Virtual Reflexes

Catholijn M. Jonker,[1] Joost Broekens,[1] Aske Plaat[2]

[1] Interactive Intelligence
Delft University of Technology
Mekelweg 4
The Netherlands
c.m.jonker@tudelft.nl,
joost.broekens@gmail.com

[2] Tilburg School of Humanities
Tilburg University
Warandelaan 2
The Netherlands
aske.plaat@gmail.com

Abstract. Virtual Reality is used successfully to treat people for regular phobias. A new challenge is to develop Virtual Reality Exposure Training for social skills. Virtual actors in such systems have to show appropriate social behavior including emotions, gaze, and keeping distance. The behavior must be realistic and real-time. Current approaches are usually based on heavy information processing in terms of behavior planning, scripting of behavior and use of predefined animations. We believe this limits the directness of human bodily reflexes and causes unrealistic responses and delay. We propose to investigate *virtual reflexes* as concurrent sensory-motor processes to control individual parts of the virtual actor's skeleton with a body integrity model that keeps the effects coherent. We explain how emotion and cognitive modulation could be embedded, and give an example description of the interplay between emotion and a reflex.

1 Introduction

The idea of using virtual reality to treat regular phobia—such as fear of heights, or flying—relies on the success with which we can immerse the patient in a virtual situation. Patients should have an experience corresponding to a real life situation. For training *social* skills, the VR setting has to be such that the emotions and intentions that trainees would attribute to a real person are now attributed to a Virtual Character (VC).

To produce appropriate social virtual character behavior, typically heavy processing is involved in deciding based on sensory input generated by the trainee what responses need to be generated at the skeleton level of the VC. In particular, pattern recognition, reasoning and behavior planning, and virtual character animations need to be addressed. In contrast to this processing intensive approach, in this paper we propose a low-level approach based on the idea of virtual reflexes, in which observations directly cause VC muscle actuations *with limited intermediate processing*. Based on various primitive inputs, the muscle actuations are immediate and create bodily reactions. This generates fluent and fast responses in the VC. Perceived emotions emerge out of the interaction between sensory and motor information. Although no cognitive intermediate processing takes place, cognition and affect do modulate the sensory motor loops. As happens in the human body, various virtual reflexes can occur simultaneously and operate as concurrent subsystems.

The idea that social signals emerge from virtual reflexes is motivated intuitively, practically and theoretically. First, when engaging in day-to-day activities, people do whatever it is they are doing, in unthinking response to the "moment-to-moment local forces acting upon them" [41, p. 263]. This is closer to a reflex-based approach than to a reasoning-based one. Second, virtual reflexes provide the speed necessary for realistic social interaction [26]. Third, reflex-based control corresponds to theories on embodied cognition and affect [42, 43]. The contributions of this paper are as follows:

- We introduce an architecture for virtual reflexes.
- We link the architecture to neuropsychological theories on emotion & cognition.
- We formalize part of the reflexes in a virtual aggression training case study.

2 Related work

Virtual reality techniques have been shown to have significant therapeutic value, and in particular, VR stress inoculation training works well in various settings [36]. Virtual reality exposure therapy [11, 23, 33] has been shown to be as effective as in vivo (real-world) exposure therapy [33]. Popovic et al [32] present a Stress Inoculation system using an interactive VR system. Virtual reality systems have yielded positive training results [7, 16, 30, 38, 3, 22], and can also be used for personality assessment [39].

The real-time aspect of emotion modeling has been addressed in, e.g., the work on autonomous real-time sensitive artificial listeners [10, 35, 40], the work on backchannel communication [5, 17, 37], to create "rapport" between virtual agents and humans [15, 18, 13], and in computational models of coping [27] and synthetic emotion generation for games [31]. The challenge of generating real-time behavior has motivated [4] to develop the subsumption architecture. Our architecture is inspired by Brooks' work in the sense that it consists of multiple subsystems running concurrently. Key novelty in our approach compared to other Virtual Character control architectures is that particular sensory inputs have immediate influences on particular parts of the VC skeleton. The overall research question is thus to what extend it is possible to generate plausible social behaviors without explicit coordination of sensory – motor loops, except coordination enforced by the VC's body integrity.

3 Virtual Reflex Architecture

The basis of our architecture is the uncoupling of various sensor-actuator channels. Behavior is generated by reflex nodes that dynamically couple sensory input and motor output. To cope with high-level influences on behavior, such as training scenarios, activity of these nodes is modulated by cognitive and emotional factors (see figure 1). Each reflex node can be seen as a small control node that influences body parts. Its output is based on whether its sensory input deviates from a preset baseline, much like drives would need to be met in a homeostatic approach [6]. Upon deviation, three things happen concurrently. First, the deviation triggers activation of the body parts coupled to the reflex node. Second, the deviation has an effect on the emotional state. We envision a Pleasure–Arousal–Dominance (PAD) representation [28] of the emotional state (Emotion, in figure 1). Third, the deviation is available for cognition to reason upon. The emotional state is simply a correlate of the aggregated deviations from the drives, and as such "setting" the emotional state will also bias the drives towards a different baseline. This provides a natural and behaviorally grounded mechanism to model the influence of emotion on behavior, and also the emergence of emotion out of behavior and reflexes [6]. The cognitive model operates on sensory-motor primitives, as the information it gets is not the raw sensory information but the deviation and drive-based control effect following from the sensory information. In our architecture, cognition is grounded in sensory-motor representations, which is in line with embodied cognition approaches [42]. Cognition influences behavior by modulating the virtual reflex decision node activities and parameters, just like emotion does. Emotion and cognition thus follow from and operate on reflexes in similar ways. In our approach the emotional state is simply a different representation of the emergent pattern of reflex activities, while cognition can hold any processing mechanism, as long as it takes as input reflex-node activity and it outputs reflex-node biases. The link from the body of the virtual character to the proprioceptive part of the perception system is in line with the body loop of Damasio [8]. It allows the virtual character to perceive, and respond to, its own actions.

The virtual character's immediate responses are controlled by the virtual reflex-loop, while the agent's high-level decisions are modeled as cognitive biases to the virtual reflex decision nodes. In this way the architecture also allows emotional coping [14] by means of influencing the reflexive behaviors, which, in turn, influence the emotional state. This is a natural way of modeling coping, as this grounds the coping process in the actual "physiology" of the virtual character instead of simply influencing the representation of the emotional state.

We assume that the VC has a body integrity model allowing it to, e.g., propagate a head nod to the torso. Candidate solutions are physics based models [12] and inverse kinematics modeling how effects of body parts propagate through the complete body.

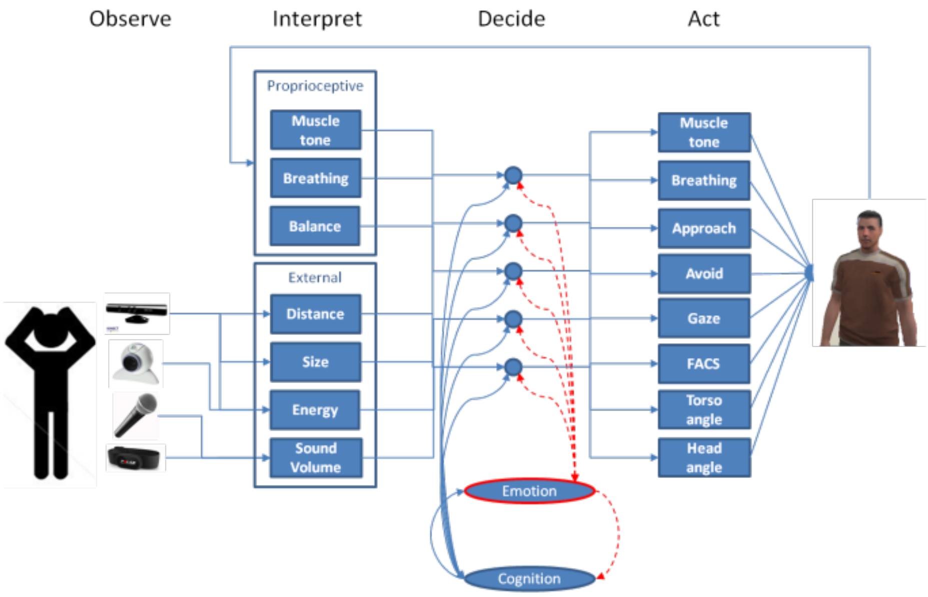

Fig. 1. Virtual Reflex architecture showing examples of reflex nodes for different sensor-subsystem. Nodes process the signals and yield appropriate responses in parallel. Note that Virtual Reflexes are modulated by cognition and emotion.

4 Neuropsychological Basis

In our approach behavior generation is the cognitive (and affective) modulation of automatic reflex processes [2]. Our approach is compatible with embodied cognition theory [42, 43], where the basic premise is that thought is tightly coupled to behavior and the representations used for behavior.

Note that the idea of multiple levels of increasingly complex processing involved in affective responses is not new. For example, LeDoux [24, 25] describes a high and a low route to emotion processing. The low route is "quick and dirty" and evaluates stimuli in a fast but inaccurate way, while the high route is cortical and evaluates stimuli in a slow but detailed way. Scherer [34] also considers appraisal as a process of multi-level sequential checking with lower levels triggering activity at higher levels. Each level typically involves more complex information processing, and is only activated to the full extent when that is needed based on simpler appraisals. For example, appraising stimulus relevance is done first based on suddenness, a simple stimulus-based appraisal, and when relevance is high this triggers implication-related appraisals such as goal-conduciveness, a more cognitive-based appraisal. This model of appraisal can be computationally integrated with other models that assume appraisal is layered from simple to complex processing [3].

The ideas of thinking fast and slow [19] contain the same basic idea, i.e., that there are multiple concurrent processes for different aspects of behavior and reasoning. The fastest behaviors we have are reflex behaviors, developed early in our evolution, and essential for survival. Body language is an important part of social interaction [1, 21], and is recognized as expressions of emotions. Mimicry is an essential part of the human social repertoire that is inexorably bound up to basic social processes of empathy, bonding, and in-group formation [20]. In contrast, higher order cognitive appraisal processes take more time, e.g., [29], and explain how we appraise our progress with respect to our social and personal goals.

Our approach is also inspired by Damasio's somatic marker hypothesis [8]. Somatic markers are the affective counterparts of situational representations in terms of sensory-motor activity. Such markers get triggered by activities and thoughts, and can bias behavior and thought at the same time (for example, during decision making). Our emotional state emerges from the activity of the reflex nodes; it is grounded in sensory-motor activity. The state itself influences these nodes, as the relation between emotion and reflex is bidirectional. If the agent is in a high arousal state, this biases the reflexes towards high energy. This, in turn, biases cognition to trigger those associations that are related to high energetic reflex behavior, closing the loop from emotion to cognition through sensory-motor representations. In our approach, "feelings are mental experiences of body states" [9].

5 Case: Aggression De-escalation

As an example case we explain how the Virtual Reflex architecture can form the basis for a Virtual Reality training system for coping with verbal aggressive situations. The system confronts a trainee in virtual reality with a verbal aggressor. During the training a virtual character confronts the human trainee with verbal aggressive behavior and subsequently reacts in real-time to the actions and behaviors of the human trainee. In this paper we focus on the VC behavior generation component by means of a virtual reflex architecture, not on the scenario or verbal behavior.

5.1 Behavior Generation and Virtual Reflex-loops Example

We now explain how the architecture presented in Section 2 is used for behavior generation in virtual aggression training. The complete system will contain parallel channels for bodily reflexes including nodes that control torso-, and head-posture, muscle tone, blush, breathing, gaze, and eyes openness. These nodes react to sensors focused on the trainee, but also on virtual sensors of the VC such as muscle tone, breathing in balance. The virtual balance sensor will impact the architecture when the VC is getting out of balance, in which case the appropriate nodes and then actuators are triggered to restore balance (e.g, by taking a step). In the case study, we focus on torso-movement only and assume postures are described using pitch, roll and yaw. We focus on the decision node for torso-pitch. Torso-pitch is influenced by the bodily movements of the trainee, but also by the VC's emotion. Furthermore, we show that in an indirect way, the Virtual Reflex-loops influence emotion. One of the modeling concept for torso-pitch is social distance as modulated by emotion (feeling of Dominance of the VC, to be precise). In this example we describe how the torso-pitch changes throughout a scenario. We propose the following rough formalization of the dynamics of torso-pitch (tp) behavior as follows:

$$tp_{t+1} = C_{sd}*(tpp_t - tpp_{t-1}) + \beta * tp_t$$
$$m_t = C_{sd}*(sd_{target} - d_t)$$
$$sd_{target} = (1-D)*sd_{default} + CD$$
$$C_{sd} = (A+1)/2$$

Here, $C_{sd} \in [0,1]$ is the social distance inertia factor, tpp_t is the torso-pitch of the player at time t, d_t is the physical distance at time t. The factor $\beta \in [0,1]$ ensures that over time, if the player does not change his torso pitch, the torso pitch of the VC will return to normal (0). The intended move at time t is denoted by m_t. Note that physics (such as the counter in the case study) might (partially) prohibit the execution of m. D is Dominance [-1,1] and relates to social stance, perceived control, and self-efficacy. Dominance moderates the default target distance. High dominant Virtual Characters will have a closer preferred social distance, and vice versa. A is Arousal [-1,1] and relates to energy. Energy thus defines the speed with which the torso angle changes. CD is defined as cultural distance. The closer two individuals are with respect to their cultural background, the smaller CD is. CD should be calibrated based on existing social science findings. $Sd_{default}$ is defined as the Virtual Character's personal preferred social distance. This factor is needed to model individual differences in preferred social distance as this varies from person to person. The parameter is set in the cognition model. Similarly, the PAD emotion values are set by the emotion model, thus modeling the effect of emotion on the Virtual Reflex-loop.

Conversely, each of the Virtual Reflex-loops potentially influences emotion and cognition (dotted lines from decision nodes to the emotion component, figure 1). In the case study, the values computed in the torso-pitch decision node are passed to the emotion component. For example, forward torso pitch can induce anxiety or aggression (depending on the VC's personality and the current affective state). Similarly, the cognitive component receives input from the sensors, the decision nodes and the emotion component. For now we focus on the input from the decision nodes that send information on the body state of the VC. The VC's cognition component plans on overall and longer term changes in behavior, e.g., changes in posture, dialogue, etc. We assume (and this is part of the open questions) that the VC's body integrity model ensures that movements caused by different Virtual Reflex-loops result in physically coherent behavior.

5.2 Virtual Reflex-based scenario formalization

In this section we describe how torso pitch changes throughout an example scenario in a social welfare office (see picture below). The scenario time labels refers to moments of change. In this way every reaction triggers a new number.

Event	Informal description	Formalisation
0	Behind the social welfare office counter is Barney (not depicted). Barney is new in his job and feels uncertain. The man in the T-shirt (the VC) is frustrated and angry as his allowance has been canceled. He came to demand his money.	tp_0: 0 /* *torso-pitch of VC neutral* */ tpp_0: 0 /* *torso-pitch Barney neutral* */ $PAD_{default}$=(0, 0, -0.5) /* *VC's personality* */ PAD = (-1, 1, 1), β = 0.95 /* *not changed during the scenario* */
1	VC is at the counter and scowls.	tp_1: 0 /* *torso-pitch of VC neutral* */ tpp_1: 0 /* *torso-pitch Barney neutral* */ $face_1$: scowl
2	Barney stretches his arms against the counter, thus pushing his torso backward.	tp_2: 0 /* *torso-pitch of VC neutral* */ tpp_2: -0.1 /* *torso-pitch Barney backwards* */
3	The torso pitch of the VC reflexively comes forward in response to Barney's movement.	C_{sd}=(A+1)/2=1 tp_3 =C_{sd}*(tpp_1-tpp_2) + β*tp_2 = 1*(0- -0.1)+0=0.1 tpp_3 = -0.1
4	VC slams his hand on the counter and shouts "I demand my money!".	tp_4: C_{sd}*(tpp_2-tpp_3) + β*tp_3 = 1*0+0.95*0.1= 0.095 tpp_4: -0.1
5	Barney, jerks back for a moment.	tp_5: C_{sd}*(tpp_3-tpp_4) + β*tp_4 = 1*0+0.95*0.095= 0.09 tpp_5: -0.2
6	VC leans in.	tp_6: C_{sd}*(tpp_4-tpp_5) + β*tp_5 = 1*(-0.1- - 0.2)+0.95*0.09= 0.185 0.09 tpp_6: -0.2
7	However, Barney relaxes his muscles, thus neutralizes his torso-pitch, and stays polite.	tp_7: C_{sd}*(tpp_5-tpp_6) + β*tp_6 = 1*(-0.2- - 0.2)+0.95*0.185= 0 + 0.176 tpp_7: 0
8	VC stops leaning on the counter by a backward torso movement.	tp_8: C_{sd}*(tpp_6-tpp_7) + β*tp_7 = 1*(-0.2- - 0)+0.95*0.176= -0.2 + 0.167 -0.03 tpp_8: 0

As Barney keeps a neutral torso-pitch, after a while, also the torso-pitch of VC returns to neutral.

Fig. 2. Case study: VC demands his money from a social welfare officer. The trainee (officer) is not in the picture. The VC described in the example wears the T-shirt.

This short example shows how behavior can be generated by reflex nodes, and how this behavior can be modulated with emotion. It does not show how emotion emerges from the reflex nodes. However, the system of equations should be interpreted as a dynamic system. The VC's Dominance results from interaction with the virtual character as well, simply by the fact that the system settles only at a particular close social distance if dominance is high. (Note the bidirectional nature of the reflex nodes and the emotional state.). So, if the trainee (Barney) is able to calm down the VC (e.g., by keeping distance and staying calm so that the PAD state will decay to $PAD_{default,}$ i.e., the personality of the VC), dominance and arousal drop due to calm sensory input that modulates C_{sd} and increases sd_{target} (not taken into account in the example). Both changes would further stabilize the situation.

9	VC's arousal drops due to calm sensory input	$PAD_9 = PAD_{default} = (0, 0, -0.5)$ $C_{sd}=(A+1)/2=0.5$ tp_9: $C_{sd}*(tpp_6-tpp_7) + \beta*tp_7 =$ 0.5*(0 - 0)+0.95*-0.03= -0.028 tpp_9: 0

6 Conclusions

The purpose of our work is to achieve immersive and realistic virtual environments for social skill training. To realize this, we propose a computational model for virtual character behavior based on parallel virtual reflexes that involve limited processing and operate directly on parts of the VC skeleton based on sensory input. Emotions emerge out of this interaction between sensory and motor information. Cognition is envisioned to modulate the sensory-motor loop. Virtual reflexes can occur simultaneously. Current limitations (we consider to be open questions) to our approach are (a) the ability of the body integrity model to enforce coherence, (b) the ability to generate scenario-relevant modulations of behavior solely based on cognitive modulation of parallel sensory motor loops, and (c) uncertainty about the emotion dynamics induced by a bidirectional relation between emotion and sensory-motor activation.

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