.1 Introduction

Our overall goal is to study context with regard to the construction of knowledge based systems. We have developed a methodological framework that originates from Newell’s knowledge-level paradigm in order to systematically study the notion of context.

Context has not been studied systematically in AI. In particular, we have not found any knowledge level account of context. Although some arbitrary use of context can be encountered, even in the early expert systems, such as MYCIN, this was not done in a systematic way. But recently some initial work has been done (e.g., International and interdisciplinarly conference on modeling and using context, Brasil, 1997). Therefore, we did not have much to build on. In this chapter we show how a task-view provides important points of leverage in recognizing and subsequently modelling the categories of contextual knowledge. We also show various types of contextual influences in problem solving.

A strong motivation for research on context is its important role in information processing. Studies within the cognitive sciences have tried to identify this role. It is generally agreed that context facilitates the selective processing of information, whereas disagreement exists as to what context actually is, and in what way it affects processes of problem solving and learning. An earlier trend was to consider context as a holistic phenomenon, and to review the context effects on various processes in a uniform way. This entails referring to context without making a distinction between various types of contexts. Yet, different types of context elements have been observed to indicate a significant difference in their effects on memory. Thus, the issue of the role of context is closely related to the issue of the distinction among several types of context elements.

In the following chapters, we clarify the elements of context relevant to a problem situation, and the roles of these elements are constraining in guiding a reasoning process. Our general research agenda is to improve artificial intelligence methods for problem solving and learning in open and weak-theory domains. An example of such a domain is medical diagnosis and treatment. Since there exists no neat theory from which to deduce conclusions for these type of domains, we have to rely on abductive methods that combine several types of available knowledge in interpreting a problem situation, generating and evaluating hypotheses, building explanations to support or reject them, etc.

In pursuit of a content theory of context’s use in problem solving, we exploit the interconnection between disparate disciplines such as cognitive psychology, philosophy, linguistics and AI. Context is studied differently in cognitive psychology and in AI. These two views are, however, intimately related; AI uses models offered by cognitive psychology.
6.2 Distinction between the elements and the roles of context

In attempting to make a theoretical account of context, we have noticed that a large number of researchers have studied context with reference to a specific area or a specific problem, isolated from other context studies. An important question is whether there may exist some aspects that are shared by several researchers or research communities that study context effects. A distinction between the elements of the context and the roles of the context may help to answer this question. Studies show that the identification of context elements heavily depends on the type of task and domain in question. On the other hand, the role that context plays can be generalized over specific tasks and domains. We will therefore start out by assuming that the role of context does not show much variance across domains or tasks, whereas the elements of a situation that play these roles do.

In the next section we present our view on the roles of context not with respect to a particular task or process, but at more abstract level. These issues are related to the elements of context which are analysed in chapters 7 and 8. The exact roles of context at the process level, and the general strategy to investigate the roles of context at that level are presented in chapter 9.

6.2.1 The role of context - relevance and focus

The notions of relevance and focus capture the essential aspects of context roles. Relevance refers to the appropriateness and usefulness of a response in a particular environment. Reasoning from natural language is dependent on the social context. For example when you ask “How is your family” to a 14-year old school girl you mean by “family” her mother and father. If you ask the same question to your colleague whose wife you know is sick, you mean his wife. The meaning of a statement may be different in different contexts. It is our ability to quickly shift from one context to another that makes our every day life bearable.

At a more detailed level, context is important for the generation and evaluation of explanations. People asking why an airplane crashed will not be satisfied with the answer, ‘because of gravity’, even though this is not wrong. A possible acceptable answer would convey an anomaly that occurred, for example, in the engine of the plane.

Generally, principled knowledge (i.e., textbook knowledge) does not change across its users or the situations in which it is used. However, the use of principled knowledge is relative to the context in which it is applied. Relevance is, therefore, directly proportional to the quality of the solution produced for a problem. In problem solving, there exist several lines along which to reason, and often several alternative solutions to a problem. Context plays an important role in choosing the most relevant candidate. For example, recommending an angioplasty in a hospital which lacks the necessary instruments will not be useful.

In addition to relevance, the other main role of context in problem solving and learning is its focusing ability. Focus is important, for ensuring efficiency of the problem solving process while maintaining relevance. At any point, the attention of a person is focused on particular issues and also particular aspects of that issue. This is necessary because the amount of information that reaches us is huge. Neither our cognitive capacities nor our
time is enough to process all that information in detail. We focus our attention in two ways: concentrating on certain goals, and focusing on a portion of knowledge and information that may be related to that goal. Context plays a significant role in concentrating on the most adequate goal among several ones, as well as in focusing on the most ‘relevant’ portion of information. When there exist several possible solutions, the one which is most relevant to and consistent with the current context is preferred.

6.3 Research goals

We investigate the notion of context along two dimensions: as a knowledge type, and as a means for focusing attention.

The view of context as a knowledge type sets up the goal of identifying elements of the context for a particular domain. Context has usually been referred to as atomic, like a closed box. We attempt to look into the box, and break it into meaningful and useful pieces, in the form of knowledge types.

The other dimension is concerned with context as a means. So, its effects are of interest in this view. The questions pertaining to this view are what is contextual knowledge for? What kind of roles and effects may it have? Where and when may these effects be the matter of fact? And how may these effects be realized?

We may now list four research subgoals which we will investigate in the following chapters:

- categorizing contextual knowledge types, i.e., defining a context ontology
- categorizing contextual effects
- mapping context effects to the context ontology
- realizing the contextual effects in an AI system that uses the ontology

6.4 A Task-centered methodology for studying context

Modelling the process of diagnosis involves identifying the subtasks which, when accomplished, lead to the achievement of the diagnostic goal, i.e., finding the fault causing the abnormal observations. It is exactly these subtasks that have a central role in modelling a shift of attention. This is because the subtasks are the loci where a shift in the focus of attention may be invoked. Knowledge level analysis can be performed from different knowledge perspectives, i.e., a task perspective, a method perspective or a domain knowledge perspective. The tasks, in turn, identify the need for knowledge, including contextual knowledge. We start by locating the subtasks of the whole diagnostic process where contextual knowledge is useful. After locating the points of contextual knowledge use, we try to understand the way these influences come into existence. The last step is in attempting to analyse the types of knowledge being utilized at these points.

The process of modelling contextual knowledge can be considered as consisting of two activities: (i) typing/categorizing contextual knowledge, and (ii) identifying what kind of role each type plays, and where/when this happens during problem solving. This leads to
two perspectives that are not mutually exclusive, but closely interrelated. They consider context as, respectively,

- capturing a special type of knowledge and information, and
- a means for triggering a shift in the focus of attention.

The first perspective leads to the study of how contextual knowledge can be categorized, starting with the context ontology. The second perspective takes, as a starting point, an application task (in our case diagnosis) and identifies the subtasks of the overall diagnostic process where some contextual influences are anticipated, as well the role of contextual knowledge in each subtask.

The “focus of attention” perspective leads to the study of the relationship between a task and the type of context that it relies on. We may also say that the first perspective adopts a static view, while the second one is more concerned with dynamic aspects of context, i.e., its use.

A discipline that provided us with much support and insight in developing a methodology for investigating context has been medical research. The link between process and content, emphasized by Barrows [Barrows 94], in teaching medical expertise, has guided us toward the way we study the contextual knowledge, a continuous attempt to keep the link between the reasoning process and the disease process.

The idea of the dependence between the knowledge and its use, proposed in AI by Chandrasekaran [Chandrasekaran 92], agrees with Barrows’ emphasis on the link between process and content in connection with problem-based curricula in medicine.

According to van Heijs et. al., [van Heijst 97] the following activities are identified in the construction of a knowledge-based system: (i) construct a task model for the application; (ii) select and configure appropriate ontologies, and if necessary refine these; (iii) map the application ontology onto the knowledge roles in the task model; (iv) instantiate the application ontology with domain knowledge. Although we have a different motivation (than reusability) for our study, we have found this account a useful basis for a knowledge level analysis of context.

Inspired by the way cognitive psychologists have studied context empirically, and from van Heijs’ approach to knowledge-level analysis and modeling, we developed a methodology which we employed in this work in order to analyse the notion of context in diagnostic problem solving. Our methodology can be expressed as a sequence of four research subprocesses:

- construct a model of diagnostic ‘process’ knowledge. This serve to explicate all the relevant application subtasks (i.e., diagnostic subprocesses),
- identify the loci of contextual effects (i.e., the subtasks where context may have an influence)
- identify the role that context plays at each locus (i.e., the way it effects each subtask)
- identify the source of context that can play these roles.

As an example, figure 6.1 illustrates the entities, such as loci and source, that our methodology explicates when applied to the medical domain. In the figure, the task-tree is a part of process knowledge, and the contextual domain knowledge is part of the general
domain knowledge. ‘Formulate-hypothesis’ is the name of a task, while ‘age’ is a concept belonging to contextual domain knowledge. What we illustrate in the figure is that the ‘generate-hypothesis’ task is a loci where context affects the process. The type (i.e., source) of this context effect is ‘age’, which is an element of the general domain knowledge, thus ‘content’. This figure also provides an insight into how we realize the link between the ‘process’ and the ‘content’ knowledge.

<table>
<thead>
<tr>
<th>loci of context effects (task name)</th>
<th>source of context effects</th>
<th>core domain related source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>age</td>
<td>high-fever</td>
</tr>
<tr>
<td>generate-hypotheses</td>
<td>habit</td>
<td></td>
</tr>
<tr>
<td>[task-tree diagram]</td>
<td>[contextual domain knowledge diagram]</td>
<td>[core domain knowledge diagram]</td>
</tr>
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FIGURE 6.1  The tasks in the task tree describes both the loci and source of contextual effects, in terms of the entities in the knowledge base. This figure partially shows the way how contextual elements are integrated in our system.

In chapter 7 we survey studies from cognitive psychology on context, and illustrate how a global interpretation of these experiments reveals two dimensions which possibly shaped the way these experiments are set up. We may see from the experiments that the two parameters which have been used for detecting context effects are the various kinds of contextual elements, and various kinds of learning tasks. So, tasks may be a starting point for investigating the elements and effects of context. We, therefore, attempt first to determine the subtasks of the diagnostic task. We do this by applying the method of scientific inquiry, as proposed by Peirce, to the diagnostic task and determine the subtasks underlying medical diagnosis. These subtasks comprise a set of loci from which we can point to various context effects.

6.5 Categorizing contextual knowledge types

We place contextual elements in both general ontology and in the domain knowledge base. In particular, we are interested in identifying different types and setups of contextual knowledge. This will make it possible to refer to, and to be able utilize contextual information of various types and at different abstraction levels. Context research in cognitive psychology has studied both theoretically and empirically the context influences. As we will see in chapter 7, the empirical studies of context are centered around experiments which study context effects on a particular task. The tasks
are most often cognitive tasks such as word learning and remembering in various contexts, face recognition, or eyewitnessing. Any context that is used in such experiments embraces a set of contextual information. The experimenters observed whether the use of a chosen set of contextual elements did or did not affect the reasoner’s cognitive performance. The aim of the early experiments was only to show context effects in general. A global look into the empirical results indicates that different tasks use different contextual information. Based on this presupposition, we classify the different types of contextual information.

6.6 Categorizing context effects

The main intention underlying the attempt to categorize the context effects is to develop a framework within which context effects may be mapped out. This research task will be accomplished when we are able to determine which type of contextual information, and in which stage, context influences an overall problem solving process.

Even though we are mainly interested in explaining context effects in diagnosis, as most context studies in psychology go hand in hand with understanding perception, we start by understanding several context effects, which we will then transfer to diagnosis.

Cognition involves an immense number of skills and processes. The acquisition and use of skill and process knowledge, according to the “information processing” view, consist of a number of separate stages. Researchers have proposed various models of perception in order to describe the subprocesses where context influences are determined. Figure 6.2 (From Reed 91, p. 5) illustrates the stages that are commonly included in the information-processing model. This model we use in order to understand the context effects observed in different areas such as perception, memory, language, concept formation, or concept categorization.

It has been recognized that perception has a selective nature. This must be so, because otherwise the human cognitive system would be overloaded with information. An implication of this is that attention must be selective. So far there is agreement among researchers. However, theories vary as to the stage at which this selection occurs. For example, does selection occur before or after pattern recognition? We will not go into the detailed discussions that one can encounter in the literature, but rather give some ideas about how some cognitive psychologists relate context to human cognition. Then we turn to diagnosis and locate the stages of diagnosis at which context effects may be postulated.

FIGURE 6.2 Stages of an information-processing model (from [Reed 91, p.5]).
External stimuli bombard human sensory receptors, where they are converted to signals. These signals are stored in the sensory store for a brief period. At this stage what differentiates between signals is their physical characteristics, such as intensity and location. When they come to the pattern recognition stage, other characteristics are used to recognize them. When we recognize a familiar pattern we utilize the knowledge that we previously stored. Some theorists claim that humans have a rather low capacity of pattern recognition. So, there must be filtering to determine which signals are to be recognized. The mission of the “filter” is thus to eliminate some signals when many patterns arrive. Other theorists argue that many patterns are recognized simultaneously but not all of them are stored. “Selection” determines which are to be stored. Thus, “the filter limits the amount of information that can be recognized at one time, and the selection limits the amount of material that can be entered into memory” [Reed 91, p 6], i.e., learned.

This implies that attention is possibly focused in several loci, in order to ensure a balance between the amount of things to be learned and the human cognitive capacities. Context is claimed to have an influence in the filtering mechanism as an attention focuser. For example, the person may be instructed to pay attention to a man’s voice rather than a woman’s [Thomson 86]. This instruction is a form of context, in this example. Another context effect may be seen when the pattern recognizer has many alternative identities. For example, when the pattern recognizer has to choose between cat or lion as the identity of the figure on a picture. It may base its selection on the biases implied by the context, such as information about adjacent objects. “Cat” will possibly be the right identification if the picture is taken inside a normal home.

We want to stress that our general approach is not to duplicate cognitive process models of human behavior when constructing computational decision support aids. We try, rather, to borrow some ideas from human context utilization and, on this basis, construct a plausible model for an AI system. In the following chapters, we develop a similar model, but for diagnosis and use that model for explaining the context effects in diagnostic procedures. The task of locating and categorizing context effects can not be accomplished without making a model of the process that one intends to deal with.

### 6.6.2 Context effects vary

In ‘empirical’ tasks such as scientific inquiry and diagnosis, we may summarize two important roles of context as situating a problem

- in the reasoner’s memory, and
- in the real world.

The former may intuitively be related to what Peirce calls ‘abductive talent’. The latter is related to the pragmatic aspects and utility considerations of problem solving. At the very top level, we classify tasks involved in real world problem solving as cognitive and physical tasks. Both types of tasks utilize contextual information, but they use different types.

Cognitive tasks are triggered by observations made in the real world, and physical tasks are guided by memories. It is just these connections between memory and the real world that shape the course of problem solving. These connections are context-sensitive. For example, when observations trigger a cognitive task, which parts of the memory that will be evoked is not independent of the context in which the observations occur. Similarly,
when it comes to acting in the real world, our knowledge about the situation determines what types of actions will be of benefit. This implies that context serves as a bridge connecting mind to reality. Figure 6.3, illustrates that parts of both memory and the real world have contextual components. In humans, the mind possesses a model of the real world. The real world is contextualized, that is, there is no single ideal world, but several versions of it. The inclusion of contextual aspects into the mind’s model of the real world, makes the mind closer to reality. At least the gap between the real world and its model gets smaller by enhancing the model with contextual components. So, an artificial system which models the mind’s model of real world will also greatly benefit from context. A contextualized artifact will be more similar to, in an indirect way, the real world than one which is not contextualized.

A system performs one of two types of tasks at any moment, i.e, either a cognitive or a physical task. Cognitive tasks are performed in the mind, based on the information available in the real world, often by using memory. Physical tasks, on the other hand, imply interaction with the physical world by way of taking some actions. The real world is contextualized and is there independent of the mind. That is, it is there regardless of whether the mind is capable of using it or not. A model which is not capable of recognizing contextual information that the real world provides cannot properly cope with such a rich world.

As stated in chapters 4 and 5 in connection with the role of abductive inference in inquiry, inquiry means formulating hypotheses at the first place that explains a surprising phenomenon in the real world. This is a cognitive task and utilizes memory in order to find stored memories that can shed light on the phenomenon. In case the memory is tuned by contextual components, then there is a large possibility to find a memory which can, to a substantial degree, help to explain the newly observed phenomenon. Testing hypotheses entails physical interaction with the world. When taking actions in the real world, the mind should recognize the realities of the world it is operating in, its resources and possibilities. The actions which are wisest to take are those that best agrees with reality.
6.7 The map between context elements and effects

Different application subtasks render different context effects which are maintained by different contextual elements. For example, some tasks involve only memory, such as recognizing somebody. You may easily recognize the bus driver whom you sometimes see when you take the bus from your job. On the other hand, you may have difficulty remembering him upon seeing him at the cinema. So, the task of recognizing people you know in connection with their job, is conditioned on the location you required to recognize them. The location-context has a facilitating effect on your recognizing people who you know in connection with their job. You associate location with such people. Another, rather different example is the task of drinking water from a glass. Here, the type of glass and whether it is completely full, or half full becomes important for how you drink water. So, for the drinking-water task, context may have a more physical importance, e.g., you may decide to make different motions in different contexts. Therefore, for a knowledge level model, it is important to make explicit links between a task, and the elements that facilitate or inhibit the performance of that task.

The preceding research tasks are assumed to establish a model of the application tasks, and to specify where and which type of contextual information is expected. What remains is to explain how these effects happen, that is, in what way contextual elements are facilitative or detrimental at each stage that they are believed to have influence. Such an elaboration is necessary before developing the model of an AI system that illustrates context-guided reasoning. Based on the importance of past experiences in problem solving and learning, we adopt the case-based reasoning paradigm to explore our context-sensitive approach to problem solving. This is elaborated in chapter 10.

6.8 Summary

This chapter highlights two concepts along which the notion of context can be investigated, its elements and its role. The role of context is twofold. It provides the loci where a shift in the focus of attention is triggered. It also provides a means to focus attention. We have also presented a methodology that supports a systematic modelling of context in a domain. In later chapters we will discuss how we applied this methodology in our work. The term ‘context’ has, in recent years, been used in order to account for a wide range of behavioral phenomena. Much empirical research is also devoted to context. However, the focus of the research was not on understanding the phenomenon itself, but context has rather been used as a tool for investigating other topics [Wickens 87]. An example is the line of research investigating the structure of semantic memory, where the question is whether words are stored as a set of interlinked features. Another line of research investigates the nature of forgetting and remembering. So, empirical research on memory has been the natural medium for context research. In the next chapter, we summarize the empirical and theoretical results provided by cognitive scientists on the study of context. In order to clarify the elements of context in any domain, a need arises for a context ontology. We will develop a context ontology in chapter 8.