Adaptive Feedback-loop Control System for Inter-reality Management

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Abstract

Times, they say, they are a-changing, and they bring with them both grand new opportunities and new challenging societal problems. One such problem is cost-effective healthcare. The traditional approaches, though effective, are often too expensive, hence novel mechanisms are currently being sought. One such family of mechanisms is the one that makes use of inter-reality coupling physical-reality objects and properties with virtual-life entities such as avatars and their attributes. This introduces a number of technical challenges for optimal management of issues such as performance, real-timeliness, and dependability. One such challenge is the creation of an effective synchronous communication link between (1) information originating in the physical reality and produced by wireless sensors, RFIDs and BANs and (2) information produced in a virtual reality environment such as a Massively Multiplayer Online Role-Playing Game. Inter-reality means basically the ability to reflect and refract events occurring in one domain into the other one. Doing so effectively means providing the designer with an effective expressive model that masks all unnecessary technicalities and reifies all meaningful entities, both physical and virtual, into a common management environment. We have designed the basic building blocks for such an inter-reality management system. Key ingredients of such system are reflective and refractive variables, i.e. dynamic objects that reflect the status of inter-reality entities and refract actions onto inter-reality actuators. This paper describes how we are going to use them to set up adaptive feedback-loop control systems to manage inter-reality healthcare services.

1. Introduction

The use of mechanisms coupling physical-reality objects and properties with virtual-life entities such as avatars and their attributes is spreading. More and more often solutions to big societal problems such as cost-effective personalized healthcare are being sought making use of *inter-reality*. One such approach is the one that is being designed by the "2b@r-health" Consortium. The starting point of 2b@r-health is the awareness that the way people think, especially those less than 25, has tremendously changed in recent years, and has become driven by technology. People no longer accept guidelines written in abstract, paternalistic language but want to experience them in a personalized way where health information is rapidly processed and new solutions are offered according to personal wishes and the availability of new technologies. The digital age has created new needs and expectations and healthcare services cannot neglect these demands.

The 2b@r-health answer to this is to "offer an innovative ICT total solution for high quality health monitoring and care delivery [..] to improve illness prevention and to facilitate active participation of the user. In this revolutionary approach treatment is disguised as *enter[care]ment*. Enter[care]ment is a never seen blended profit/non profit design in medicine and offers an attractive way to control the increasing healthcare expenditure in Europe."

In practice, the core idea of 2b@r-health is to place the user into a hybrid world that contains viable medical models disguised by indirect field strategies such as games, chat rooms, virtual libraries, discussion islands; then, to monitor each user's activity and interactions, and to make use of advanced computational techniques in computer science, artificial intelligence, and machine learning so as to capture complex inter-reality emergent behaviours and phenomena; and eventually, to use the newly acquired knowledge to deliver highly tailored healthcare. In 2b@r-health medical interventions are embedded in iterative processes of knowledge generation that are, in turn, fed back to either the physical or virtual reality. The biggest challenge here is to make healthcare part of the user's global life experience. Key design goals are the ability to be ubiquitous, easy accessible, enjoyable and "invisible" (the approach shall not interfere with the user's sense of pleasure.)

A full description of the 2b@r-health concept is clearly out of the scope of this text; what is important in what follows is that an important prerequisite to the inter-reality concept is the "engine" driving the adaptive control loops around the users. This component provides the inter-reality designer with a tool for the expression of the control loops. In the following we briefly introduce the characteristics and properties of this tool (in Sect. 2) and show how we shall use it in the framework of the 2b@r-health and other research actions (in Sect. 3). Our conclusions so far are finally drawn in Sect. 4.

2. Reflective and Refractive Variables

Reflective and refractive variables (RR vars) are a syntactical framework for the expression of adaptive control loops. RR vars have three main design goals:

1. To provide a homogeneous environment in which any heterogeneous resource may be abstracted and reflected.
2. To provide a homogeneous access to public methods exported by those resources.
3. To provide a straightforward access pattern to query and invoke the reflected entities in a homogeneous way, masking all differences in nature and technology.

In practice, RR vars are volatile variables of any programming language—regardless its paradigm. The identifier of an RR var has an extra functionality—it does not just link to some memory cells, but also to some external *device*. For instance, in

$$\text{Ref\_t int cpu;} \tag{1}$$

identifier "cpu" refers to (typically) 4 consecutive bytes in memory (let us refer to them as "&cpu") but also to thread "reflect_cpu()", which continuously checks whether the amount of CPU currently employed by the local host has changed— if that is the case, that thread updates &cpu with the new value. As a result, variable cpu "tracks" the local CPU.

After definition (1) the programmer does not need to know how to interface the local operating system to access the current value of the CPU—he or she only needs to access variable "cpu". We use to say that "cpu reflects the CPU". We call a "sensor" an external device that is linked to such a variable.

In some cases the variables are linked to devices that can not just be queried but also controlled. An example follows:

$$\text{Ref\_t int tcpTxRate;} \tag{2}$$

defines another variable, "tcpTxRate", which reflects the value of the transmission rate from the local transport network layer. Thread "reflect_tcpTxRate" updates the memory referenced by "&tcpTxRate" and continuously exports the corresponding values to the application layer. But there is an extra feature here: By setting variable tcpTxRate, one requests to adjust the corresponding attribute in the local transport layer. As a result, variable tcpTxRate controls the remote attribute with the same name.

We call an "actuator" any external device linked with one such variable. Again, the programmer does not need to know how to interface, e.g., the transport layer to read or set a certain attribute. More than that, this approach removes the need for an action like that, which clearly violates the basic principles of layered design.

We call refractive one such variable and say for instance that "tcpTxRate refracts" on the corresponding parameter in the TCP local entity.

We conclude that RR vars provide a model for the expression of adaptation procedures structured as monitoring-and-control loops. These procedures reside in the application layer of a hosting language such as C[1].

Figure 1 shows a C program using the two above introduced RR vars. Figure 2 shows an execution of the code in Fig. 1 on a Win32 PC. Again in Fig. 1, the Windows Task Manager describes graphically how variable cpu "tracks" the local CPU.

3. Adaptive Feedback-loop Control Systems through RR vars

As mentioned above, at the core of the 2b@r-health initiative is its inter-reality control loop, which shall be expressed as programs manipulating RR vars. The host programming language has not been selected yet, though it will probably be in the domain of objected oriented languages. In 2b@r-health RR vars will be objects that dynamically reflect the status of inter-reality entities and refract (that is, redirect [10]) actions onto inter-reality actuators. This shall be used e.g. to trigger instantaneous, or delayed, or gradual reactions in a virtual world as a consequence of changes in the physical one (and viceversa).

In more formal terms, let us call L_1 some non-empty set of trackable information originating in physical life and M_1 a set of memory cells addressable by program p. Then

$$\rho_1 : L_1 \to M_1 \tag{3}$$

is an isomorphism "linking" physical life information and memory cells. An isomorphism is an invertible structure-preserving mapping [11]: Actions in the physical life are "preserved" into memory accesses, and vice-versa.

Furthermore, let us call L_2 a non-empty set of trackable information produced in a virtual world W such as Second Life [15, 16] or Entropia Universe [5, 6], and M_2 a second set of memory cells also addressable by p, disjoint from M_1. Then let us consider

$$\rho_2 : L_2 \to M_2, \tag{4}$$

this time an isomorphism linking virtual-life information and some other memory cells. Not surprisingly enough, function ρ_2 preseverses actions occurring in W into memory cells, and vice-versa.

[1]In [3] we describe a prototypic implementation in the C language.

The 2b@r-health challenge can be rephrased as being able to use ρ_1 and ρ_2 to build an effective inter-reality isomorphism

$$\varphi : L_1 \to L_2 \tag{5}$$

such that L_1 and L_2 can be mapped onto each other[2], or in other words, to make L_1 and L_2 isomorphic[3].

The RR vars are the means through which φ shall be practically defined.

Instances of the RR vars shall represent in a homogeneous way heterogeneous objects and attributes in L_2, such as an avatars height, weight, speed, and abilities, or a L_1 user's attribute or state, e.g., pose, weight, pulse, or temperature—a few examples are given in Table 1. Soft computing (especially evolutionary computation and machine learning) shall be used to understand, model and analyze the processes ongoing in L_1 and L_2. Taking actions and steering courses shall also take advantage of RR vars, which allows to concentrate on the scientific problems (in the case of 2b@r-health, obesity) without having to care about technicalities, locations, and nature of events.

Through this approach design complexity gets decomposed into two separate parts—functional complexity (how to *express* inter-reality processes) and non functional complexity (how to *achieve* inter-reality processes) and mask choices such as e.g. which virtual-world architecture or which Wireless Sensor Network to make use of. In so doing we separate concerns and create two separate but communicating environments, one in which the specialists in the problem (e.g. the MD, the psychologist, the nutritionist) study their strategies, and one where the specialists in technology (e.g. ICT engineer, the Soft Computing engineer, the VR specialist, the MMORPG [12] specialist, or the software programmer) study how to achieve, deploy, and render those strategies.

3.1. Other uses of RR vars

Adaptive feedback-loops expressed through RR vars are being designed in contexts other than inter-reality. One such context is cross-layer adaptation. As hinted in Sect. 2, RR vars may conveniently represent network layer status information and "knobs", as explained e.g. in [2, 1, 14]. We plan to make use of RR vars for this

[2]Quoting Douglas Hofstadter [8], through an isomorphism "two complex structures can be mapped onto each other in such a way that to each part of one structure there is a corresponding part in the other structure, where 'corresponding' means that the two parts play similar roles in their respective structures."

[3]"In a certain sense, isomorphic structures are structurally identical, if you choose to ignore finer-grained differences that may arise from how they are defined." [11].

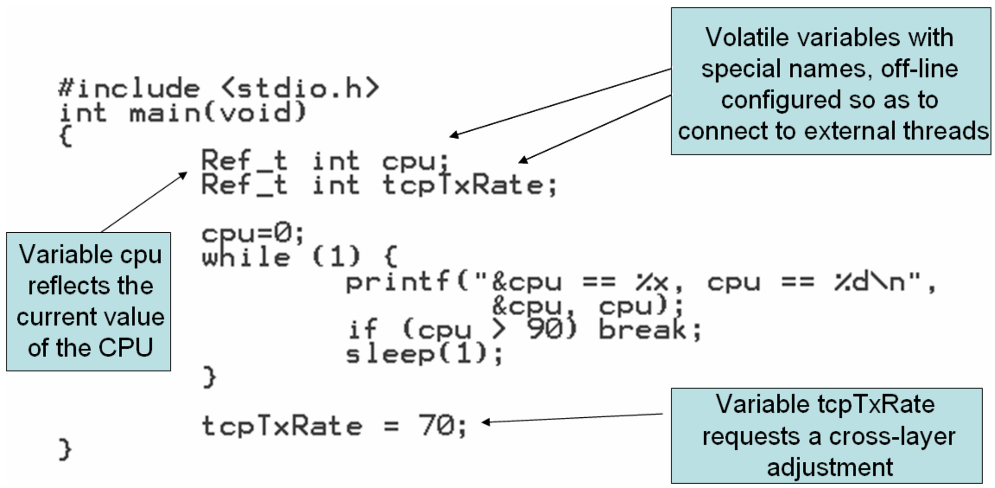

Figure 1. A simple example of the use of RR vars.

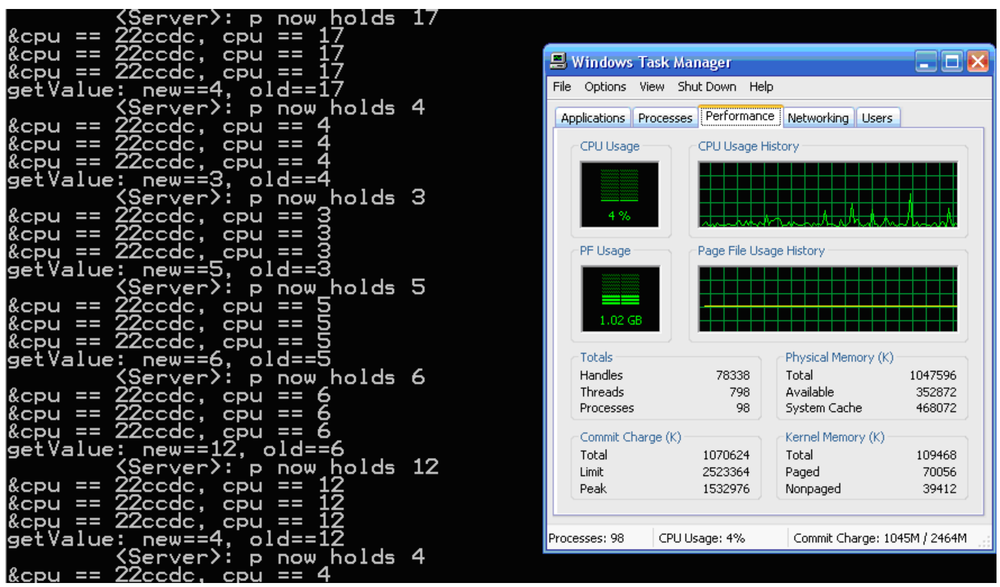

Figure 2. An excerpt from the execution of the code in Fig. 1. Note how the Windows Task Manager shows that indeed the CPU and the contents of reflective variable cpu follow the same course.

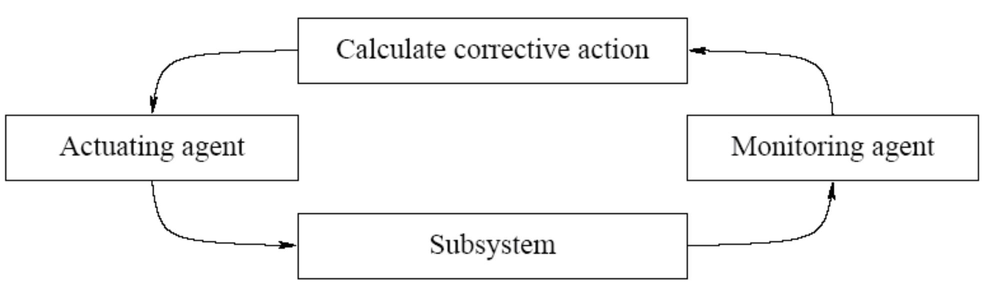

Figure 3. Classical feedback-loop structure.

```
Avatar_t * Avatar = new Avatar_t [10]; // Initial population in L_2
Player_t * Player = new Player_t [10]; // and in L_1

Avatar[0].location  = MUIR_ISLAND; // location, height etc are Ref_t:
Avatar[0].height = 6;              // setting them changes the avatar
Avatar[0].weigth = 82;
Avatar[0].speed =  80;
Avatar[0].abilities = { WALKS, FLIES, TELEPORTS };
Player[0].Sensor1 = ACTIVATE;

Avatar[0].height = Avatar.height - 0.2;
if ( Player[j].Trend[WEIGHT] == INCREASING ) {
     // Modifies the shape of the avatar...
     Avatar[j].shape += ROUNDING;

     // ...and activates a sensor that measures the movement of
     // the jaw during eating and in parallel to this, the acoustic
     // signal arising from chewing and swallowing
     Player[j].IntraOralSensor = ACTIVATE;
}
```

Table 1. In this example RR vars represent in a homogeneous way both L_1 and L_2 objects, attributes, and processes.

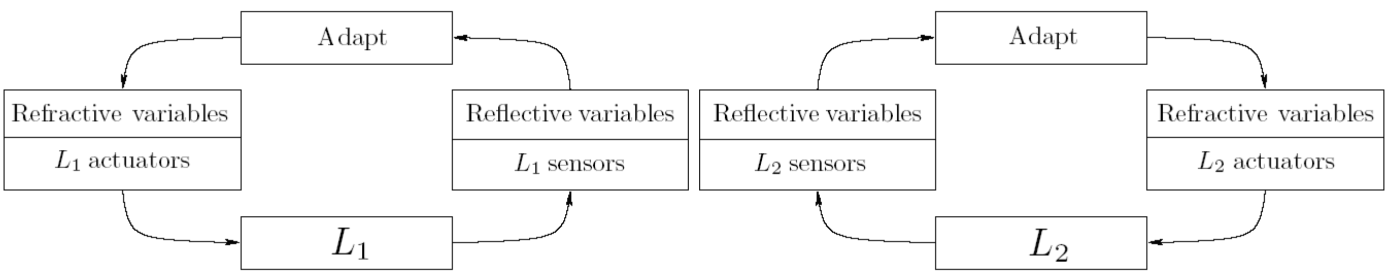

Figure 4. The adaptive feed-back loops of 2b@r-health. The "Adapt" modules (corresponding to program p of Sect. 3) shall contain soft computing methods and possibly a rule engine such as JESS [7, 13] to infer the required control actions, to be expressed in terms of refractive variables.

purpose in the framework of IBBT [9] project "End-to-end Quality of Experience" [4]. In that same project, several concurrent strategies of adaptation are bein devised, and we are currently designing an approach to reconciliate them. A paper describing this experience appears in this Volume [17].

Another area where we plan to exercise our tool is that of adaptive interfaces, i.e. structured as a feedback loop and able to adapt themselves to the user's needs and capabilities. The feedback loop would measure the ability of the user, tracking mistakes and assessing whether the user is proceeding slowly or fluently. Consequently the system would react by gradually simplifying or enhancing the features offered by the interface, so as to reach the right man-machine balance, capable of adapting the system rather than requiring the man to adjust to the machine. A tool like this may be particularly important for those users that are more affected by the so-called digital divide, e.g., elder people with few or no technological awareness or background.

It has been conjectured [18] that models such as the one treated in this text may provide an effective solution for the design of self-managing systems[4]. In this context we are planning to use RR vars to design self-healing components able to monitor their mutual state and adapt themselves, their functional aspects as well

[4] "Self-managing software systems consist of hierarchies of interacting feedback loops; programming with feedback loops becomes common and should be supported by the language" [19].

as their dependability strategy so as to guarantee high reliability, safety, and availability.

4. Conclusions

We have introduced a structured model to express tasks such as adaptive or self-healing systems in an elegant, non intrusive and cost-effective way. We have described how to make use of this model to set up adaptive feedback loops to control tasks such as inter-reality healthcare, cross-layer optimization, and intelligent interfaces. In the first case, we have detailed our approach and sketched a formal model of its basic principles. Future publications will further elaborate on the above themes.

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