A Categorization of Contextual Constraints*

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Abstract

We present a categorization of contextual constraints, and discuss their uses in embodied agent architectures. "Context" has been described as a difficult term to define, because it's: (1) used across numerous disciplines in cognitive science and computer science; (2) relative to an agent, or device; and (3) relative to the cognitive process being examined and experimented upon. As such, context is a consequence of theories about cognitive processes, not something observed. It has a theoretical role, not one of a measurable unit. We will take context to be *the structured set of variable, external constraints to some (**natural** or **artificial**) cognitive process that influences the behavior of that process in the agent(s) under consideration.* By reviewing the cognitive science disciplines of linguistics, psychology, knowledge representation, and human-computer interaction, we've identified contextual factors that can serve several uses among embodied cognitive architectures, such as knowledge acquisition, knowledge partitioning, and context switching.

Introduction

In this paper we present a categorization of contextual constraints, and discuss their uses in embodied agent architectures. "Context" has been described as a difficult term to define as it's: (1) used across numerous disciplines in cognitive science and computer science; (2) relative to an agent, or device; and (3) relative to the cognitive process being examined and experimented upon. As such, context is a consequence of theories about cognitive processes[1], not something observed. It has a theoretical role, not one of a measurable unit.[2] It follows that any discussion necessitates knowledge of the relevant background information, or more properly a definition. Several surveys have been undertaken previously (Bradley & Dunlop 2005; Brézillon 1999c; 1999a; Bazire & Brézillon 2005; Bouquet *et al.* 2003) that analyze what context means across cognitive science, and some have offered multi-disciplinary definitions. For our purposes, we will take context to be *the structured set of variable, external constraints to some (**natural** or **artificial**) cognitive process that influence the behavior of that process in the agent(s) under consideration.* Though this definition is broad in scope, it does exclude some factors. For example, if examining the effects of context on memory recall, contextual constraints would include aspects of the surrounding environment, such as a bookshelf, but not constraints internal to the recall process, such as interference from other encoded memories. The goal of this paper is two-part; present a categorization of contextual factors, and how they constrain various processes; and present some uses of contextual factors in embodied knowledge representation, reasoning, and acting. Typically, reviews of context have focused on the use of "context" in linguistics, cognitive/experimental psychology, human computer interaction, and knowledge representation. In the following sections we discuss the various process constrained by context in these disciplines. By examining the use of "context" in the various disciplines, we develop a categorization of contextual constraints. Uses for this categorization in embodied knowledge representation and reasoning are briefly considered before concluding.

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[1]For example, a consequence of memory theories that explain the role of environmental changes on recall (Smith & Vela 2001), or linguistic theories that explain the role of surrounding text on dialogue decision procedures (Bunt 1999).

[2]This is not to say that there are no measurable elements of context in these theories, just that context is a theoretical framework that "binds" them together.

Contextual Constraints and Processes

Contextual constraints have gone under various names across the various disciplines considered. It has been termed "context parameters" (Benerecetti, Bouquet, & Ghidini 2000; McCarthy 1987; McCarthy & Buvač 1997), "dimensions of context" (Bunt 1994; Lenat 1998), "contextual elements" (Brézillon 1999b; Brézillon & Brézillon 2007). Despite the abundance of terms, the concept being expressed is clear. These aspects of context are important for the task of identifying the context, and determining how they constrain the process under consideration. As can be expected, these processes vary between disciplines, though there is some overlap. These processes are briefly summarized below.

Linguistics approaches the study of context as an influence on the processes of interpreting an utterance, and producing an utterance. A type of process that is useful, but still a form of interpretation, is constructing a mental context for interpretation (e.g., when reading a work of fiction) (Bradley & Dunlop 2005).

Cognitive and experimental psychology, hereafter, "psychology", examines contextual influence on the cognitive processes, such as perception, learning, and memory (Bradley & Dunlop 2005). While each of these is a process of its own, the interplay of each process can fall under the general process, cognition. In this sense, each cognitive process can act as a constraint on another cognitive process, and thus, the former is a contextual constraint on the latter. This notion is exemplified in experiments that study the influence of environment on the recall process (Godden & Baddeley 1975; Smith & Vela 2001), and those that demonstrate the effects of mental reinstate of environment, demonstrating how another cognitive process, namely "imagination", can serve as a constraint on the recall process (Smith 1979; Smith & Vela 2001).

Human computer interaction (HCI) examines the influence of contextual constraints on computational devices that interact with a user. This research endeavor falls under the broad category of "context-aware computing", which uses context to provide relevant services and information to a user (Dey 2001). Typical processes in HCI include: user preference learning and selection, autobiographical construction, providing relevant information based on context, and relevant operations (Dey 2001; Chen & Kotz 2000; Bradley & Dunlop 2005).

Knowledge representation and reasoning (KRR) seeks to formalize context, a need that grew out of the identification of the *problem of generality*, which is essentially the notion that any representation of knowledge can be criticized as eliminating some influential properties useful to other domains not (yet) represented in the current knowledge base (McCarthy 1987). As such, one process that context can constrain is the process of representation itself,[3] where the context determines how general or specific a logical representation can be. Furthermore, the process of developing the logic used for reasoning is also constrained by contextual aspects, such as: the locality of logical semantics and syntax, and *a priori* considerations that effect initial relationships between contexts (Buvač 1996; Benerecetti, Bouquet, & Ghidini 2000; Bouquet *et al.* 2003).

Other processes that can be constrained by context in KRR include; knowledge acquisition (Brézillon 1999c; 1999a), large-scale knowledge base partitioning (Bouquet *et al.* 2003; Brézillon 1999b; Lenat 1998), providing relevant information (Arritt & Turner 2003), and providing semantic interpretation (Brézillon 1999b).

[3]More appropriately, this can be viewed as constraining the memory encoding process of some agent, though a knowledge engineer is performing the encoding process.

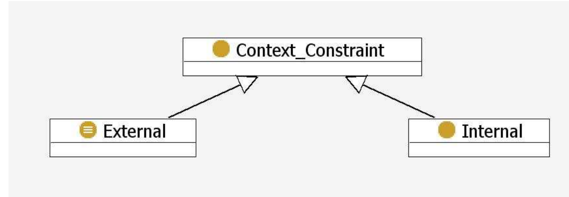

Figure 1: The Top-level of Contextual Constraints

A Categorization of Contextual Constraints

The cognitive processes discussed in the previous section can aid in the elicitation of a general categorization of contextual constraints. Though the processes vary between the disciplines considered, there is much overlap in the contextual constraints utilized in recognizing and using context among them. The top-level of the categorization is depicted in Fig. 1,[4] with arrows indicating subclass-superclass directionality. The various "levels" of this categorization, how these factors are viewed in the independent disciplines, if at all, and typical instantiations of them as discussed below. However, this categorization serves as an overview of constraints discussed in the field, without getting into too specific details (e.g., the categorization stops at "events" in the "external" subtree. We can easily categorize more event types, such as weather systems).

The External-Internal Dichotomy

If context is the set of constraints external to some cognitive process, as we claim, it might seem contrary to the proposed definition to consider contextual constraints that are *internal*. Furthermore, "context" is often used synonymously with the environment, arguably *the all-encompassing external* constraint. Despite these intuitions, the literature does make a distinction between contextual constraints that are *external* or *internal* to an agent "executing" the process constrained. These two constraints can go under numerous pseudonyms,[5] but denote the same categories of constraints.

In linguistic processes, like CVA,[6] a distinction is placed between *external* contextual sources, like dictionaries and the words themselves, and the reader's *internal* "prior knowledge" (Rapaport 2005). *Internal*

[4]Hierarchy constructed using Topbraid (Top Quadrant Inc. 2007)

[5]As is the case for many of the categories considered in the categorization.

[6]A process of determining word meaning from surrounding text and background knowledge.

and *external* constraints have also been found to play a role in the *dialogue control* processes, called, by Bunt, the "cognitive context" (which contains background beliefs, intentions, and plans) and "physical context" respectively (Bunt 1994; 1999).

In a brief review of psychology literature on context, Bradley and Dunlop (2005) present a distinction between the two, "*[external] context* would be the situation or environment the person is in, and the *internal context* would be the internal knowledge/mechanisms underlying the person's cognitive processes (e.g., mood, state-dependent effects)". Consistent distinctions are made by Smith (1979; 2001) in the psychological memory literature.

In HCI, Gwizdka (2000) introduces a *context model* for context-aware applications that makes a clear distinction between "internal context", which takes into account the user's state, and "external context", which includes factors external to the user. The concept of using the user's internal state and physical environment as a constraint for devices is prevalent in the HCI literature (Abowd *et al.* 1999; Chen & Kotz 2000; Dey 2001; Bradley & Dunlop 2005).

Finally, in KRR, most work has concerned itself with constraints placed on the representation of the knowledge itself,[7] and typically these constraints, or parameters, are external in nature. Part of this can be attributed to the notion that knowledge bases aren't always treated as embodied agents but rather disembodied, logical databases. However, not all proposed uses for contextual parameters are divorced from *internal* constraints. McCarthy and Buvač (1997), propose a use for contextual parameters as justification for belief in propositions, where the agent's *internal* rationality for believing all the propositions in a context is a parameter. In (Brézillon 2005) three types of knowledge involved in context are proposed, one of which, named "contextual knowledge", is said to "[depend] on the actor and the decision at hand". Here, a decision can be considered an *internal* constraint.

It's clear from the previous that there is a distinction between *internal* and *external* contextual constraints that appears when considering the perspective of an agent or device. Since context, as we've defined it, is considered relative to both a process and an agent or device executing that process, all contextual factors will fall into either category when both a particular agent/device and process are taken into consideration. The following sections will discuss the type of constraints that emerge in both categories when considering particular agents, and cognitive process.

External Constraints

While all of the disciplines discussed have constraints *external* to the processes considered, the constraints

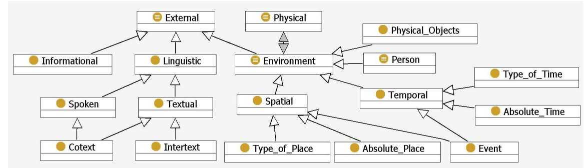

Figure 2: The External Contextual Constraints

that fall into this category vary between disciplines. We've identified three general categories of *external* constraints depicted in Fig. 2.

Environmental constraints are discussed across all disciplines, and sometimes it's taken to be synonymous with context (Dey 2001). However, what is typically regarded as a type of environmental constraint varies. In linguistics, Bunt (1999; 1994) has developed a model of dialogue control that incorporates a "physical/perceptual context" that includes the *environmental* constraints discussed above. The "physical context" is divided into "global" constraints, which include *spatial* and *temporal* constraints; and "local" constraints, which include the *people* or *agents* involved in the dialogue. Bradley and Dunlop (2005) describe similar models in the area of linguistic "situation theory".

In psychology, all of the *environmental* constraints appear as influential to the variety of cognitive processes. Most notably are studies involving memory. Godden and Baddeley (1975) demonstrate that individuals tested in the same environment that they learned the information have superior recall of that information, showing the *spatial* effects of context on memory recall. Such studies were expanded to show improved ability when *physical objects* (Smith 1979), and experimenter (Smith & Vela 2001), a *person*, were the same. Finally, Anderson (2007b) notes the importance of *temporal* recency of learned material in recall when combined with spatial factors.

Similar to psychology, KRR has incorporated *environmental* constraints as parameters to the sets of axioms that represent a "context". Lenat (1998) has contributed twelve such constraints, among those are *absolute time/space*, which are specific spatio-temporal values (e.g. Mike's Office at 12:00pm); and *Type of time/space*, which are general spatio-temporal locations (e.g. in bed at bedtime). The use of *time* is also supported by McCarthy's (1997) contextualized blocks world example, while the use of *people* is introduced through his use of 'Holmes' as a concept needing interpretation in context[8]. In (Benerecetti, Bouquet, & Ghidini 2000) *people* are utilized to provide interpretation for indexicals.

All of these *environmental* constraints are discussed in the HCI literature. The inclusion of *people* is hardly surprising, since many applications are meant

[7] Though "why" these constraints are placed is subject to the numerous proposed uses for context in KR (c.f. *Uses in Embodied Knowledge Representation and Reasoning*).

[8] More correctly a fictional and real individual named 'Holmes' are used as a constraint, though both are people.

to provide services customized for the user using them (Abowd *et al.* 1999; Dey 2001; Dourish 2004). *Spatial*, sometimes called "physical", and *time* constraints are also discussed frequently (Chen & Kotz 2000). HCI also considers events and actions as constraints. Intuitively, these are spatial and temporal, and as such, they are classified as a subcategory of both *space* and *time*.

HCI is unique from the other disciplines in that it also considers *informational* constraints, or the *computing context*. These include information about services available to a device in question. Such information can include local printing services, workstations, network connectivity, and communication costs (Lamming & Flynn 1994; Chen & Kotz 2000). In general, informational constraints are dependent on data sources, and capable of being sensed and interpreted by the agent or device in question.

Finally, *linguistic* constraints are, unsurprisingly, seen in the linguistics, but also in AI applications, such as CVA (Rapaport 2005). Important to the discussion of context in linguistics is the concept of *cotext*, which is the text that surrounds a unit of language (e.g. words, phrases, etc), and *intertext* the external information sources that are required for interpretation (e.g. dictionaries, books, etc.) (Bradley & Dunlop 2005; Rapaport 2005). With this in mind linguistic constraints can be categorized as *spoken cotext*, *spoken intertext*, *textual cotext*, or *textual intertext*. As can be expected *cotext* can come from two sources, the *spoken* variety or the *textual* variety (Bunt 1994). Intuitively, this notion isn't extended to *intertext* as previous *spoken* dialogues required for interpretation would be a part of an agent's *internalized* memory (c.f., *Internal Constraints*).

That some external constraints, such as *informational*, can be found in some of the disciplines, and not in others shouldn't suggest that these constraints aren't useful in the others. Nor should it indicate that these constraints should be excluded from a theoretical model, or application that wants to make the greatest use of context. Rather, it's further evidence that context is relative to the process and agent executing the process. For example, HCI processes that provide relevant information about the network environment have no need for the spoken cotext or intertext constraints, while a cognitive architecture modeling communication would.

Internal Constraints

The *internal* constraints (depicted in Fig. 3) are split among among two subcategories. Though not typically considered contextual factors, *system resources* act as constraints to the computation underlying processes, as do the sensory capabilities of the devices themselves, and thus fit the initial definition for context provided. However, when *internal* constraints are mentioned in the HCI literature, it's usually in consideration of the user's mental state (c.f., *The External-Internal Dichotomy*).

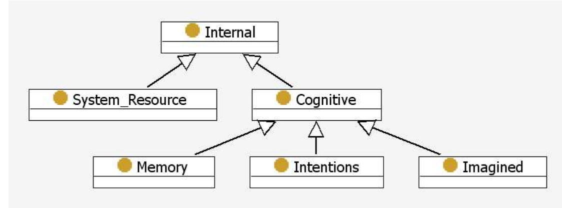

Figure 3: The Internal Contextual Constraints

The *cognitive* side of the *internal* category is largely dominated by the linguistics and psychology fields. There are three primary cognitive aspects that can constrain other cognitive processes; *memory*, *intentions*, and *imagination*.

In linguistics, the contents of an individual's memory play an important role in linguistics as they allow the user to bring to bear appropriate contextual information when interpreting (Bradley & Dunlop 2005). The role of *memory* is also important to CVA (Rapaport 2005), where "personal knowledge" is used to make inferences about potential word meaning. Bunt (1994; 1999) includes *cognitive* constraints in his dialogue control model, which includes *memory* as well as *intentions* and other cognitive attitudes.

In psychology, learned concepts in memory and behaviors can result in effects on other cognitive systems, such as vision, where familiarity with an object can increase object recognition times. Memory studies once again provide a useful source for contextual factors. In (Smith & Vela 2001) one of the hypotheses tested was the mental reinstatement of an environment. The use of *imagination* to visualize an environment where a particular information item was learned, causes that item to be recalled easier. Finally, cognitive models, like ACT-R (Anderson 2007a), integrate several cognitive modules, like *intentionality* and *memory*, each constraining the activities of others in order to better approximate cognitive functionality.

As was the case with the *external* constraints, the *internal* constraints do not occur across all disciplines. However, this is mostly due to the difference in the processing unit under consideration. One one side of the category we have *human cognition*, the other side deals with *device internals*. Though it should be observed that some metaphorical parallels can occur, such as between RAM, and human memory.

Uses in Embodied Knowledge Representation and Reasoning

Embodied cognitive architectures (Kandefer & Shapiro 2007; Hexmoor, Lammens, & Shapiro 1993; Wray & Jones 2005; Anderson 2005) can benefit from the (*conscious* or *unconscious*) recognition and utilization of contextual constraints. The possibilities are probably as numerous as there are cognitive processes influenced by context, but three general categories include:

Knowledge-base partitioning

Large-scale knowledge bases, such as Cyc (Lenat & Guha 1989), can grow to unmanageable sizes, where reasoning is hindered by the vast number of propositions that need to be considered. Also due to the size of such repositories, contradictions can be introduced easily by knowledge engineers. As such, Cyc has split its knowledge base into partitioned belief spaces, called "microtheories". However, how to determine which belief space a proposition belongs to requires a method of indexing. Lenat (Lenat 1998) has proposed twelve dimensions for indexing his "microtheories". While many of these twelve dimensions are considered in the contextual constraint categorization above, some of Lenat's appear custom tailored for Cyc's considerations, and not general embodied architectures (which, to be fair, Cyc isn't). Through the use of such indexing, knowledge engineers can specify where in the KB a proposition belongs by specifying values for any number of the constraint slots (or dimensions), thus, partitioning the knowledge base as it's built.

Contextual Knowledge Acquisition

Knowledge acquisition can be contextualized with the above context factors. If cognitive architectures can recognize certain contextual constraints in their environment, coupled with the contextual constraints in the information they are acquiring, contexts can be constructed automatically by the architecture, instead of relying on a knowledge engineer to place the information in the correct belief space. This is similar to knowledge partitioning, except, rather than taking a large KB and divvying it up, an agent automatically handles the assignment of knowledge to a context as it is learned. A formal logic system that takes into account the contextual background knowledge of an agent coupled with new information being introduced to it, in order to determine where the information belongs, if anywhere, has been proposed in (Sperber & Wilson 1995).

Context Swapping

A "relevancy problem" can be addressed through the use of such factors. The relevancy problem is defined by Ekbia and Maguitman (Ekbia & Maguitman 2001) as "the problem of identifying and using properly [only] the information that should exert an influence on our beliefs, goals, or plans". In their paper they discuss the "Pragmatic View of Context" (a theory of context posited by John Dewey) and, more importantly, the necessity of context to relevancy. One methodology for solving this problem is to index belief spaces with contextual constraints, and then swap in relevant belief spaces when external or internal "cues" align with those indices.

Similar systems have been proposed that address the relevancy problem using contextual constraints, such as the context-based, logic system developed for information communication discussed in (Sperber & Wilson 1995). This system takes new information entering it, couples that with the existing working knowledge, and from that determines the relevancy of the current working knowledge to the input. If the current working knowledge isn't relevant, then a new belief set can be swapped in as working knowledge. Similarly, a system for analyzing perceptual information and using that to "diagnose" the situation, and bring to bear appropriate contextual information for that situation in underwater exploration vehicles has been proposed in (Arritt & Turner 2003).

Conclusions

A categorization of contextual constraints was constructed from a review of the cognitive science literature. This categorization provides useful "parameters" for divvying knowledge into belief spaces, encoding information in the correct belief space, and bringing relevant belief space(s) to bear given contextual "cues". Though many of the constraints included in the architecture were found across all disciplines, some remained unique to their respective disciplines, in particular HCI had *internal* constraints that included *system resources*, and *external* constraints that involved data available to the devices in question. Such distinctions are notable as they support the view that context is relative to a process, and the agents or device under consideration.

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