Soft-Coding the Transitions Between Contexts in CGF's: The Competing Context Concept

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ABSTRACT: This article describes a constraint-based approach for implementing the competing context concept in the Context-Based Reasoning (CxBR) Paradigm. CxBR is an automated reasoning paradigm that can simulate human tactical behavior simply and effectively by using an intuitive identifier called a *Context*. A Context, which addresses all the conditions in the current situation, controls the behavior of the AIP (Autonomous Intelligent Platform) in a tactical simulation. When the situation changes, the currently active Context searches for a possible next Context that addresses the changing situation. Once it finds one that addresses the conditions in the new situation, it deactivates itself and activates this newly found one. An AIP can be intelligently controlled through a continuous transitioning from one Context to the next as the situation demands. However, it can be very difficult to define all of Context shifting by "hard-coding" which Context would follow any other Context. While this can be realistic in some situations, such as actions upon reaching a certain phase line, or action upon orders from a superior, hard-coding the transitions in all situations is unrealistic. This would require either uncanny predictability by the system developer of the situations to be faced by the AIP, or an excessively large and complex set of Contexts, each activated by certain very specific conditions in the simulation. Both are highly unrealistic. Thus, the competing context approach has been developed to address the cases where several Contexts are able to address the situation acceptably well. This competing context concept can determine the "best" Context for the new situation and its immediate goal by using a constraint-based technique and time-warp simulation. An example of this will be provided. The competing context concept has one other significant benefit besides "soft-coding" the tactics: It can pave the way for easy on-line learning.

1. Introduction

There exist several practical techniques to represent human behavior through artificial intelligence technology. Several techniques exist in the technical literature, but the following are the most popular and successful.

ModSAF utilizes a finite state machine (FSM) architecture that represents the task-based explicit behavior of company level forces. FSM is the most widely used behavior representation paradigm in the military simulation environment [Paw and Mavor, 1998].

TacAir-Soar system has proven its effectiveness in representing pilot-level behavior for a wide range of air missions in STOW-97 [van Lent and Laird, 1998]. The TacAir-Soar architecture is a rule-based system whose knowledge base consists of 5,200 rules extracted from subject matter experts.

The CASTFOREM (the Army's Combined Arms and Support Task Force Evaluation Model) was designed specifically to allow military experts to model doctrine and military behavior. To implement automated human behavior, a data-driven, knowledge-based expert system has been developed for CASTFOREM [Hoffman, Mackey and Baker, 1998].

The CxBR paradigm has been developed for effective and intuitive management of tactical human behavioral knowledge. CxBR assumes that humans need not always apply their entire knowledge base to control behavior in a specific situation. Instead, they can successfully apply a limited and closely related set of knowledge. For example, when someone drives a car on a limited access freeway, he/she doesn't typically worry about a pedestrian crossing the street, or another car in an intersection, as those are incompatible occurrences in such highways. They worry most about overtaking traffic on their left, stopped vehicles by the side of the road, and police with radars. Thus, it is enough that only the specific knowledge that is closely related to driving on a freeway be categorized within the "**freeway-driving**" task. If the car is on the freeway, CxBR should select the "**freeway-driving**" task, which has the limited search space applicable to the current situation. The intuitive identifier, called a *Context*, is applied to express this task. Like the **freeway-driving** Context, a **suburban-driving** Context can be defined for driving in the suburban part of the city. If the car exits the freeway to go into a suburban area, the **freeway-driving** Context should give way to the **suburban-driving** Context. A general description of CxBR is shown below.

2. General description of Context-based reasoning

2.1 Assumptions

As described by [Gonzalez and Ahlers, 1998], CxBR is based on the following assumptions:

1) Life for an Autonomous Intelligent Platform (AIP) is a continuous sequence of *contexts*, which change as the situation changes. A Context can be likened to a situation that has been recognized, and which has a prescribed set of procedures that must be carried out, either sequentially or arbitrarily. The behavior of an AIP in the simulation is controlled by the context that is *active* for it at the time.

2) The active context may not be the same for all AIP's. This is reasonable to expect, since each may have a different mission, different sensor inputs, and different capabilities.

3) Contexts are represented temporally as intervals of time rather than time points. Contexts are considered to be transitions to reach a goal.

4) Goals can be time points, but only to serve as transitions to other contexts.

5) Only a limited number of things can take place in any single context. A situation, therefore, by its very nature, will limit the number of other situations that can take place. Using the example of an automobile driver, it would not be normally expected that a tire blowout take place while waiting at a stoplight. This can be used to advantage to prune the search space of the problem, since there is no need to consider a blowout while waiting at stoplight. Getting rear-ended, on the other hand, is a much more likely proposition.

6) The presence of a new context will alter the present course of action and the applicable expectations to some degree. For example, the recognition of a blowout at highway speeds will cause the driver to attempt to coast to a stop while maintaining a firm grip on the steering wheel, and directing the car towards the shoulder of the road. Thus, the context changed from on of **normal-highway-driving**, to one of **blowout**, with its attendant requisite action. This context remains in effect until the car comes to a complete stop (the goal), at which point another context will be recognized and acted upon (e.g., **change-tire**).

Associating the potential contexts and corresponding actions to specific situations can simplify the identification of a situation because only a subset of all possible situations is applicable under the active context. This context-based approach also easily addresses what actionable information to use when a situation is recognized.

2.2 Representation of Contexts

In CxBR, there are three kinds of Contexts and they are hierarchically defined: (1) Mission Context, (2) Main Context and (3) Sub-Context.

The Mission-Context defines the constraints as well as the Main Contexts that are used in the execution of the mission described. It is a class definition in an object-oriented environment and contains the following attributes:

Constraints: This attribute lists all the constraints that are imposed on the AIP during this mission. These can be territorial (such as do not venture outside of the designated battle area to avoid fratricide, weapons readiness, etc.).

Avoid: This attribute describes anything that must be avoided throughout the scenario. One obvious one is destruction of self, but there may be others, such as progression across a phase line prior to a certain time to allow for friendly artillery barrages.

Mission Objectives: What will indicate successful completion of the mission.

Main-Contexts: This attribute lists the Main Contexts applicable to the mission. For example, car-driving mission can possess **city-driving** Context, **highway-driving** Context, **suburban-driving** Context and so on. This can serve as a plan for the actions to be taken in execution of the mission.

A Main Context is likewise defined as a class in an object-oriented environment, and possesses the following attributes:

Initializer: References the name of the initializing function, which is executed whenever the Context/Sub-Context is activated to initialize all required variables.

Objectives: The objective puts a message as to what the objective of the Context/Sub-Context is. The objective is in general terms and it references a frame that has some attributes that are the goal of this Context/Sub-Context.

Compatible-next-Main-Context: This attribute lists all those Main Contexts to which a shift from the current context is possible.

Compatible-Sub-Context: This attribute is a list of all Sub-Contexts, which are compatible with the current context. For example, it would not be advisable to put an automobile in **cruise-control** when a tire-blowout has taken place. Thus, the **cruise-control** Sub-Context would not appear on that list.

Sub-Contexts are lower level tactical procedures, which are not critical in and of them to reaching the mission objectives. They are typically of temporally short duration. Sub-Contexts are at this time mutually exclusive with one another, but can be compatible, and thus co-exist, with the Contexts. The attributes of a Sub-Context are quite similar to those of a Main-Context.

The currently active Main Contexts and Sub-Contexts control an AIP intelligently in a simulation. When the situation changes, the current Context searches for a possible next Context, and upon finding another one that addresses the needs of the new situation, it deactivates itself and activates this newly found one. No matter how the situation changes, an AIP can be controlled intelligently through a continuous transitioning from the current Context to another appropriate Context. This is called *Context shifting*.

3. The concept of competing context

In many cases it can be easy as well as appropriate to predefine the Context shifting based on one event (e.g., shift from a **freeway-driving** Context to a **suburban-driving** Context at the point where the freeway exit is reached). However, in more complex tactical situations, such as those typically involving military tactics, it can be difficult to predefine (i.e., "hardcode") these transitions, as they depend on several variables. Therefore, there may be more than one potential context to which the control of the AIP can transition, and this can be difficult to predefine without a multitude of rules. For example, using the case of traveling in an automobile, let’s say that the driver is cruising normally on an interstate at the speed limit. This may be characterized as being in a **freeway-driving** context. He is anxious to get to his destination, as he has an appointment, and time is somewhat tight. However, he is also hungry. At a point in the trip, the car is running low on fuel, and he comes to a potential transition point – an exit. This causes a context shift to **an exit-freeway** context, and subsequently to **a country-road-driving** context as he seeks the gasoline station. Upon filling the tank with fuel, our context-controlled driver is faced with a decision: Get back to the freeway (the **country-road-driving** context, followed by **exit-ramp** context, followed by **freeway-driving**), or pursue **country-road-driving** to find a restaurant. Since he is more anxious to arrive at the destination than he is hungry, then the first situation will dictate the action being undertaken and, therefore, the contexts to become activated.

In such cases, it is beneficial to define the current situation as a set of *needs* to be addressed by the AIP in order to accomplish its mission and/or survive. Likewise, the Contexts to which the control of the AIP can potentially transition are designed to address some or all of these needs. The contexts then can be said to *compete* for the right to become the next activated Context to control the AIP. The successful Context would ideally be the one that best addresses the identified needs of the situation currently faced by the AIP. In our example, the need to get to the destination on time overrode his hunger, and thus influenced the choice of next active context.

3.1 Another example of competing contexts

A better example of competing context can be described with a tire-blowout event, which occurs while a car travels on a freeway. This is discussed below.

It can be assumed that there is **freeway-driving** Context that has four compatible next Main Contexts such as **exit-ramp**, **enter-the-rest-area**, **fix-tire**, and **abandon-the-car**. If a tire-blowout event occurs, **fix-tire** and **abandon-the-car** Contexts would compete for the right to become the next activated one.

It is also assumed that there are two immediate goals and two situations as shown below.

Immediate goal 1: Reach the destination as soon as possible at any cost.

Immediate goal 2: Reach the destination driving the car.

Situation 1: Tire-blowout event occurs at a point half mile away from the destination.

Figure 1 - Situation1

Situation 2: Tire-blowout event occurs at a point five miles away from the destination.

Figure 2 - Situation 2

If it takes 30 minutes to fix tire, the speed limit of this highway is 60 mph and walking speed is 2.5 mph, the relationship between each situation and each competing Context can be shown in table 1. With respect to the immediate goals, the "best" Context for each immediate goal and situation can be shown in table 2.

Table 1 - Situation and Context

Situation / Context	Situation 1	Situation 2
fix-tire	Car: tire is fixed Time to destination: 30.5 min	Car: tire is fixed Time to destination: 35 min
abandon-the-car	Car: none Time to destination: 12 min	Car: none Time to destination: 120 min

Table 2 - Immediate goal and situation

Situation / Goal	Situation 1	Situation 2
Immediate goal 1	**abandon-the-car**	**fix-tire**
Immediate goal 2	**fix-tire**	**fix-tire**

As shown above, the "best" Context changes dynamically depending on the situation and its immediate goal. The "best" Context cannot always be the best Context through entire simulation. If **fix-tire** Context is selected in Situation 2 and a collision event later occurs at a point 3 miles from the destination, the best Context through the entire simulation would have been the **abandon-the-car** Context instead of the **fix-tire** Context. However, since such a future event cannot be predicted, the "best" Context gets the right to become the next activated one at the current time.

3.2 Description of competing context approach

To implement the competing context concept, we propose a constraint-based approach that integrates the matching of constraints and the ability to seek and take advantage of opportunities as they arise. There are three processes: (1) Situation interpretation metrics generation, (2) Relevant Context group selection, (3) Context attribute matching and (4) Time-warp simulation. The general flow of competing Context is shown in figure 3 and each of these processes is discussed below.

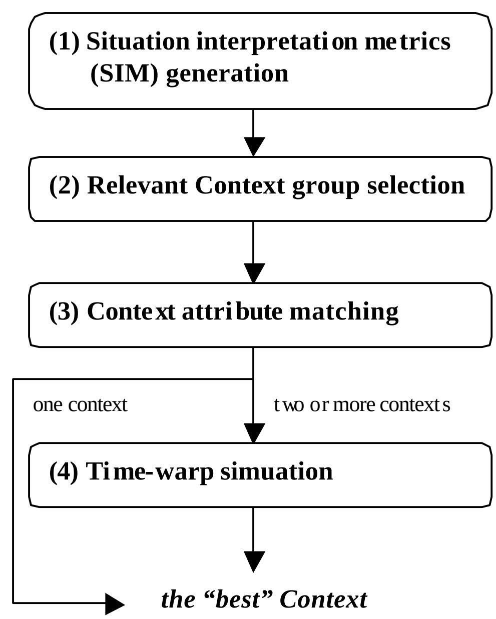

Figure 3 - General flow of competing context approach

3.2.1 Situation interpretation metrics generation

Situation interpretation metrics (SIM) generation is the process that generates the SIMs to recognize the current situation. When the Mission Contexts are defined, these SIMs should be also defined. For example, the SIMs consists of the following items that are similar to the METT-T (Mission, Enemy, Terrain, Troops and Time) for tactical military simulation.

- Enemy forces present
- Friendly forces present
- Terrain
- Weather
- Degraded state of AIP
- Time to accomplish the objective

These are some examples of SIMs: The Enemy (Friendly) forces presence SIM has the list of variables such as *the number of enemy (friendly) tanks*, *enemy (friendly) distance*, *enemy (friendly) speed* and *enemy (friendly) firepower*. The Terrain SIM has the list of the critical obstacles around the tank such as *gap*, *cover*, *hill*, *forest*, *river* and so on. The Weather SIM has the list of variables such as weather (sunny, rain, snow, etc.) with the visibility range. The Degraded state SIM has the variables of the current vehicle (human) status. As described by [Hauck, Hudson and Atikune, 1999], the DWARS and CASTFOREM model have the degraded options such as *M-KILL (mobility), C-KILL (crew status), A-KILL (target acquisition), F-KILL (firepower)* and so on. The Time to accomplish the objective SIM is the estimated time to accomplish the objective in the current situation with the current Context. In this process, these SIMs would be calculated and presented to the Context competition.

The immediate goal is important inasmuch as it describes how the current situation changes to accomplish the ultimate goal, the so-called "mission". Thus, those can be expressed by the priority list of some combinations of the SIMs. This priority list represents a variable whose value is of primary importance. It will also define the desired value of the variable. A Context is then to be found that is most likely to successfully cause this variable to achieve the desired value. The order of this list indicates the priority. The notation about the immediate goal can be defined as followed.

{<*SIM1*>, <desired value1>}
{<*SIM2*>, <desired value2>}
:

In the tire-burst example above, the immediate goal 1 might be to work towards setting the value of the applicable variable to desired values. For example,

{*Time_to_destination*, min}
{*Car_status*, ok}

Since the "Time to destination" immediate goal is prior to "Car status", the **abandon-the-car** Context better addresses the needs of the situation and should be selected. This is because he/she can reach the destination by walking faster than by driving his/her car after fixing the tire.

On the other hand, if the objective is the attrition of enemy forces in a tank tactical simulation, the immediate goal might be:

{*Number_of_enemy_tanks*, min}
{*Number_of_friendly_tanks*, max}
{*Time_to_accomplish_the_objective*, min}

If the objective is the support of the friendly forces, the immediate goal might be:

{*Number_of_friendly_tanks*, max}
{*Time_to_accomplish_the_objective*, min}
{*Number_of_enemy_tanks*, min}

The Mission Context has some immediate goals to which the current immediate goal changes another one with respect to one of SIMs. If the objective is to survive, the immediate goal might be as followed by using the degraded options described in [Hauck, Hudson and Atikune, 1999]:

{*C-KILL*, C0} (C0: 0 crew casualties)
{*M-KILL*, M0} (M0: No mobility damage)
{*F-KILL*, F0} (F0: No firepower capability loss)

Furthermore, It can be assumed that if the distance to one of the enemy tanks is shorter than the minimum, the AIP must decisively engage the enemy. Thus, the immediate goal may be expressed as followed.

```
(Enemy_distance <= minimum distance)
(F-KILL = F0)
(Visibility_range >= value)
  begin
   {Number_of_enemy_tanks, min}
   {C-KILL, C0}
   {M-KILL, M0}
   {F-KILL, F0}
   {Time_to_accomplish_the_objective, min}
   {Number_of_friendly_tanks, max}
 end

(default)
 begin
   {C-KILL, C0}
   {M-KILL, M0}
   {F-KILL, F0}
 end
```

In our approach, these immediate goals, which consist of conditional priority list, can be changed on-line by using soft-coding.

3.2.2 Relevant Context group selection

This step reduces the world of potential Contexts to transition to. The Relevant Context group selection is the process that selects the set of candidates for the "best" Context to which the current Context may transition from among all of the Contexts, to match the SIMs to their attributes. Once the immediate goal is decided with respect to the current situation, some of the attributes of all of the Contexts that address the conditions are used to decide the current immediate goal. In the SIM example above, if the immediate goal is the decisive engagement, the conditions, which are (*Enemy_distance* <= minimum distance), (*F-KILL* = F0), (*Visibility_range* >= value) are considered. The Contexts whose attributes address these conditions can be selected as a set of the candidates Contexts to match the rest of their attributes, while the rest of the Contexts that are not useful to consider can be eliminated. This has the effect of pruning the search space of potential best Contexts.

3.2.3 Context attribute matching

The Context attribute matching is the process by which the Contexts match their attributes to the SIMs. It can be assumed that there are three possible Contexts to which the **traveling-to-the-checkpoint** Context can transition with respect to the current immediate goal. These are the **look-for-cover-and-engage**, the **maneuver-and-engage** and the **pop-a-smoke** Contexts. If one of the attributes of the **look-for-cover-and-engage** Context requires some sort of terrain to hide behind and there are no critical obstacles around the tank, the **look-for-cover-and-engage** Context should be eliminated. On the other hand, the **maneuver-and-engage** and the **pop-a-smoke** Context may remain as the candidates for the "best" Context. They must be disambiguated, since only one Context can "win" the competition.

3.2.4 Time-warp simulation

If the above steps cannot uniquely identify one best context, then the remaining candidates are "tried" using Time-warp simulation. The Time-warp simulation is the process that executes a super real-time simulation until the "best" Context can be selected while the current simulation time is stopped. The time-warp simulation starts the current Context with the current SIM and simulates the transition alternately to each candidate "best" Context. In the example above, the **maneuver-and-engage**, the **pop-a-smoke** Context will be the candidates for the "best" Context to which the **traveling-to-the-checkpoint** Context may transition. The Time-warp simulation executes the super real-time simulation for each candidate Context separately and generates the temporal SIMs to check the achievement of the current immediate goal (Figure 4). The one that best projects the satisfaction of the goal is selected as the winner and activated.

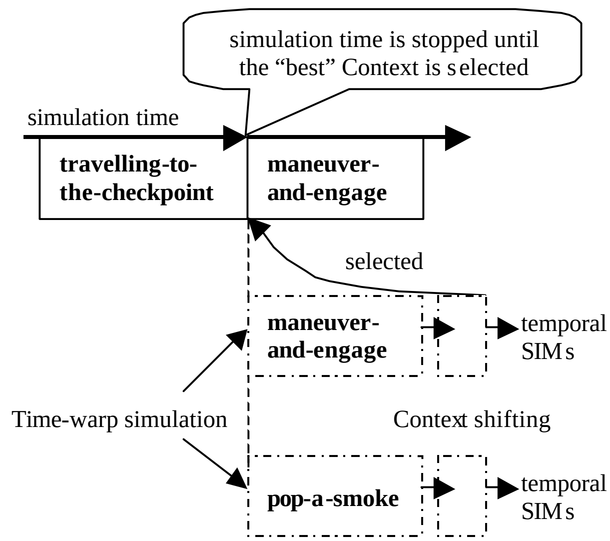

Figure 4 - An example of the Time-warp simulation

In our example, it is assumed that the enemy shot hit the gun turret in the Time-warp simulation with the **maneuver-and-engage** Context. The temporal SIMs may become as shown below:

Number_of_enemy_tanks = current number - 2
C-KILL = C0
M-KILL = M0
F-KILL = F1 (F1: degradation of main armament)
Time_to_accomplish_the_objective = 30 min
Number_of_friendly_tanks = current number

On the other hand, if the enemy shot did not hit the tank in the Time-warp simulation with the **pop-a-smoke** Context, the temporal SIMs Context may become as shown below:

Number_of_enemy_tanks = current number
C-KILL = C0
M-KILL = M0
F-KILL = F0
Time_to_accomplish_the_objective = 40 min
Number_of_friendly_tanks = current number

Immediate goal designates that the "best" Context can generate the minimum value of *Number of enemy tanks*. Thus, the **maneuver-and-engage** Context will be selected as the "best" Context and applied to the real-time simulation environment in order to start the simulation time again.

On the other hand, if it can be assumed that there is the alternative immediate goal, which is slightly different from that in the example above; this alternative one indicates that keeping the current state of the tank is of higher priority than killing the enemy forces. Considering the results of temporal SIMs in the example above, the **maneuver-and-engage** Context generated the *F-KILL* SIM as "F1", so the **pop-a-smoke** Context would be selected. The alternative one is shown below.

(*Enemy_distance* <= minimum distance)
(*F-KILL* = F0)
(*Visibility_range* >= value)
begin
{*C-KILL*, C0}
{*M-KILL*, M0}
{*F-KILL*, F0}
{*Number_of_enemy_tanks*, min}
{*Time_to_accomplish_the_objective*, min}
{*Number_of_friendly_tanks*, max}
end

Since the Time-warp simulation continues to execute until the SIMs, which the current immediate goal designates, are obtained, it is probable that Context shifting occurs in the Time-warp simulation. Usually, the current Context from which the candidate for the "best" Context is transitioned is selected in order to accomplish its objective. However, if a Context competition were required in the Time-warp simulation (which we call *nesting*), the "best" Context would be selected at random among the candidates. This is done in order to avoid consuming excessive computation time. This is acceptable because future events cannot be predicted exactly.

4. Current status of our research

As described in this paper, the concept of the Competing Context has been defined. The notation of the soft-coding the immediate goals, which consist of the conditional priority list of the SIMs, may change according to the progress of our research.

5. Further research

A prototype will be developed to prove the effectiveness of the Competing Context Concept with soft-coding function in order to represent the realistic human behavior. To prove this concept, the test scenario should be a more complex situation than the car-driving situation. Thus, the military situation, such as the tank tactics as described above, should be implemented in the prototype.

6. Acknowledgment

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