

# A Novel Application of the 3D VirCA Environment: Modeling a Standard Ethological Test of Dog-Human Interactions

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*Abstract: The concept of 'Future Internet', 'Internet of Things' and '3D Internet' opens a novel way for modeling ethological tests by rebuilding models of human-animal interaction in an augmented environment as an interactive mixture of virtual actors and real human observers. On the one hand these experiments can serve as a proof of concept, as a kind of experimental validation of formal ethological models, but on the other hand they can also serve as examples for the ways a human can communicate with things (i.e., with everyday objects) in a virtual environment (e.g. on the Internet). These kinds of experiments can also support Cognitive Infocommunication related research, the field that investigates how a human can co-evolve with artificially cognitive systems through infocommunications devices. The goal of the paper is to introduce an example for such an ethological test system, a possible way for embedding a prototype ethological model described as a fuzzy automaton in MATLAB to the 3D VirCA collaborative augmented reality environment. Some details of the applied ethological experiment paradigm developed for studying the dog-owner relationship in a standard laboratory procedure, as a demonstrative example for ethological model implementation, will also be discussed briefly in this paper.*

*Keywords: Cognitive Infocommunication; VirCA; modeling ethological experiments*

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# 1 Introduction

The concept of ‘Internet of Things’ and ‘3D Internet’ are two of the major directions in ‘Future Internet’ research. Both research directions expect users to be able to communicate with things (i.e., everyday objects) on the Internet, and also to collaborate with them in ways that depend only on the (artificially cognitive) capabilities of the objects. Because the objects, as viewed from the Internet, can be combinations of physical and virtual components, collaboration in this case can be regarded as augmented collaboration.

Cognitive robotics is also a key trend in EU-supported research which aims to motivate advances in the artificial cognitive subsystems in robots. As results in cognitive robotics are expected to lead to artificially cognitive systems, it is a natural step to deploy them not only in robots, but also in the augmented reality representation of objects in the Internet of Things.

Cognitive Infocommunications (CogInfoCom) [1] is an emerging field that investigates how the human cognitive system can co-evolve with artificially cognitive systems through infocommunications devices. If the augmented 3D space that is created by 3D Internet is regarded as an infocommunications platform, we may conclude that the investigation of how humans can collaborate with artificially cognitive systems, while making full use of their cognitive capabilities through 3D Internet, truly belongs to CogInfoCom.

The primary goal of the research introduced in this paper is the inter-cognitive sensor-sharing CogInfoCom, in which a human collaborates with an artificially cognitive system. If collaboration involves action-reaction processes, then interaction is controlled by the human on the one hand, and by the artificial system on the other. From this point of view, the paper focuses on interactions in which the artificially cognitive system controls the communication based on ethological considerations. This is referred to as ethology-based CogInfoCom interaction.

In this paper an example of such an ethology-based CogInfoCom interaction, the implementation of an ethological test procedure in a virtual collaboration environment called VirCA [22], will be introduced in some detail. (The VirCA was developed by the Hunorob Consortium.)

The ethological test procedure is modeled by fuzzy automata, by giving the rules of the state-transition Fuzzy Rule Interpolation (FRI) models. Ethologists can supply only verbally defined rules for engineers; hence variables are not defined exactly and also the gathered expert knowledge is incomplete from the viewpoint of rule base construction of the whole system. As for the variables, it is plausible to use fuzzy description, where linguistic terms can be easily incorporated. To overcome the problem of rule base incompleteness, FRI models are applied because FRI can supply conclusions by design in these situations. In contrast, when using traditional fuzzy inference systems, a considerable amount of

redundant rules should be added to make the inference system complete, which makes fuzzy reasoning practically unusable in the case of high input dimensions.

The dog-owner relationship is a working example for an already existing CogInfoCom relation, where a real dog acts the task of the artificial system. Nature has had thousands of years to evolve such a CogInfoCom relation to be close to the most effective, or at least straightforward enough for both the human and the dog. Modeling the actions and reactions of the dog by the artificial system can therefore directly lead to the model of ethology-based CogInfoCom interaction. One basic limitation of such an extension is the weakness of the modeling techniques, which can describe observable actions and reactions only in specific test situations. The other problem is the question of the CogInfoCom sensor-bridging, i.e. whether in some sense it is possible to transfer the situation-specific reactions of a dog to the reactions of an artificial system in the same meaning but in different appearance. These are important questions of the ethology-based CogInfoCom interaction, but they are not discussed further in this paper, as it has the goal of introducing a possible way for modeling a specific test case.

The paper is structured in the following way. First, the example ethological model, the original standard laboratory procedure developed for studying the dog-owner relationship, is introduced briefly. Then the structure of the fuzzy description of the laboratory procedure is discussed. The second main part of the paper introduces the MATLAB implemented prototype ethological model and the details of its interconnection with the 3D VirCA augmented reality environment.

## **2 The Ethological Test Procedure**

This section describes the components of the entire ethological model. First, the ethological test procedure is introduced, and then the method and structure of the modeling is described, along with the applied fuzzy automaton and fuzzy rule interpolation techniques. Finally there is a short introduction of the VirCA system, which is used for realizing the 3D user interface of the software implemented model.

The ethological test has been developed for studying the affiliative relationship between a dog and its owner. The procedure is made up of several episodes in which the dog is in different situations: first with the owner, then with a stranger, or alone. Throughout the test, the dog's behavior is evaluated mainly by focusing on the dogs' responses related to their proximity-seeking with the owner [21].

This test is originally conducted in a test room and consists of seven episodes, each lasting for two minutes. The owner and the stranger act according to a strict protocol; the dog can move free (off the leash) in the room throughout the test. In

the first episode, the dog and the owner are in the room. First the owner is passive, then he/she stimulates playing. The second episode is where the stranger comes into the room and starts to stimulate play with the dog. Then the owner leaves the room, so in the third episode the dog is separated from the owner; the stranger tries to play with the dog, then sits for a while and offers petting. The owner comes back in the beginning of the fourth episode, and this is the first reunion. Meanwhile, the stranger leaves the room and the dog is with the owner for two minutes. Then the owner also leaves, so in the fifth episode the dog is alone in the room. In the next episode, the stranger returns and tries to stimulate playing or to comfort the dog by petting it. The return of the owner marks the beginning of the last episode. The stranger leaves the room, the owner interacts with the dog for two minutes, and the test ends.

During evaluation, ethologists record 9 behavioral variables for describing the dogs' responses related to both the owner and the stranger, and they analyze the data to reveal significant differences in behaviors showed towards the two persons.

## **2.1 Modeling the Test Procedure**

Describing ethological models of human–animal interaction and acting the animal as a virtual actor in augmented reality environment can in some sense yield direct observations similar to the real observation of a real animal. Of course these observations serve a different purpose than ethological observations performed in the natural environment. They help in model validation by evaluating the correctness of existing models in similar but disturbance free circumstances as they were originally collected.

Existing ethological models are usually descriptive verbal models based on numerous observations of animal reactions in different situations. Many of them are built around a predefined sequence of environmental situations and events, where the reaction of the animal is noted and evaluated in detail. Some of the observations are partially related to the actual inner state of the animal, e.g. tail movement or position. The knowledge representation of an ethological model is a series of observations of various facts and action-reaction rules. For mathematical modeling of such system, the rule-based knowledge representation is straightforward. Moreover, the need of following observed sequences calls a model structure of a state machine or an automaton. Adding the fact that the observable or hidden states are continuous measures, the situation is quite complicated. Summarizing the above requirements, the model needs to have a rule-based knowledge representation with the ability of describing event sequences, continuous values and continuous states. The suggested modeling method is the application of the fuzzy automaton, where the state is a vector of membership values, the state-transitions are controlled by a fuzzy rule base and the observations and conclusions are continuous values.

The main problem in the case of the practical implementation of such a fuzzy automaton based model is the size of the state-transition rule base. In classical fuzzy reasoning the rule base size is exponential to the number of observations, in this case the length of the state vector. In the case of an ethological model with moderate complexity, it could be 10-20 state variables, i.e. thousands of rules are required for the complete classical rule base (e.g. the Zadeh-Mamdani-Larsen Compositional Rule of Inference (CRI) (Zadeh [24]) (Mamdani [16]) (Larsen [12]) or the Takagi-Sugeno fuzzy inference (Sugeno [19], Takagi-Sugeno [20]). Moreover, the existing knowledge is usually a few dozen rules, which means that most of the rules are undefined. In the case of classical fuzzy reasoning this contradiction is hardly solvable.

The solution applied in the example model for handling the exponential complexity problem of the required fuzzy automation state-transition rule base is the application of Fuzzy Rule Interpolation (FRI) methods (see more detailed in [11], [12], [13]). By the application of FRI methods the number of the rules required for the FRI state-transition fuzzy model can be reduced to the existing (known from the ethological model) rules. Moreover, in the case of automatic model generation or fine tuning based on given input-output sample data, the application of the FRI model can lead to fewer rules, and hence to fewer parameters which need to be optimized. This also means better convergence of the optimization algorithm.

The ethological model implementation introduced in this paper is built upon the framework of fuzzy automaton and low computational demand Fuzzy Rule Interpolation (FRI) methods [6], [7], [9], [10]. The knowledge representation style of the FRI method fits well the conceptually “sparse rule-based” structure of the existing descriptive verbal ethological models, where the “completeness” of the rule-base is essentially not required. FRI methods can provide reasonable (interpolated) conclusions even if none of the existing rules fires under the current observation. From the beginning of 1990s numerous FRI methods have been proposed ([21], [4]). One of the first FRI methods was introduced in [5].

## 2.2 The Structure of the Model

The structure of the example model follows the behavior-based control concept [18], i.e. the actual behavior of the system is formed as a fusion of the known component behaviors that appeared to be the most appropriate in the actual situation.

For behavior fusion in the applied model, the concept of the Fuzzy Automaton is adapted. Numerous versions and interpretations of the fuzzy automaton can be found in the literature (a good overview can be found in [3]). The most common definition of Fuzzy Finite-state Automaton (FFA, summarized in [3]) is defined by a tuple (according to [1], [3] and [17]):

$$\tilde{F} = (Q, \Sigma, \delta, R, Z, \omega), \tag{1}$$

where  $Q$  is a finite set of states,  $Q = \{q_1, q_2, \dots, q_n\}$ ,  $\Sigma$  is a finite set of input symbols,  $\Sigma = \{a_1, a_2, \dots, a_m\}$ ,  $R \in Q$  is the (possibly fuzzy) start state of  $\tilde{F}$ ,  $Z$  is a finite set of output symbols,  $Z = \{b_1, b_2, \dots, b_n\}$ ,  $\delta: Q \times \Sigma \times Q \rightarrow [0,1]$  is the fuzzy transition function which is used to map a state (current state) into another state (next state) upon an input symbol, attributing a value in the fuzzy interval  $[0,1]$  to the next state, and  $\omega: Q \rightarrow Z$  is the output function which is used to map a (fuzzy) state to the output.

Extending the concept of FFA from finite set of input symbols to finite dimensional input values turns to the following:

$$\tilde{F} = (S, X, \delta, P, Y, \omega), \tag{2}$$

where  $S$  is a finite set of fuzzy states,  $S = \{\mu_{s1}, \mu_{s2}, \dots, \mu_{sn}\}$ ,  $X$  is a finite dimensional input vector,  $X = \{x_1, x_2, \dots, x_m\}$ ,  $P \in S$  is the fuzzy start state of  $\tilde{F}$ ,  $Y$  is a finite dimensional output vector,  $Y = \{y_1, y_2, \dots, y_l\}$ ,  $\delta: S \times X \rightarrow S$  is the fuzzy state-transition function which is used to map the current fuzzy state into the next fuzzy state upon an input value, and  $\omega: S \times X \rightarrow Y$  is the output function which is used to map the fuzzy state and input to the output value. See e.g. in Figure 1.

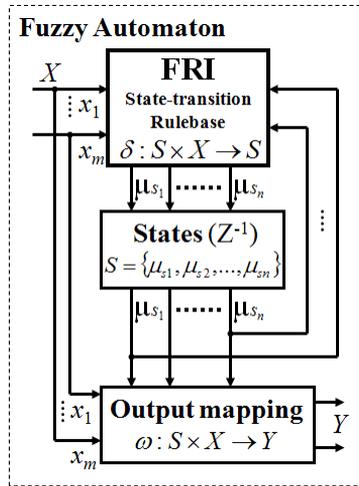


Figure 1  
FRI based Fuzzy Automaton

In the case of fuzzy rule based representation of the state-transition function  $\delta: S \times X \rightarrow S$ , the rules have  $n+m$  dimensional antecedent space, and  $n$  dimensional consequent space. Applying classical fuzzy reasoning methods, the

complete state-transition rule base size can be approximated by the following formula:

$$|R| = n \cdot i^n \cdot j^m, \quad (3)$$

where  $n$  is the length of the fuzzy state vector  $S$ ,  $m$  is the input dimension,  $i$  is the number of the term sets in each dimension of the state vector, and  $j$  is the number of the term sets in each dimension of the input vector.

According to (3), the state-transition rule-base size is exponential with the length of the fuzzy state vector and the number of the input dimensions. Applying FRI methods for the state-transition function fuzzy model can dramatically reduce the rule base size. See e.g. [7], where the originally exponential sized state-transition rule base of a simple heuristical model became polynomial thanks to the FRI.

In the case of direct application of the suggested FRI based Fuzzy Automaton for behavior-based control structures, the output function  $\omega: S \times X \rightarrow Y$  can be decomposed to parallel component behaviors and an independent behavior fusion. In this case the structure of the above-introduced fuzzy automaton can turn to a very similar form, as is expected in behavior-based control (see Figure 2). Some more details of the model implementation can be found in [11], [12], [13].

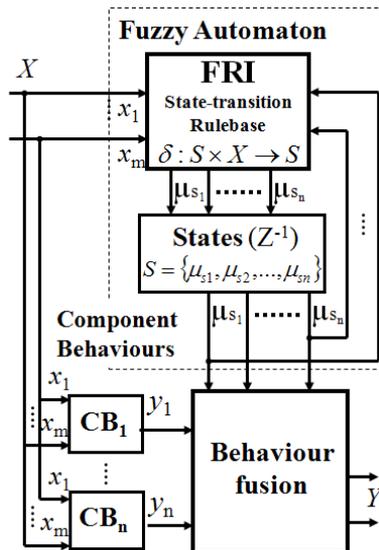


Figure 2

The suggested FRI behaviour-based structure

### 3 Interfacing the Model and the VirCA

The Virtual Collaboration Arena (VirCA) is a modular, easy to use 3D framework supporting the development of augmented reality applications. Augmented reality, the mixture of real and virtual environments, gives the unbeatable chance for experiencing the most realistic direct personal interaction with a virtual entity available only in a virtual environment.

The main idea of VirCA is to place physical devices in a computer generated virtual space, where objects can interact. These objects are called CyberDevices and can be either representations of physically existing objects or completely virtual objects. VirCA is a mixture of different technologies. For visualization it uses a 3D engine called OGRE 3D (Object-Oriented Graphics Rendering Engine), which is a scene-oriented, flexible 3D engine designed to make it easier and more intuitive for developers to produce applications utilizing hardware-accelerated 3D graphics. Also, a component called Bullet is integrated, which is an open source physics engine featuring 3D collision detection, soft body dynamics, and rigid body dynamics. VirCA can connect research groups and distant laboratories (devices) over the Internet using standard protocols. For communication between the components, the Robot Technology Middleware (RTM) is applied. RTM communication is based on the well-known CORBA middleware, but can also make use of the flexible communication channels of the Internet Communication Engine (ICE) [12]. According to the RTM concept, the VirCA is also an RT-Component, which brings the components together and provides a simple to use visualization and user interface by utilizing the aforementioned technologies.

In this way, VirCA can provide a solution for users to collaborate with each other to control physically existing devices remotely in an easy to use mixed real and virtual 3D environment. For example, when industrial robots are working in dangerous environments, the presence of human operators is an unnecessary risk. In this case, the devices can be controlled with methods close to real world methods, avoiding direct human presence. (The VirCA package is available at [25].)

The described model, which simulates the ethological test, has a working software implementation. It was implemented in a MATLAB environment, as MATLAB is a suitable tool for building a prototype application. As mentioned in the introduction of the previous sections, the example model consists of fuzzy automata, several fuzzy rule bases filled with rules according to the knowledge representation of the ethological model, and a complex framework operating the whole system. The framework is also responsible for displaying information and visualizing the outputs of the fuzzy automata used in the simulation, and also for supplying artificial inputs for the fuzzy automata. The three participants of the test procedure: the dog, the owner, the stranger are represented with simple objects. The movement and behavior of the dog object is strictly controlled by the

application, as this is the main purpose of the implemented model. The two human objects can be freely controlled by the operator of the application, but it can be also controlled by the framework based on the pre-defined commands stored in a simple text file. This latter can be useful for benchmarking and tuning, as it simulates exactly the same behavior for the owner and the stranger in every iteration.

To apply the services provided by VirCA, special VirCA interfaces (RTM) are needed in the actual programming environment. Since MATLAB has no native RTM interface (which could be used for direct VirCA communication), an intermediate adapter was developed and acts as a proxy between the two systems. For communication, the standardized User Datagram Protocol (UDP) over IP (Internet Protocol) was selected. The proxy was developed in the way to be easily adapted to other MATLAB applications too.

According to the actors of the model, as described earlier, the adapter consists of four components: *dog*, *owner*, *stranger* and *toy*. These are called CyberDevices in the VirCA terminology. Each CyberDevice has its own function and ports. For example, the *dog* component is responsible for receiving and processing messages from the MATLAB simulation program, and then it has to send the rescaled and recalculated coordinates to the VirCA component.

In the original standalone MATLAB model, the *dog* is composed of two circular objects, the body and the head (see Figure 3). However in VirCA, the *dog* is one solid detailed dog shaped object with head, torso, legs and tail. The position of the dog's head and the dog's body from the 2D space is used for calculating the orientation of the *dog*. This additional value is required for displaying the 3D *dog* object properly.

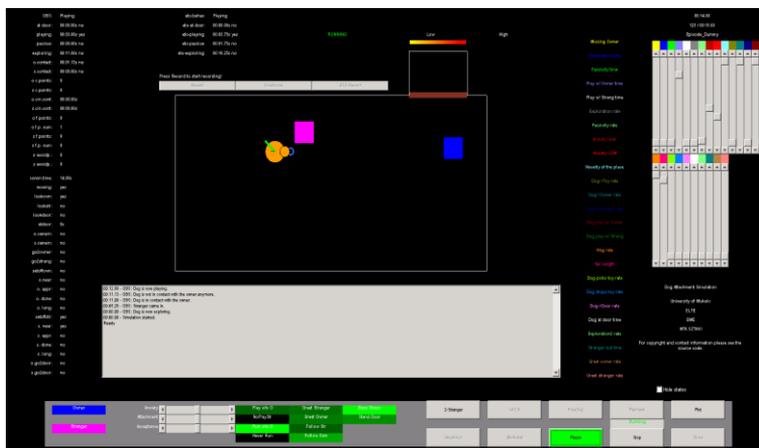


Figure 3

Screenshot of the model running in the original MATLAB environment

The *owner* and *stranger* components are the same from the viewpoint of CyberDevice communication, but the reverse directions must also be handled. This latter means that users can interact with these objects in the VirCA augmented space and the new positions should be transferred back to the MATLAB model. The dog component communicates only one-way, from MATLAB to VirCA. The new coordinates of the *dog* object are calculated by the model based on the observations and the inner system states. The *toy* component is somewhat different, in addition to handling the coordinate conversions between the two environments. The *toy* object can be picked up, dropped and thrown by the other participants.

The communication between the applications is achieved by encapsulating the coordinates and other required data into UDP packets. All the above mentioned components possess their own UDP ports for separate communication. The UDP port assignment can be changed via a configuration file. The defaults port list is summarized in Table I.

Table 1  
UDP port allocations of the CyberDevices

CyberDevice name	ID (register_no)	UDP port
dog	1	4131
owner	2	4132
stranger	3	4133
toy	4	4134

The data encoded in the UDP packets varies over the different CyberDevices. The first data element in every UDP packet is a packet counter. This serves for handling the omission of delayed packets. The internet is a best-effort service style network; it does not guarantee that all the packets sent will arrive at the destination, and even if they arrive, there is no guarantee that the packets will keep the same order as they were sent. The packet counter increases with every packet sent, and at the receiving side, if a packet received contains a packet counter value with less than the received maximum value, the packet is simply ignored. In this way, the problem of omitting obsolete information is solved. The second field called *virca\_regno* is also present in all the packets used in the communication. It is the register number, the identifier of the actual component selected for manipulation (see ID field in Table I). The other data fields are coordinates and states of the objects. The packet coding scheme for sending the properties of the *dog* object is summarized in Table II. Table III shows the packet format for the data of the *owner* object coming from the VirCA environment. The properties of the *owner*, *stranger* and *toy* objects are practically the same, and use nearly identical packet formats.

Table 2  
Packet coding scheme for the Dog component

Field no.	Field name	Type	Description
1	Currentpacketno	16-bit uint	Packet counter
2	virca_registerno	8-bit uint	Register to access (see Table I.)
3	Dogposx	16-bit uint	Position X of the Dog
4	Dogposy	16-bit uint	Position Y of the Dog
5	Dogangle	8-bit uint	Orientation of the Dog (0 – North, 64 – East, 128 – South, 192 – West)
6	Doghastoy	8-bit uint	Whether the Dog has the toy or not

Table 3  
Packet coding scheme for the Owner component

Field no.	Field name	Type	Description
1	Currentpacketno	16-bit uint	Packet counter
2	virca_registerno	8-bit uint	Register to access (see Table I.)
3	Ownerposx	16-bit uint	Position X of the Owner
4	Ownerposy	16-bit uint	Position Y of the Owner
5	Owneroutside	8-bit uint	Whether the Owner is outside the room
6	toy_state	8-bit uint	Whether the Owner possesses the Toy (0) or not (1), and whether the Stranger has just thrown the Toy (2)

The virtual room in the augmented VirCA environment was constructed to resemble the real laboratory room used for conducting the real test. (See Figure 4 for a screenshot of the model running in the VirCA environment.)



Figure 4  
Screenshot of the simulation running in VirCA

## Conclusions

The goal of this paper was to introduce a possible way for interconnecting the Virtual Collaboration Arena (VirCA) 3D environment and other 3<sup>rd</sup> party applications, the programming environments of which had no native VirCA interfaces, such as the most common modeling languages, e.g. MATLAB. Supporting such an interconnection could dramatically simplify the introduction of existing behavior models, such as an ethologically inspired CogInfoCom interaction. Hence, in this case the original implementation of the model can be applied directly, without rewriting it to a programming environment which has native VirCA interfaces. The solution suggested in this paper is the definition of proxy CyberDevices in VirCA (also required for the visualization of the model components), and their control from the model through standard UDP based network communication. In this case, the programming environment of the model must be instrumented with standard UDP based communication only, which is quite common in many environments, e.g. it also exists in MATLAB.

To demonstrate such an interconnection development, some details of the adaptation of a standard laboratory procedure for studying the dog-owner relationship to the VirCA augmented reality environment is introduced in the paper. The appearance of augmented reality in ethological modeling can lead to novel experiments where the formal description of a human–animal interaction model can be tested in the similar way (direct human – simulated animal) as the natural observations of the model were performed. In this way the simulation becomes much more “life-like” and hence easier for ethnologists to work on further.

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