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# EXTENDING THE C-K DESIGN THEORY TO PROVIDE THEORETICAL BACKGROUND FOR PERSONAL DESIGN ASSISTANTS

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## 1. Introduction

In this paper, we extend the initial framework of the C-K design theory. The original theory is based on the distinction between two expandable spaces: the space C of concepts and the space K of knowledge. The process of design is defined as the co-evolution of C and K through four types of interdependent operators; C → K, K → C, K → K and C → C [Hatchuel and Weil 2002], [Hatchuel and Weil 1999]. It is claimed that the theory is a generalisation of all usual design theories, especially of those whose underlying paradigm is Simon's problem solving [Hatchuel and Weil 2002]. It gives a consistent and formal account of creativity and learning during design. This allows the operationalization of the concept of 'expandable rationality', which is claimed to be better adapted to design then Simon's bounded rationality [Hatchuel 2002]. Yet, despite many practical applications in organizing innovative design processes and recording design rationale, no computational tools that has been built based on the C-K design theory has been reported. In fact, an investigation on how such tools can be built let appear that the theory must be extended to take into account the environment of designers and their situated nature. The aim of the present study is to introduce this extended version and point out how it can be computationally implemented.

To achieve the above-mentioned objective, we use the idea of situatedness. Situatedness is a specific standpoint in cognitive sciences. It holds that the action and the adaptation of an agent cannot be thought independently of the environments within which the agent has been placed [Clancey 1997]. The relevance of the situatedness in the context of designing has also been recognized [Gero 1998], [Suwa *et al*., 1999]. Designers use external representations of designs as means to conceptualise during the design process: it is by the reinterpretations of the results of design actions that the process is (re)oriented [Gero 1998], [Suwa *et al*., 1999].

Based on the essential notions of the situatedness approach, we formulate a new version of the C-K design theory by including the environment space E; the C\K\E theory. Extending the C-K theory by including the environment allows its operationalisation in the form of (computational) situated design agents. Beside powerful features like learning, creativity and adaptation, such tools have solid theoretical background based on C\K\E design theory and situated cognition.

The plan of the paper is as follows. In section 2, we present the main notions of the C-K design theory. In section 3, we argue that a third space, the environment space E must be introduced into the theory in order to build computational tools based on its principles. In section 4, we briefly present the idea of situatedness and use its main notions to modify the original C-K theory by including the space E and two new operators; C → E and E → K. We also argue that computational models of situated design agents are compatible with this new version and therefore, they can be used to build personal design assistants –creative and adaptive design aiding tools. In the final section, we summarize with a conclusion.

## 2. The C – K design theory

The C-K design theory is a theory of reasoning in design [Hatchuel and Weil 2002], [Hatchuel and Weil 1999], [Hatchuel 2002]. Its underlying concepts and formalism give a consistent account of how concepts are formed, analyzed and further developed or discarded within a design process. The theory is based on the fundamental distinction between the concept space C and the knowledge space K; Figure 1. Concepts are elaborated by using knowledge through four types of operators, C → K, K → C, K → K and C → C. The following presentation is mainly based on [Hatchuel and Weil 2002] and [Hatchuel and Weil 1999].

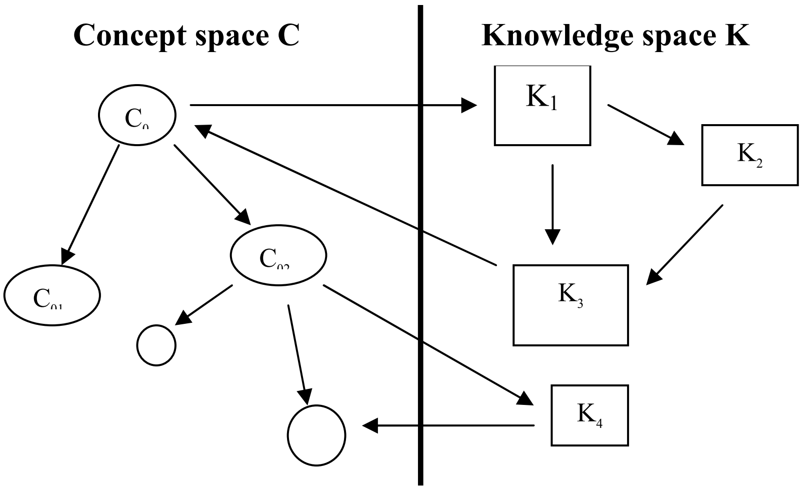


**Figure 1. The concept space C and the knowledge space K, after [Hatchuel and Weil 1999]**

### 2.1 The concept space C and the knowledge space K

A knowledge item is a set of propositions whose logical value (true, false, etc.) is known by a designer with respect to the space K. The knowledge space K consists of knowledge items [Hatchuel and Weil 2002]. The concept space consists of concepts. These are innovative propositions from which design processes may be initiated [Hatchuel and Weil 2002]. A concept has no logical value associated with it; said in other terms, a concept is an 'unknown' entity whose logical value cannot be readily determined with respect to the knowledge available to the designer [Hatchuel and Weil 2002]. Let us consider the concept "mobile dwelling". Indeed, this is a concept: despite our knowledge about what is a dwelling or how something can be mobile, it is hard to describe what is a "mobile dwelling" without first reflecting upon how the conjunction of "mobile" and "dwelling" might be possible.

With each concept can be associated a set of its sub-concepts [Hatchuel and Weil 2002]. In fact, concepts, with their absence of logical status, are partially defined entities. When considering concepts such as "mobile dwelling", "flying ship" or "phone for teenagers" the imprecision that weighs on those concepts creates a semantic richness. Even if we are able to precise some of the properties of a "flying ship" we would not be able to state all of its properties; thus, it is possible to define it in many ways. The set associated with a concept is the set of all concepts that can be defined by developing that concept. Let us remark that such a set violates the choice axiom of the standard set theoretic universe; otherwise, this would be acknowledging the existence of concepts among which it is possible to choose a concept that is yet to be constructed [Hatchuel and Weil 2002]!

**2.2 The beginning and the end of a design process: semantic disjunction and conjunction**

How is it that a concept is formulated? The theory posits that the operation that allows the formulation of a concept is a *semantic disjunction*. An operation from the space K towards the space C is a semantic disjunction if all the terms of the proposition thus created belongs to K (i.e. are known in K) but their conjunction do not have a logical status in K (otherwise, the proposition would be a knowledge item and not a concept) [Hatchuel and Weil 2002]. Hence, the operation leading to the formulation of "mobile dwelling" is a semantic disjunction. Although the terms "mobile" and "dwelling" are known, their conjunction has no meaning before the end of a design process.

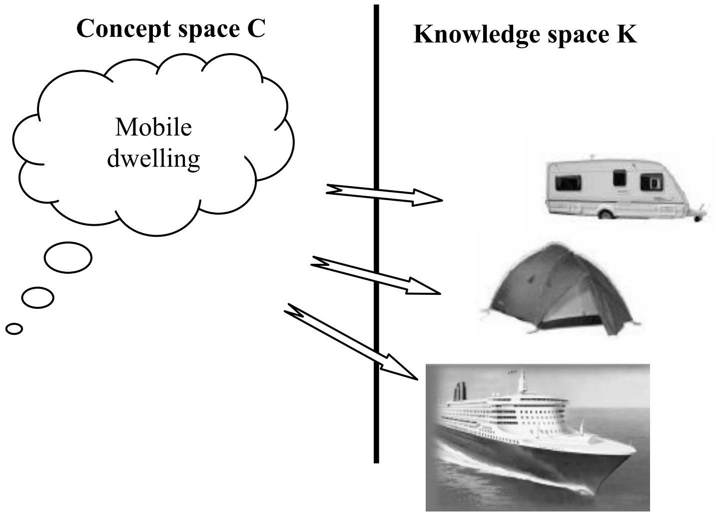


**Figure 2. A semantic disjunction leading to diverse semantic conjunctions, after [Kazakci 2004]**

The symmetric operation of a semantic disjunction is a *semantic conjunction*. This is an operation from the concept space C towards the knowledge space K and it marks the end of a design process [Hatchuel and Weil 2002]. The moment where the designer considers that he knows enough about the concept: "a mobile dwelling has the properties p1,p2,…" At that point, the concept is no longer a concept; it has become a knowledge item. A single semantic disjunction can lead to several semantic conjunctions; Figure 2. Hence, starting with the "mobile dwelling" concept we can finish up with a caravan, a tent or even a yacht [Kazakci 2004].

**2.3 Expansive partitions and K-Validation**

In traditional theories of reasoning such as problem solving or search, methods like branch and bound are used to search within a state space a best, or failing that, a satisfying solution. It is assumed that the boundaries of the state space are known and fixed; it is not possible to change the definition of the set of solution during the process. This is a severely restrictive hypothesis for modelling the act of designing where the principal aim is to construct new sets of solutions [Hatchuel and Weil 1999], [Hatchuel and Weil 2002]. The implication of such a hypothesis is that in those types of reasoning there is no place for creativity and unexpected discoveries: the design has to be chosen from a set of known solutions [Hatchuel and Weil 2002]! This kind of reasoning is better adapted to the problems such as the selection of a "movie" from the set of "movies presently projected in town" [Hatchuel and Weil 2002]. The set of solutions can be progressively *partitioned* by placing *restrictions* upon it, according to predefined criteria. (e.g., the movies in theatres close to Place Opéra, the comedies within those movies, etc.) By contrast, in design we must take into account the possibility of constructing new sets of solutions to conduct the process towards new directions. In the C-K design theory, this is taken into account by the notion of *expansive partitions* (in contrast to restrictive partitions). An expansive partition adds a definitional property to a concept in order to partition the set associated with this concept [Hatchuel and Weil 2002]. By adding a new property, a new restriction is placed upon the set of concepts that can be derived from the initial concept (hence, concepts that do not verify the restriction are eliminated) and the definition of the set of concepts to be considered is changed. It is the expansion of the concept space (by expansive partitions) that makes creativity possible by allowing the introduction of new ideas into a concept under consideration [Hatchuel and Weil 2002]. For instance, when organizing a "nice surprise party" we can expand this concept by various properties such as "disguised" or "that takes place on a boat" to construct new and previously undefined concepts [Hatchuel and Weil 2002], [Hatchuel 2002]. Remark that it is impossible to construct an exhaustive list of "nice surprise party"; the associated set is uncountable by contrast to the list "movies presently projected in town".

Once new concepts emerge this way, they will have to be analysed and evaluated through a sequence of operations. In methods like branch and bound, the criteria used to evaluate the quality of a solution is predetermined and fixed. Reconsidering the example of movie selection, those could be "personal taste", "proximity to a given place", "the kind of the movie", etc. In C-K theory, this stability disappear [Hatchuel and Weil 2002]. The notion of evaluation with fixed set of criteria is replaced by a notion of the construction and application of an appropriate evaluation *process* for each type of concept under consideration. The evaluation process for a tent design is most likely to be different from the evaluation process for a yacht design! In all the cases, such a process requires the use of knowledge and is called K-Validation within the framework of the C-K theory.

### 2.4 Reasoning in design: interactions between and within the two spaces

We have seen through which operations a design process begins and ends. Yet, how a design process is conducted? How concepts are elaborated? The C-K theory suggests four types of operators for modelling the elaboration of concepts. Those operators can be used to model different kind of reasoning processes such as the expansion of concepts, their K-validation, learning (expansion of K!).

$C \rightarrow K$ is an operation from the concept space C to the knowledge space K. Through this operator the concepts attempts to activate relevant knowledge items of K. A concept will generally activate two types of knowledge; about how to further elaborate it (by expansive partitions) or about how to analyse and evaluate it (by K-validation). For instance, "mobile dwelling" can activate K to obtain answers to questions like "can a mobile dwelling exist?" or "how could a mobile dwelling exist?" Once relevant knowledge is thus activated, the concept can be reconsidered by an operation $K \rightarrow C$. This is an operation from K to C that either partitions or departitions a concept. A concepts is partitioned either by an expansion (mobile dwellings "have wheels" or mobile dwellings "are portable") or by a restriction ("mobile dwellings are not portable" or "mobile dwellings with wheels are preferable"). The departitioning occurs when the concept cannot activate any knowledge in K or it is judged unsatisfactory (not feasible or not preferable, [Kazakci 2004]). In that case, a more abstract concept whose associated set contains the actual one is considered. It may happen that no useful knowledge can be activated in K. What happen then? If no concepts worth elaborating can be found (by departioning), then the knowledge space should be *expanded* by an operation $K \rightarrow K$. This operation acts within K; it may correspond to a deductive or associative process between knowledge elements to produce new knowledge. For example, the use of a known evaluation method for processing preferences and other information activated from a set of concepts is an operation $K \rightarrow K$ [Kazakci 2004]. Alternatively, this requires the consultation of an external source (experts, databases, etc.). Finally, concepts that are being explored can be related between themselves with operations of the type $C \rightarrow C$ (a tent is a mobile dwelling). This kind of operations marks the 'trace' of a sequence of operations.

The C-K design theory is a formal theory of reasoning in design. Despite its theoretical nature, it had many practical applications [Hatchuel and Weil 2002]. However, the theory has not been operationalised yet in the form of a design aiding software. In the next section, we argue that a third space, the environment E, must be introduced to the theory for this and other reasons.

## 3. Creative and adaptive design tools based on the C-K theory: The need for a third space

How creative and adaptive design aiding tools can be built? We believe that any such tool must verify the principles of the C-K theory. A tool must be able to do expansive partitions in order to be creative. It must be able to expand its knowledge space for being adaptive. However, we claim that to build such a tool based on the C-K theory, we first must introduce a third space: the environment space E. There are at least three reasons for introducing a third space. First, the external representations and their reinterpretations are the main engines through which design processes progress [Gero 1998], [Suwa *et al*., 1999]. Designers make changes to the external design representations in order to elaborate them. By observing the results of these changes they discover aspects that were not intentionally introduced. The reinterpretation of those aspects allows designers to reorient the design process towards new directions [Gero 1998], [Suwa *et al*., 1999]. The C-K design theory must take into account the *situated nature of the designer*.

Second, the design representation and the designers are external entities to the tool; they are situated in its environment. It should be apparent from this statement that we are not in a design automation perspective. Rather, we adhere to a design aiding perspective within a constructivist spirit [Kazakci and Tsoukias 2003]. In this framework, a design tool is a medium a designer uses to enrich his dialogue with the design situation and the design representation he is constructing.

Third, it is impossible to neglect the environment without making impossible the acquisition of any knowledge: where do come from the first knowledge items? If we assume they had been obtained as a result of a first design process, we also have to admit that a semantic disjunction had been operated to initiate the process. But, the terms of the first concept thus formulated must be “known” in the knowledge space (see paragraph 2.2)! However, nothing is known at that time, since the knowledge space K does not exist yet! How to progress then? We see that there is no way to advance but to introduce a third space that will allow the acquisition of the first knowledge items.

In fact, the C-K theory does not deny the existence of the environment; on the contrary, it holds that an operation $K \rightarrow K$ can necessitate the interaction with the environment (the consultation of a database, an expert, etc.) [Hatchuel and Weil, 2002]. Yet, it does not represent it explicitly. However, to account for the evolution of concepts, creativity, and learning we must admit and represent the environment. This would be only, because in the contrary case, that would come down to saying that the theory is valid only for designers designing in their minds without ever externalising their designs! Such a conception of design is possible, but has little value for creating design-aiding tools helpful to a designer, an entity external to the tool, therefore in its environment.

## 4. Modifying the C-K theory to introduce the environment space

How to integrate a third space corresponding to the environment into the framework of the C-K design theory without violating its integrity and internal coherence? In particular, which novel operators should be introduced; $E \rightarrow C$, $C \rightarrow E$, $E \rightarrow K$, $K \rightarrow E$? We will use the idea of *situatedness* to deal with these questions and to extend the C-K design theory.

### 4.1 Situatedness and design

Situatedness refers to the fact that cognition emerges from the interaction of a cognitive agent with its environment [Clancey 1997]. It emphasises the strong coupling existing between the perception, conception and action processes. A situated agent acts upon the environment then observes the results of its actions. Its conception of the situation is influenced by the way it perceives those results and its environment. This conception influences in turn its subsequent actions on that environment. As a result of these mutual dependencies, what a situated agent perceives, how it conceives of its activity and environment and what it physically does develop together [Clancey 1997].

[Gero and Kannengiesser 2002] describe situatedness as the interaction of three different worlds; Figure 3. The external world corresponds to objects and representations external to the agent. The interpreted world consists of the knowledge of the agent in terms of sensory experiences, percepts and concepts. Percepts are knowledge that allows an agent to recognize and perceive the world; whereas concepts are higher order knowledge elements that are constructed based on the percepts and other concepts [Clancey, 1997]. Percepts and concepts are grounded on the interaction of the agent with the external world. In the expected world expectations as to which results the imagined actions will produce are formed [Gero and Kannengiesser 2002]. These three worlds are dynamically coupled with each other through three types of process. The interpretation process transforms the incoming information from the external world into the interpretations of sensory experiences, percepts and concepts by grounding them on previous knowledge [Gero and Kannengiesser 2002]. This is accomplished by the interaction of sensation, perception and conception processes [Gero and Fujii 2000]. The focusing process distinguishes some aspects of the interpreted world. These aspects are used to formulate plans of actions that will bring about in the external world the desired state [Gero and Kannengiesser 2002]. Any change in one of these three worlds has the potential to change all three of them [Gero and Kannengiesser 2002].

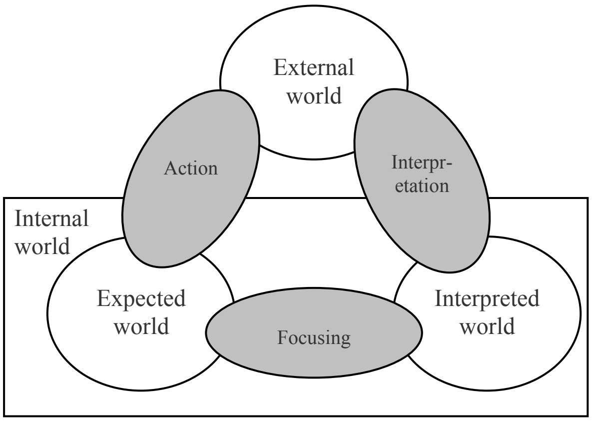


**Figure 3. Situatedness as the interaction of three world, after [Gero and Kannengiesser 2002]**

As we have mentioned in section 3, the notion of situatedness is also relevant in the context of design [Gero 1998], [Suwa *et al*., 1999]. Designers conduct design processes by acting upon design representations, observe and interpret the result and then decide what to do next, [Suwa *et al*., 1999]. We will discuss how the C-K theory can be fitted within the situated framework in the next paragraph.

### 4.2 Situatedness and the C-K design theory

What does the situated framework in the above paragraph implies for the C-K theory? Some associations are rather straightforward. The environment space E we want to introduce corresponds to the external world of the situated agent. The knowledge space K corresponds to the internal world of the agent that consists of the expected and the interpreted worlds. Where is the concept space C?

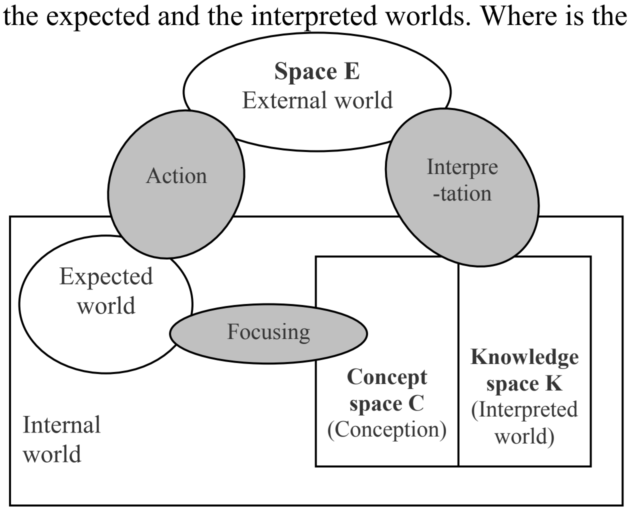


**Figure 4. Situatedness and the concept, knowledge and environment spaces, [Kazakci 2004]**

In fact, it appears momentarily within the interpreted world when a semantic disjunction is operated and a design process begins! Under such a perspective, the concept space is temporary: it is created when a design process begins and a new concept is being formulated and it disappears when the concept is elaborated to the point where it is considered as knowledge; Figure 4. More precisely, the concept space C is created within the conception process that interacts with the sensation and perception processes [Gero and Fujii 2000].
Conception is the process that creates and manages all the concepts of the agent. Consequently, it is by this process that a semantic disjunction is operated to initiate a design process. During the design process, the actual percepts and concepts learned in the past (which are presently knowledge items!) interacts to analyse, evaluate and expand the concepts of the concept space C (that are yet to be 'known'!)
In this new model, we have all the specificities of the original C-K theory but also the representation of the environment. Within this framework, we need only two novel operators; C → E and K → E. The first one for modelling the 'effectors' of an agent, means by which it is able to modify its environment according to goals formulated in the expected world. The second one for modelling the reception of information from the environment and its interpretation.
An operator E → C is not necessary since the information coming from the external world is always processed first by the sensation and perception processes before interacting with the conception (thus, with the concept space). As a consequence, there is no semantic disjunction E → C.

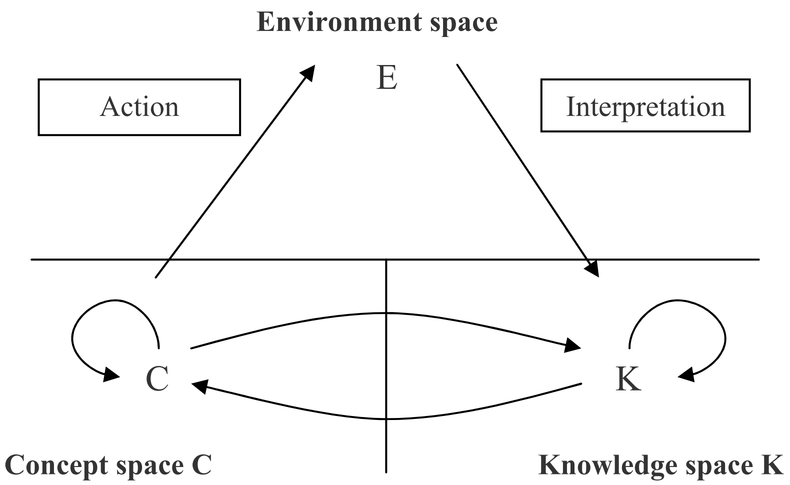


**Figure 5. The environment space E and its interaction with the concept space C and the knowledge space K [Kazakci 2003]**

Also we do not need an operator K → E since the actions taken to change the external world depend mainly on the goals formulated in the expected world, which, in turn, is based on the concept space. With these conjectures, the C-K model becomes as in Figure 5. We call this new version of the theory the C\K\E design theory.

### 4.3 Situated design assistants: tools based on the C\K\E design theory

Computational models for design agents verifying the situated framework described above (such as the one in [Gero and Fujii 2000]) are by construction compatible with the C\K\E design theory. Therefore, such models can be exploited to operationalise the theory. Any such tool built based on the C\K\E design theory can be seen as a personal design assistant – a creative and adaptive design tool aiming at supporting designers' activities [Kazakci 2004]. A personal design assistant can be used as a design aiding tool within a constructivist paradigm: the assistant will cooperate with the designer by observing the external design representation on which he is working, making suggestions to him on how to elaborate this representation and adapting its (suggestion) behaviour according to the designer's reactions [Kazakci 2004]. A design tool conforming to this scheme would amplify the situational awareness of a designer enriching its interaction with the design situation, thus facilitating designing.

## 5. Conclusion

The literature about intelligent, adaptive and creative design tools is fast growing. However, a widely disseminated tool issued from that literature helping real designers to deal with real design situations does not exist yet. Possibly, one reason for that is the lack of theoretical background for the approaches underlying these tools. We believe that the C-K design theory has some important features to provide theoretical founding for such tools. With the four operators it suggests together with the distinction between the concept and knowledge spaces, it gives a formal and tangible account of diverse reasoning processes occurring during design. Building on those, it explains two important notions; creativity (expansion of concepts) and learning (expansion of the knowledge space) occuring in design processes. These notions together with the formalism associated with the theory enable formal analysis and design of creative and adaptive design tools.
However, as we showed during the paper, in order to build such tools the original theory must be extended to include a third space; the environment space E. We used the idea of situatedness to propose an extension to the theory that we call the C\K\E design theory. As we emphasised, computational situated design agents verify the principles of the C\K\E theory and can be used as personal design assistants – creative and adaptive design tools. The realisation of such an assistant, a personal synthesis assistant, is one of the research directions that our team presently follows.

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