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Basing artificial emotion on process and resource management

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Abstract. Executable computational process models of emotion are based on specific sets of modelling primitives. Motivated by the requirements of a specific scenario and concepts used by emotion theories, we propose as building blocks explicitly bounded resources and concurrent processes acquiring and using them. Our approach is intended for the incremental modelling of a growing collection of emotional episodes, with a clear delineation of technically necessary simplifications of the natural phenomena. An episode of disgust is used to discuss the approach, which is realised using real-time cooperative microthreading technology.

Key words: affective agent architectures, appraisal theories, computational modelling, design criteria, disgust, embodiment, real-time systems

1 Introduction

The contribution of this paper is the proposal to use explicitly bounded resources and concurrent processes as building blocks for computational modelling of emotion in a virtual world (section 3). This approach acknowledges that ongoing "always on" interaction of the agent with its environment[1] is fundamental, and that physical and material constraints are important. These tenets can be put to use in a virtual agent situated in a virtual world without sacrificing the benefits of dealing with an environment under the control of the modeller (as opposed to the real world). Further, we argue that this approach can be used to cover phenomena as described by current theories of emotion, while making explicit the symbolic and computational shortcuts necessary to achieve a certain depth of modelling. This furthers the line of research of Tabasco [20]: at first, we did away with reification of emotions; we now in particular aim at deconstructing the notion of static appraisal frames, to be replaced by coordination mechanisms in

[1] Terminology used in this paper: *agents* (virtual bodies plus control architectures) are embedded in *their environment*; agents and environment form the virtual *world*.

a concurrent model. We have to emphasise that the proposal of using processes and resources as abstractions concerns the runtime of models. At design time, there may well be more suitable, higher-level abstractions.

Models of artificial emotion are a crucial element for building intelligent agents in social virtual worlds [13], and can also provide valuable benefits for theorising in emotion psychology [5,10]. Human emotions, however, are extremely complex phenomena involving cognitive, perceptual, and expressive competences. Attempts at operationalising mechanisms of emotion for an artificial system in a virtual world need to choose from a range of approaches differing in scope, detail, and fidelity of simulation—both of the system itself and the environment it is embedded in. The structure of current computer systems and the abstractions that are easily available in current programming languages often bias the structure of computational models: A single locus of control, widespread use of symbols for internal state and communication, absence of timing constraints, and conceptually unbounded use of resources are typical symptoms.

In early cognitive architectures, such features of implementations have posed difficulties for their application in robotic scenarios, and the concept of embodiment is often used to argue for the need of a different approach for agents in the real world [4]. More generally, the particular scenario of use, including the motivation for modelling emotion, determines the requirements that a particular implementation needs to meet [23]. For the purpose of the present paper, we assume the scenario of modelling a specific emotional phenomenon, disgust, in a virtual world similar to a computer game (section 2). In section 4, we illustrate our approach by sketching the resources and processes involved in the modelling of a specific episode of disgust.

2 Requirements analysis

Affective agent architectures are used to construct agents for environments, such as (serious) computer games, that require autonomy and believable interaction with humans. A foundation for such affective agents are computational models of emotion that are executable in real-time. The context of virtual worlds and real-time interaction restricts the set of usable techniques. Furthermore, there are many approaches, based on abstractions readily available in mainstream programming languages, that fail to meet the requirements of our specific scenario, as described in this section. The scenario includes (the modelling of) two or more virtual characters in a three-dimensional world that can be manipulated by a human user. This world is to be a test-bed for the incremental modelling of a growing collection of specific emotion phenomena in a grounded fashion, explicating all simplifications considered as technically necessary. This section details the requirements that impinge on our choice of basic building blocks for such simulations.

Cognitive architectures often use a single control structure and a small set of general representation schemes. An example is Soar and emotion models based on it [12,16] which use, at the core, a single execution cycle and a central hierarchical data structure modified by operators. Similarly, logic-based agents employ propositions and an inference mechanism. Such mechanisms and representations have their uses, and the present proposal is not aimed at replacing them with a single "better" mechanism. Rather, we try to identify building blocks for our approach that allow the use of diverse resourceful [18] methods, while providing the features that we deem fundamental: fidelity of simulation, compatibility with theories of emotion, tractability, and the explication of modelling shortcuts.

Fidelity of simulation The agent is to be simulated as a physical system with resource bounds in both space and time. The simulation of the physical system *"emotional mind"* in a digital computer that is inherently serial calls for mechanisms that approximate the analogue and massively parallel nature of emotional agents acting in the real world, i.e., living beings. Further, all the resources in the model are part not only of the agent but also of the (simulated) world and thus not under the exclusive control of the agent. As an example of an external influence, consider a physics simulation that is part of the environment: Given its continuous effect on the agent, it warrants inclusion of adaptive action monitoring processes in the agent. Similarly, simulated visual perception has to be actively directed to focus on specific parts of the environment, and processes internal to the agent are bounded in terms of e.g. available processing time. Fidelity of simulation also implies that robotic architectures, where physical and material constraints cannot be abstracted, are a relevant source of insights. Arzi-Gonczarowski [1] argues for transferring the issues of embodied grounding that are relevant in creating particular but approximate models of intelligence for robots to the theoretical foundations for general accounts of intelligence. Similarly, Aylett [2] presents an example of applying the striving for applicability in the real world, as in robotic architectures, to virtual worlds.

Emotion processes in psychology The building blocks chosen should allow assembly of simple models that are compatible with the rich descriptions of emotion processes in the psychological literature. Two specific accounts of appraisal theories of emotion [6] are considered here: Scherer's component process model [25] and Frijda's description of the laws of emotion [7,8] are both well suited for a process-oriented modelling approach. The following two aspects of these theories have a main impact on the choice of modelling primitives.

First, emotions are an inherently temporal phenomenon. They are events over time, vary over time, and include constituent processes at different time scales [8]. Descriptive accounts of emotion that disregard the temporal development of emotion episodes are of limited use in real-time environments. The chosen modelling primitives should support modelling the temporal characteristics of emotional mechanisms. Second, both theories assume that the normal operation of a (human) agent involves many parallel processes, mostly unsynchronised and not reflected in overt behaviour. This can be inferred from the descriptions of the internal changes making up emotion: Scherer characterises emotion as an episode of interrelated, synchronised changes in several organismic subsystems;

Frijda [8] highlights the control precedence of the action readiness associated with an emotion, i.e. the tendency to override other activities. Multiple action readinesses can be aroused in response to concurrent formation of appraisal patterns and while only one may initially instigate overt action, others can surface later. Further, the primary effect of control precedence is counteracted by simultaneously active regulation processes. The emotion episode modelled in section 4 includes examples of such processes.

Tractability The requirement of the model of emotion to run on mainstream hardware entails simplifications of the modelled phenomena and the use of standard engineering methods to create a modular and parsimonious architecture. These design properties are worthwhile modelling goals in themselves that do not necessarily need to correspond to features of the modelled system.

Explication of shortcuts In addition to tractability concerns, modelling activities may introduce further simplifications. One of our aims is the clear delineation and characterisation of any such shortcuts deemed necessary. Two prominent examples unavoidable in current designs of broad virtual agents regard sensing and acting, and common-sense reasoning. Subsequent modelling efforts may refine the model by selectively reducing the amount of simplifications.

Sociality Emotional phenomena combine aspects internal to the organism, such as the synchronisation of subsystems, with external aspects of social behaviour, including dispositions and roles [19]. As another consideration explicitly included from the start, the social aspect of emotion has no direct impact on our choice of building blocks, but it motivates starting points for models of specific emotional phenomena to be refined incrementally. Disgust was chosen as an example, as the notion encompasses both, an emotion with comparatively straightforward elicitors—core disgust—as well as a distinctly social phenomenon in the form of socio-moral disgust [24].

A further possible aim for designing a model of emotion could be correspondence with current knowledge about brain anatomy [9]. We currently exclude such considerations, to constrain the scope of our effort.

3 Building blocks for artificial emotion

We use concurrent processes directly to model the activities within an agent, thereby avoiding the use of parameterised states to model effects that arise immediately from interactions of processes over time. The resource bounds of the modelled agent are represented explicitly by distinct resources that need to be acquired explicitly by processes for use.

3.1 Processes

A process models one concurrent strand of activity in the agent[2]. It can be active, i.e. allocated a "processing time" resource, or dormant. A change to the dormant state is triggered by waiting: for a specific resource; for communication from another process; or for the notification of a change in an observed process. A process can request control of resources. A process can start or stop another process, and transfer its processing time and other resources to it. Similarly, a (meta-level) process can act as a scheduler for other processes. Processes can actively observe and inspect the status of other processes, their communication patterns, their resource use, or they may request to be notified of such changes.

Building on these capabilities of processes, we can model what Frijda [8] calls competences: a behaviour system that includes sensitivities for triggering activation, and criteria for well-functioning used in system monitoring. Such competences in turn form the basis for on-line appraisal processes and major concerns of an agent.

3.2 Resources

A resource is an abstraction for the limited control an agent has over the part of the world that constitutes it. Processing time is an abstract resource that limits the number and the speed of concurrently running processes. In the context of a simulation on a serial computer, this translates to how frequently and then for how long a process is allowed to run. Communication channels are a specific form of resource that allow direct communication between processes. Further, communication can be used as a means for synchronisation to model interdependencies between processes. Scherer assumes that parallel appraisal processes usually complete in a specific sequence because of such interdependencies [25].

Resources at the boundary to the agent's environment group sensors and actuators, reflecting the fact that the agent is always interacting with the environment rather than receiving or sending [3]. These are subject to influences from both, the environment and the agent. Internal resources and processes are only indirectly affected by the environment through communication links (we thus exclude scenarios involving drug use and brain surgery, while conceptually internal effects of e.g. hormones may be modelled as processes). They can be shielded explicitly, i.e. decoupled, from the environment to form emulators [14] or prediction machines [18].

3.3 Configurations

Figure 1 shows a notation for processes, resources, and their interactions. Given a system configuration of dormant and active concurrent processes, a first issue regards the starting configuration. This question is obviously important for

[2] We use the computer science term 'processes' rather than 'threads', as usually threads indicate strands of control that share global data, while processes communicate by message passing only.

designing and running an artificial system. Translated to the context of adult humans, the question is equivalent to obtaining a snapshot of a mind at a specific moment. A starting point for our incremental modelling approach is to assume that there is at least one active process per resource on the boundary to the environment, that tries to identify changes (i.e., sensors are active by default). There also is one process for each sensitivity of the major concerns [8] of the agent, which in turn creates specific monitoring processes that operationalise the motivation to act on opportunities and threats.

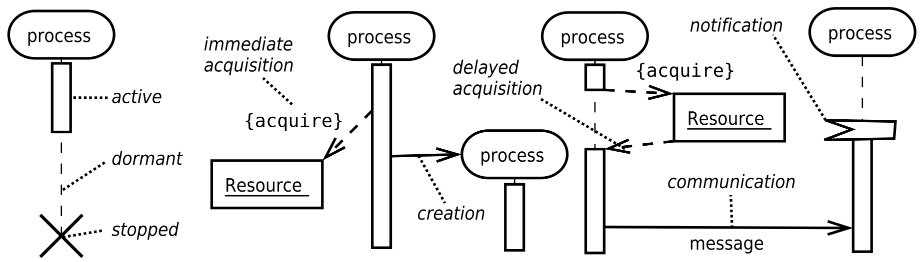

Fig. 1. Notation for some possible interactions of processes and resources, adapted from UML (time flows downwards, comments are indicated with dotted lines).

Based on these building blocks, the following architectural questions need to be answered for any specific scenario:

- What (types of) processes and resources are there, and how many instances of the different types exist? (e.g. regulation, monitors, schedulers)
- What processes run periodically and most frequently? Which processes compete on which resources? Which processes monitor what of other processes?

The current implementation uses cooperative microthreading, with complete control over scheduling and significantly less overhead than operating system threads or processes; the set of resources is static over the lifetime of an agent. The next section presents a first iteration for a specific scenario.

4 A disgusting example

As mentioned earlier, disgust was chosen as a first testing ground for the proposed modelling approach because this emotion word subsumes response dispositions aimed at protecting the body (core-disgust, [15]), and social and personal values (socio-moral disgust, [28]). Disgust is assumed to have evolved from a distaste response, but the current form of human disgust is largely social. It seems to require inculturation since it is not present in infants, and is a rather common topic of adolescent humour [24]. According to Frijda [7], the expression of disgust reduces sensory contact with distasteful substances in the mouth and tends toward expelling those substances (p.11). The associated action tendency is labelled “Rejecting (closing)”, with the function of protection and the end state “Removal of object” (p.88). The appraisal pattern predicted by Scherer [25] involves low levels of familiarity, predictability, and need relevance; very low intrinsic pleasantness; medium urgency; and a very high outcome probability.

The actual example described below is a blend of core-disgust and the use of a disgust expression for social signalling. The short episode describes the interaction between two simulated agents and a single object in the environment: a mother, a child, and a pile of dog poop made of chocolate.

4.1 The disgust episode

We will describe a possible set of processes active in the mother during the following short scene:

> The child notices the dog poop and moves towards it. The mother notices that the child moves, that there is dog poop, and that the child is moving towards it. Finally, the mother moves towards the child to grab it and strongly expresses disgust even though in the meantime she has noticed the true nature of the “dog poop”.

Figure 2 is a sequence diagram of the interactions between processes inside the “mother-agent” during this short episode[3].

1) Initially, there are several processes active in the mother-agent. One process, look-after-child, is responsible for satisfying the mother’s concern for the well-being of the child. This process is active periodically to look for matches with its sensitivities, as are other concern-relevant processes: protect-child, teach-child, and a regulation process regulate-conflicts.
2) The process look-after-child acquires the resource Eyes, actively looks for the child, and detects that the child is moving[4], a novel and unexpected event. It spawns a process to interpret that movement.
3) Interpret-move uses the resource Eyes to find a target object in the direction of movement. It spawns a process to identify the object and another one to predict what the child will be doing.
4) As soon as identify-object has a first identification (*dog poop*) it starts an evaluation process. Similarly, the prediction process, after using a Child Predictor resource and the current result of the identify-object process, spawns a process to evaluate the predicted action.
5) The evaluation of the *dog poop* appraises it as unfamiliar and intrinsically unpleasant. The resulting relational action tendency (not shown in the

[3] The example is constructed to illustrate the potential of modelling with concurrent processes. It is not directly based on examples from the psychological literature.

[4] Another possibility would be that some other process that uses the Eyes detects the movement. Look-after-child is then notified because it was monitoring any changes involving the “child object”.

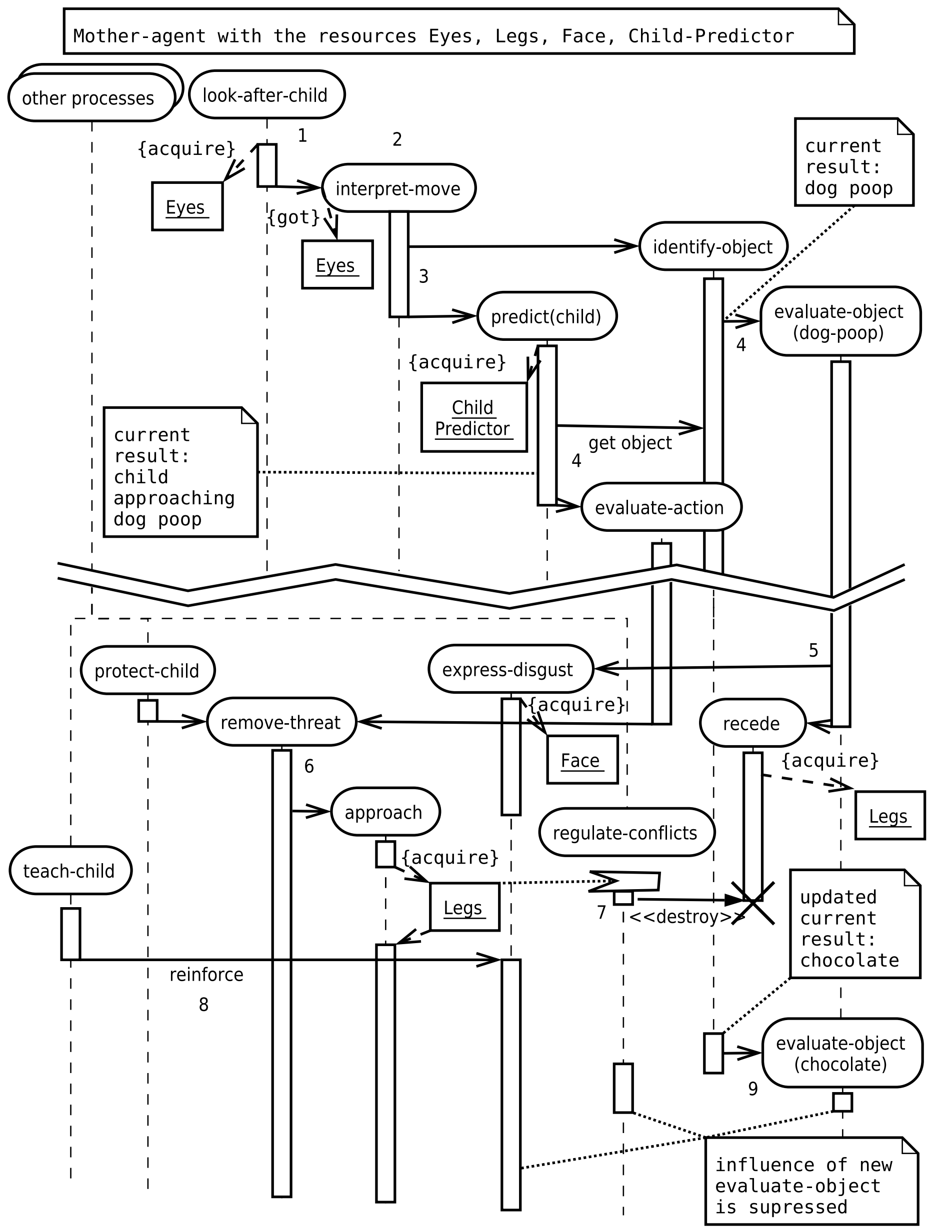

Fig. 2. Processes in the mother-agent during the disgust episode. See Fig.1 for the notation used. Action tendencies not shown due to lack of space, see main text.

diagram due to lack of space) triggers the process for expressing disgust and receding from the object as coping action. Each of these processes starts by acquiring the relevant resources, Face and Legs.

6) The evaluation of the predicted action (the child taking the *dog poop*) has identified a threat: possible harm for the child. The process protect-child, because of its sensitivity for threat constellations, reacts by creating a new process to remove the threat which, in turn, instantiates a process for approaching the child (again part of an action readiness).
7) The approach process tries to acquire the Legs but fails, because the recede process controls this resource. The process regulate-conflicts is notified by the action monitoring provisions of approach and arbitrates by ending the process recede.
8) Concurrently, the process teach-child detects that the processes remove-threat and express-disgust are related via the object involved. It reinforces the process for expressing disgust.
9) Finally, the object identification process finds new evidence (the *dog poop* is actually made of *chocolate*) and restarts the evaluation process. Consequences this might normally have (overt signs of alleviation and humour, related internal process reconfiguration) are suppressed by regulation as incompatible with the ongoing, reinforced, expression of disgust.

4.2 Shortcuts

Several shortcuts have been taken in this process-based description of a disgust episode. Most notably, the intricacies of sensing and acting in the environment have been simplified to a process that employs a resource. Predicting actions of others and forming expectations by internal simulation has also been abstracted into a ready-made resource. Further, any knowledge required and used by the processes is not accounted for in the model. As an example, the identification of objects has to access some body of prior knowledge. This might be modelled as exclusive and specific to this type of process or as a shared (set of) resource(s). The same holds for the detection of the relation between threat, disgust, and *dog poop* based on the examination of (relations between) active processes. We expect that during the evolution of our framework and building of simulations of increasing detail shared knowledge will be introduced as resources.

5 Related work

The APOC framework [27] is intended to provide a universal formalism for (primarily robotic) agent architectures, based on building blocks called components that are connected by four different types of communication links. A component consists of an update function that updates the internal state and continuously produces output (in discrete steps) based on previous state and inputs. Further, a component can control an external process, thereby encapsulating an asynchronous physical or computational activity. The premises of APOC are similar to those of our proposal, but the framework differs not only in the intended application area—robotics versus virtual environments—but also in conceptual focus. While our proposal focuses on the dynamic run-time properties of the simulated system, APOC is geared towards modelling data flow and, although dynamically self-modifying architectures are possible, APOC's formalism specifies a relatively static architectural layout for instantiated architectures.

In [30], Sloman argues again that what is generally called emotion needs to be defined more rigorously in terms of architectural components. Sloman's H-CogAff architecture was used to propose three different classes of emotion, based on the architectural layout of many concurrently active tasks and interactions between them. Our approach is similar in spirit, but complementary. By incrementally modelling specific emotional phenomena, building on psychological theories and their implied dynamic run-time requirements, we aim to inform the architectural requirements for human-level competencies. Another high-level architectural account of the human mind very similar to H-CogAff has been proposed by Minsky [18]. The basic notion of Minsky's work is that the mind consists of many resources ("agents" in earlier publications) that can be activated or suppressed. The distinctive feature of the human mind is its "resourcefulness", i.e. the ability to selectively activate and suppress sets of resources suitable for a situation while dynamically switching between them and recognising opportunities and needs for switching (even during the same situation). EM-ONE [29] is an implementation by Push Singh based on Minsky's theory that focuses on common-sense thinking in a physical scenario with two agents. The present proposal rather tries to model emotional phenomena while clearly delineating that certain capabilities, such as common-sense thinking, have to be simplified.

EMA [12] is a computational model of appraisal that implements checks posited by appraisal theories based on a symbolic representation of the agent's interpretation of its relationship to the environment. In [17], the authors apply EMA to a relatively fast-paced emotional episode (captured on video) to model the dynamics of the situation. They argue that each appraisal check is always a fast and parallel process, while other cognitive and perceptual processes alter the central subjective interpretation at different speeds. Our approach aims to avoid fixed appraisal processes, but rather models appraisals and related processes as ongoing activities that can start and be refined before, while, and after symbolic representations are formed or altered (possibly by other appraisal processes).

6 Conclusion and future work

We have presented an incremental approach to modelling emotional episodes based on concurrent processes. The concept of a resource is used to explicitly model boundedness. These building blocks are motivated by the needs of modelling a physical system, by the characterisation of emotion by psychological theories, and by practical implementation concerns. A major goal of the work is to make explicit shortcuts necessary to arrive at an executable model of emotion in an interesting virtual scenario. Implementation efforts are currently underway based on a game-like scenario allowing for human interaction with a virtual environment inhabited by agents based on our affective architecture building on earlier work [21,22]. Therein, possibilities to operationalise the theoretical concept of relational action tendencies will be identified and evaluated. Future work includes the incremental addition of models suitable for further emotional episodes, building architectural abstractions as the need arises. To verify consistency of the models, they will be integrated in the same game-like scenario. Further work will investigate modelling of effects in social interactions as process and resource dependencies across agents.

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