Development of Robot-enhanced Therapy for Children with Autism Spectrum Disorders

# Project No. 611391

# DREAM
# Development of Robot-enhanced Therapy for Children with Autism Spectrum Disorders

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# D6.1 Reactive Subsystem

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Organisation name of lead contractor for this deliverable: **Plymouth University**

Responsible Person: **Tony Belpaeme** Revision: **1.4**

| Project co-funded by the European Commission within the Seventh Framework Programme | | |
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| Dissemination Level | | |
| PU | Public | PU |
| PP | Restricted to other programme participants (including the Commission Service) | |
| RE | Restricted to a group specified by the consortium (including the Commission Service) | |
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# Contents

# Executive Summary

Deliverable D6.1 defines the specification, design and implementation of the Reactive subsystem within the cognitive architecture in Work Package 6.

Specifically, this report presents the outcome of task T6.1 over the first 18 months of the DREAM project. During this first year the Cognitive Controller (WP6) has been designed, with subsequent refinement. This update to the Cognitive Controller details the context in which the Reactive Subsystem operates, and therefore is described here. Motivations and technical details of the Reactive Subsystem itself are primarily contained within the annex to this report.

## Principal Contributors

The main authors of this deliverable are as follows (in alphabetical order).

Paul Baxter, Plymouth University
Tony Belpaeme, Plymouth University
Hoang-Long Cao, Vrije Universiteit Brussel
Albert de Beir, Vrije Universiteit Brussel
Pablo Gómez, Vrije Universiteit Brussel
Emmanuel Senft, Plymouth University
Greet Van de Perre, Vrije Universiteit Brussel
Bram Vanderborght, Vrije Universiteit Brussel

## Revision History

Version 1.0 (P.B. 19-08-2015)
First draft of deliverable structure.

Version 1.1 (P.B. 27-08-2015)
Outline of contents of deliverable.

Version 1.2 (P.B. 09-09-2015)
Addition of further detail on the updated cognitive control architecture, and update of the introduction.

Version 1.3 (P.G. 14-09-2015)
Update of the technical annex to the deliverable.

Version 1.4 (P.B. 30-09-2015)
Final updates and corrections.

# 1 Outline of this deliverable

## 1.1 Description of Task 6.1

[*From the DREAM Description of Work*]: The reactive subsystem is constituted of the lowest-level processes. In natural systems, these processes are genetically determined and not typically sensitive to learning. State information, coming from the sensory inputs, is immediately acted upon with appropriate motor outputs. The reactive subsystem, while absent in many robot systems, is essential in social robots. It creates the illusion of the robot being alive, and acts as a catalyst for acceptance and bonding between the young user and the robot. The reactive subsystems takes care of small motions, appropriate eye blinking and gazing behaviour, balancing, whole body motion during gesturing and head motion, recovering from falls, and appropriately reacting to affective displays by young users. The amplitude and timing of these responses are important, and all efforts will be made to consult the literature or design pilot experiments to inform the design of reactive behaviours. The behaviours will be configurable by the therapist as it might not be desirable for some children to have the robot display a full gamut of reactive responses (for example, a negative reaction when being pushed).

## 1.2 Description of D6.1

The purpose of this deliverable is to report the progress of development of the reactive subsystem. It defines the specification, design and implementation of this component within the cognitive controller architecture as defined in Work Package 6 (see previous section).

# 2 Update of the Cognitive Control System Architecture

This is an update on the Cognitive Control component as described in D6.3.1 and D6.4.1, following further developments in the Reactive Subsystem, the Deliberative Subsystem, and integration of robot actuation in the DREAM integration framework with the Sandtray device (as used in the turn-taking intervention; see D6.3.1). The purpose of including this update in this deliverable is that it provides the context in which the Reactive subsystem operates, outlining the interactions with the other subsytems of the DREAM architecture Cognitive Controller component.

There are a number of features resultant from this that should be noted. Firstly, the role that the reactive subsystem plays in generating the executed robot behaviour depends on a number of factors: the processing within the deliberative subsystem, and the oversight of the therapist (through the self-monitoring subsystem as interacted with through the system GUI). This means that, as with other layered control architectures (e.g. subsumption, etc), the reactive subsystem contributes to, rather than completely specifies, the overall robot behaviour. Secondly, the reactive subsystem has 'independent' access to sensory data from the WP4 systems (in the sense that this access does not depend on the other cognitive control subsystems), as well as to the robot sensors if they are available. This facilitates asynchronous operation of the component, and thus also its contribution to behaviour.

A number of refinements have been made to the existing schema. Firstly, while always part of the design specification, we now acknowledge in the cognitive controller architecture the explicit control that the supervising therapist can exert over the behaviour of the robot (effectively a limited 'remote control' functionality). This naturally has a number of operational consequences for other subsystems of the cognitive controller, which will be handled through the oversight of the Self-Monitoring subsystem (to prevent conflicting commands for example). Secondly, greater acknowledgement of the role of the Actuation and Expression subsystem in the generation of morphology-appropriate motor

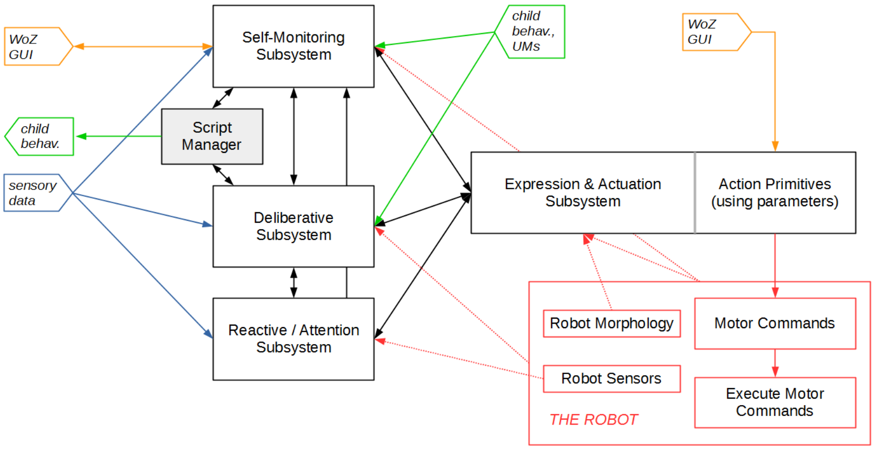


Figure 1: Updated description of the cognitive controller subsystems and their relationships. The script manager is separate from, but tightly interacts with, the deliberative subsystem to enable the robot control system to generate appropriate social/interaction behaviour even in the absence of an explicit interaction script. The Expression and Actuation subsystem is closely related to the action primitives in terms of generating the appropriate motor commands depending on robot morphology. The Reactive subsystem has access to the full range of sensory data available, but is constrained in operation by the deliberative and self-monitoring subsystems. The GUI input directly to the action primitives fulfils the interfaces defined within deliverable D3.1 to facilitate direct remote control: this will be possible, but it is anticipated that the main means of influence from the therapist will be at a higher level of abstraction. Finally, the robot sensors are considered part of WP6 (rather than the interpreted sensory data emanating from WP4) since they are completely specified by the specific robot itself rather than the intervention table, and may even be absent: it is envisaged that only coarse processing will be applied to this additional data, where available, to facilitate the operation of the Reactive / Attention subsystems. UMs: User Models.

commands is made. The close relationship with the action primitives (as defined in D1.2 and D3.1) is thus emphasised, with the resulting consequences on subsystem interactions. Finally, an explicit role for the sensors of the robot is included, specifically for informing the behaviour reactive and attention subsystem. In DREAM, the primary source of sensory data for action selection etc is from the sensory setup on the intervention table, i.e. not robot-based sensors. However, where sensors are available (some platforms, such as Nao, has a range of sensory competencies, whereas others may have none), then these can be used, with this envisaged to be restricted to informing the operation of the reactive/Attention Subsystem. It should be noted though that this is not a requirement for the operation of any of the cognitive controller subsystems given that different platforms may vary substantially in the level of sensory data that can be provided (and thus why this data is not relied upon for sensory interpretation or child behaviour analysis).

# 3 The Reactive Subsystem

The background and technical details of the reactive subsystem may be found in the annex to this deliverable.

# 4 Integration with the Attention subsystem

As described in the first preliminary deliverables (D6.3.1 and D6.4.1), the intention is to at least partially integrate the functionality of the Reactive subsystem and the Attention subsystem, due to overlaps in both the sensory and effector requirements for the two sub-systems, despite the variation in desired functionality and theoretical basis. In terms of reporting, details of the Attention subsystem will appear in deliverable D6.2.

# 5 Annexes

## 5.1 Esteban, P.G. et al. (2015), Technical Report: Reactive subsystem

**Abstract -** The purpose of this technical report is to summarize the motivations and constraints underlying the Reactive subsystem, and to outline an organisation of it. This is a proposal only; this document is intended to be a working one, to be updated as required during development. This version of the report is based primarily on the discussions that took place in Brussels (23/01/15).

**Relation to WP** This work outlines the technical implementation of the reactive sub-system, and the background thereof. This is relevant to T6.1.

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# Project No. 611391

# DREAM
# Development of Robot-enhanced Therapy for Children with Autism Spectrum Disorders

# TECHNICAL REPORT
# Reactive subsystem

Date: **17/08/2015**


Technical report lead partner: **Vrije Universiteit Brussel**

Primary Author: **P. Gómez Esteban**


Revision: **1.3**


| Project co-funded by the European Commission within the Seventh Framework Programme | | |
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| **PP** | Restricted to other programme participants (including the Commission Service) | **PP** |
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# Contents

## Summary

The purpose of this technical report is to summarize the motivations and constraints underlying the Reactive subsystem, and to outline an organisation of it. This is a proposal only; this document is intended to be a working one, to be updated as required during development. This version of the report is based primarily on the discussions that took place in Brussels (23/01/15).

## Principal Contributors

The main authors of this document are as follows (in alphabetical order).

Paul Baxter, Plymouth University
Tony Belpaeme, Plymouth University
Hoang-Long Cao, VUB
Cristina Costescu, UBB
Albert De Beir, VUB
Pablo Gomez, VUB
Emmanuel Senft, Plymouth University
Greet Van de Perre, VUB
Bram Vanderborght, VUB

## Revision History

Version 1.0 (P.G. 11-05-2015)
Initial outline of ideas for the DREAM reactive subsystem.

Version 1.1 (P.G. 28-05-2015)
Some modifications made after a discussion.

Version 1.2 (P.G. 11-06-2015)
Included feedback from UBB

Version 1.3 (P.G. 17-08-2015)
Final notes about the implementation process.

# 1 Overall Organisation

A general high level description of the Reactive subsystem is shown in figure 1. This describes how, given the sensory information and the inputs from the Deliberative subsystem, the robot reacts to the current situation. Note that both Reactive and Attention subsystems are combined into a single component. Both systems require access to features of the environment and interacting person(s) to respond appropriately (e.g. looking at a face or diverting attention to a loud noise somewhere in the environment). Managing this in a single component therefore seems a sensible choice so that functionality is not replicated. Within this document only the Reactive subsystem is described. Deliverable D6.2 regarding the Attention subsystem is due to month 24.

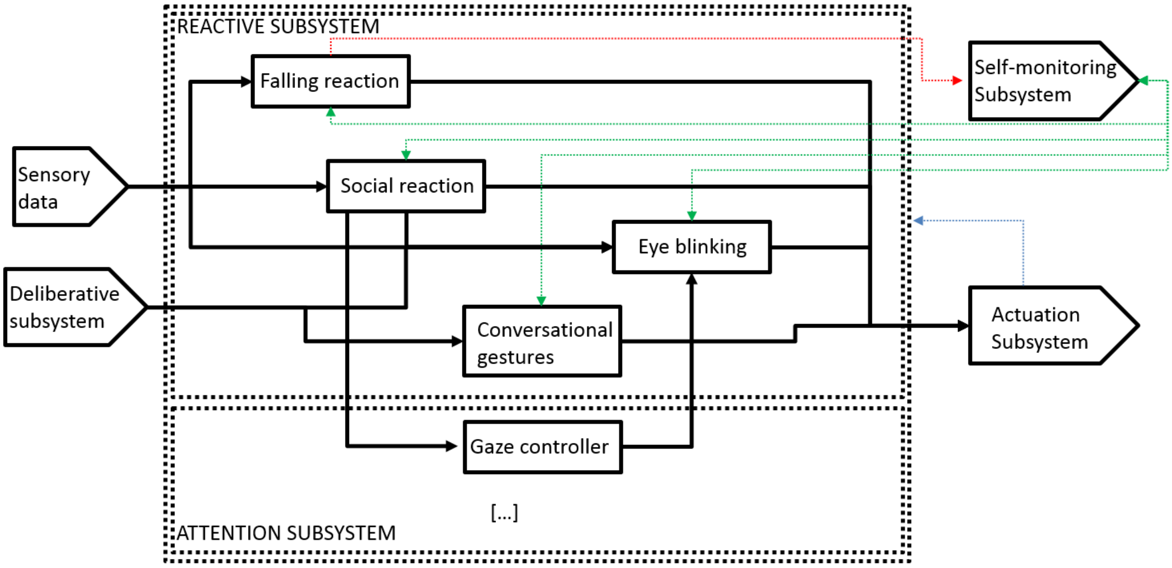


Figure 1: High level description of the Reactive subsystem. It is composed of several modules which combined they will give the impression of the robot being alive.

The Reactive subsystem is composed of a number of modules:

- Falling Reaction module: which takes care of the balance of the robot and in case of a fall, it triggers a damage avoidance posture and a restoring intervention behavior.
- Social Reaction module: its purpose is to appropriately react to social displays of the children and to provide micromotions that will give the impression of the robot being alive.
- Eye Blinking module: it provides a variable blinking rate that complements other gestures and behaviors.
- Conversational gestures module: it will complement the speech acts with body gestures and lip synchronization.

Being this the first component to be developed, a simplified but functional simulator of those components that interact with it have been developed. For instance, the facial expression of the robot from the Deliberative subsystem, or a change on the gaze coming from the Attention subsystem, see Section 6 of this Technical Report for further details.

## 2 Falling Reaction

Within social interaction with children it may happen that the robot lose its balance and has to recover it or even it may fall down. These robotic platforms are expensive so that in case they fall, minimizing the hardware damage would be a priority. As seen in Deliverable 1.1, the robot will be seated so a fall is lowly probably to occur. Nevertheless, this module needs to be implemented to face such hypothetical situations.

As it may be seen in figure 2, the Falling Reaction module will be periodically checking the balance of the robot using the sensory information available. Changes in the balance may end up in a fall. In such case, a signal (red arrow in figure 1) will be sent to the Self-Monitoring subsystem to interrupt any other running behavior, and a damage avoidance behavior that fits the situation will be triggered, see [1] for a case of minimizing damage to a humanoid robot, and [2] for a case of a NAO robot that modifies its falling trajectory to avoid causing injuries in people in front of it. These behaviors might be highly dependent on the morphology of the robot. Reducing the stiffness of the joints will avoid any mechanical problem independently of its morphology. Since the robot will be placed on a table and in case it falls it will be on the floor from certain height, there is no actual need to implement getting up behaviors. However, as the Nao robot includes such behaviors they will be taken into account. Additionally, the robot should include some speech acts to reduce the impact of such dramatic situation for the kid as saying that it has been a little bit clumsy or that it is tired today.

Finally, back at its feet, the robot may apologize in order to engage the child back to the intervention or call the re-engagement module in the Deliberative subsystem and it will send a signal to the Self-Monitoring subsystem to restore the system functionality.

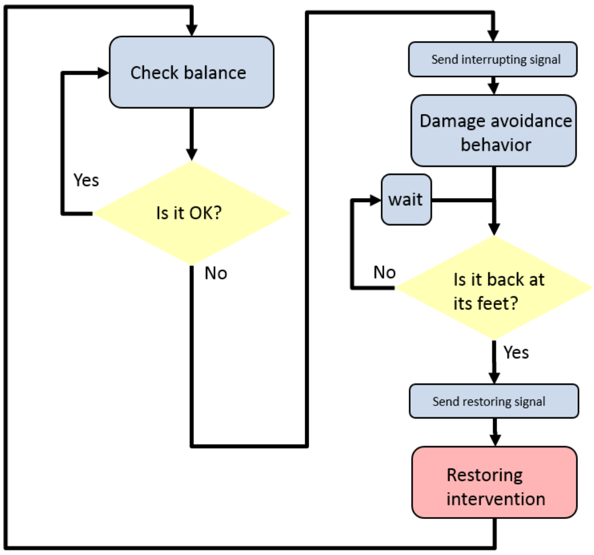


Figure 2: The module is periodically checking the balance of the robot. In case of a fall, a signal will be sent to interrupt any other running behavior, and a damage avoidance behavior will be triggered. Finally, back at its feet, the module will send a signal to restore the intervention.

The functionality of this module can be switched on and off by the therapist when needed through the Self-Monitoring subsystem, see green arrow in figure 1 which sends and receives commands from the Self-Monitoring subsystem.

Summarizing what this module does: it receives as input the sensory data and produce as outputs

- signal to interrupt and restore main functionality (to the Self-Monitoring subsystem),
- damage avoidance behavior (to the Actuation subsystem),
- restoring intervention behavior (to the Actuation subsystem).

# 3 Social Reaction

In social situations multiple verbal and non-verbal interactive encounters may occur. The child may behave friendly with the robot affectively touching it or may feel unfavorable to it and eventually hit it. These situations may be very conflicting as a special care must be paid with the potential audience of this subsystem. If it would be the case of a regular social robot, for such both situations the robot may appropriately react, but under these circumstances, the reaction will be simplified to facial expressions and speech acts, always under the supervision of the therapist. Moreover, in order to reach an effective social interaction, emulating certain degree of empathy towards the social partner plays a key role in patient-centered therapy [3], i.e. if the child is expressing an emotion, the robot should be aware of that and react accordingly expressing a compatible emotion. In those cases in which there is no social interaction, this module will randomize among a set of micromotions to recreate a life-like behavior such as a breathing motion or gaze-shifts. The purpose of this module is to provide the appropriate social behavior in order to give the impression of the robot being socially alive.

This module receives as input the sensory information where it is specified the child's social and affective state i.e. whether she/he is expressing an emotion or is performing a physical behavior (such as touching the robot unexpectedly), see figure 1. For each of these behaviors there should be a set of facial expressions and speech acts available to choose among them. Ideally it should randomize among them in order to look less predictable. Such reactive facial expressions and speech acts should be defined by the therapists and will be stored in the library of the Actuation subsystem.

The functionalities of this module can be switched on and off by the therapist when needed through the Self-Monitoring subsystem, see green arrow in figure 1 which sends and receives commands from the Self-Monitoring subsystem.

Summarizing what this module does: it receives as input the sensory data and produce as outputs

- signal sending information (to the Self-Monitoring subsystem),
- micromotions (to the Actuation subsystem),
- affective sequence of motions (to the Actuation subsystem),
- the output behavior which will be interpreted by the Eye Blinking module to choose the corresponding eye blinking behavior (to the Eye Blinking module).

# 4 Conversational gestures

Despite not being specified in the DoW, exhibiting co-verbal gestures would make the robot appear more expressive and intelligible which will help to build social rapport with their users [4]. As it was not a requirement for DREAM its development has been delayed in favor of other modules.

Co-verbal gestures are defined as the spontaneous gestures that accompany human speech, and have been shown to be an integral part of human-human interactive communications [5] [6]. According to [7], it has been demonstrated in anthropological studies that co-verbal gestures have a number of positive effects on listener behaviour [6] [8] [9].

For the purposes of DREAM project we don't aim at building a highly sophisticated conversational agent as [4] or [10] but to complement the speech with neutral conversational gestures, that the robot can randomly perform while speaking, and lip synchronization to make the interaction more natural.

It's needless to say that other systems will provide a better impression of the robot being a conversational agent, but our goal is to use these gestures as a complement not as the robot's main functionality.

For our purposes we need to include a set of conversational gestures into the library of behaviors of the Actuation subsystem and define a set of rules to trigger them.

Lip synchronization in robotics looks for matching lip movements with the audio generated by the robot. The use of different lip synchronization algorithms not only are limited to use in robotics, but also to the lip animation in virtual models used in HRI systems with computers. Several works use synchronization algorithms based directly on the use of audio phonemes to determine the levels of mouth aperture [11] [12]. These approaches require additional information such as dictionaries of phonemes.

For the purpose of DREAM, we don't need a highly sophisticated lip synchronization mechanism but something efficient that improves the acceptability of the robot during the social interaction. For such reason we will either implement a basic method like [11] or use a commercial software to implement this functionality, depending on the requirements of the system.

This module receives as input the speech act or text-to-speech output file from the deliberative subsystem, see figure 1.

The functionality of this module can be switched on and off by the therapist when needed through the Self-Monitoring subsystem, see green arrow in figure 1 which sends and receives commands from the Self-Monitoring subsystem.

Summarizing what this module does: it receives as input the speech data or text-to-speech output file from the Deliberative subsystem and produce as outputs

- signal sending information (to the Self-Monitoring subsystem),
- conversational gestures (to the Actuation subsystem),
- sequence of lip motions (to the Actuation subsystem).

# 5 Eye Blinking

The acceptability of the robot can be further increased if the robot mimics the human blinking behavior. Simulating blinking behavior requires a human-level blinking model that should be derived from real data of human.

Several works have been done concerning the dependencies of human eye blinking behavior on different physiological and psychological factors. Ford et al. [13] proposed the "blink model" for HRI, which integrates blinking as a function of communicative behaviors. Doughty [14] described in his work three distinct blinking patterns during reading, during conversation and while idly looking at nothing specific. Lee et al. [15] proposed a model of animated eye gaze that integrates blinking as depending on eye movements constituting gaze direction.

Given the amount of studies made to model human blinking behavior we don't need to do our own but to use that one that best fits our requirements. Within the context in which DREAM will be applied, we need to recreate a blinking behavior mainly focused on the communicative behaviors and gaze shifts. For such reason, we consider that Ford et al.'s model covers these needs and provide accurate data to implement their model.

Ford et al. defines a model which considers multiple communicative facial behaviors and includes an individual blinking model for each of them, see figure 3. For each identified communicative behavior there is a probability to blink, a determined length, and so on. Moreover there is a passive behavior which simulates a physiological blink mechanism (for cleaning or humidifying the eye) that can be activated when no other blinking behavior has been triggered. To perform the blinking motion there is a blink morphology model which defines, based on statistics, if the blink is simple or multiple, full or half, its duration, etc. see figure 4.

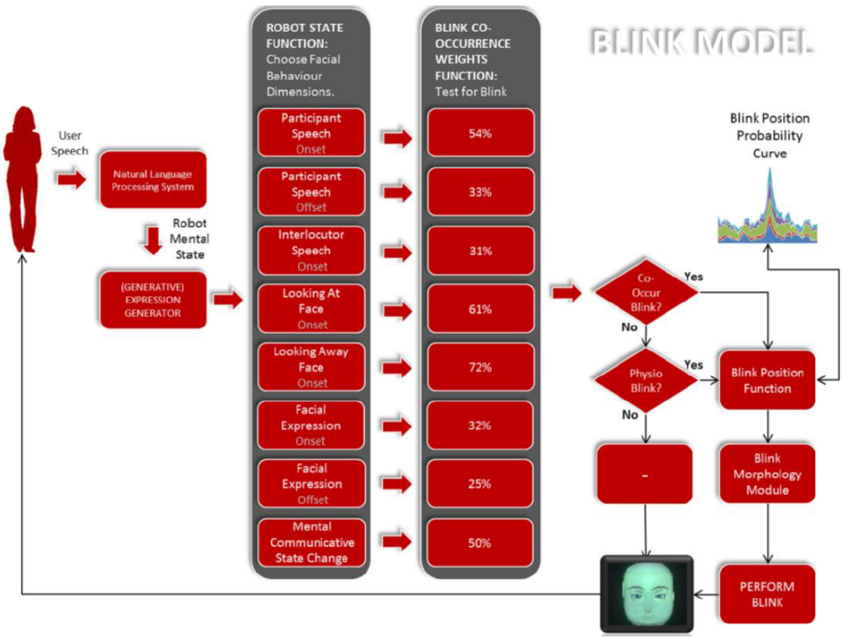


Figure 3: Ford. et al blinking behavior model [13].

The functionality of this module can be switched on and off by the therapist when needed through the Self-Monitoring subsystem, see green arrow in figure 1 which sends and receives commands from the Self-Monitoring subsystem.

Summarizing what this module does: it receives as inputs

- the social reaction (from Social Reaction module),
- a flag when a speech act is started (from the Deliberative subsystem),
- sensory data to know when someone talked,
- affective state (from Deliberative subsystem),
- gaze-shifts (from Attention subsystem).

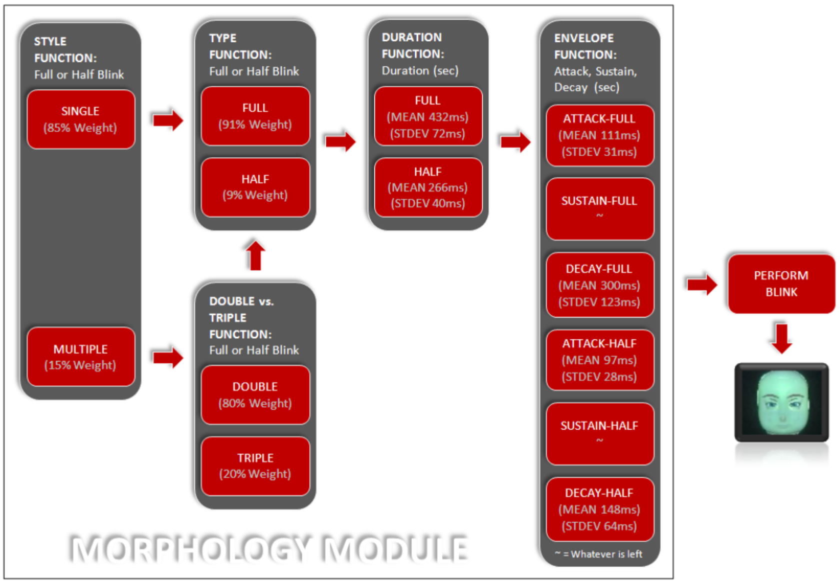


Figure 4: Ford. et al blinking morphology model [13].

And produce as outputs:

- signal sending information (to the Self-Monitoring subsystem),
- the blinking motion (to the Actuation subsystem).

# 6 Implementation

As mentioned in Section 1 this is the first component to be developed within the cognitive controller of DREAM. For such reason the components that interact with this one have been developed as basic simulators that provide the expected output. For some of them, such expected output was provided through a GUI, see figure 5. That is the case of the Deliberative subsystem (facial expression) and the Attention subsystem (shift of gaze).

Such GUI has been used to simulate the sensory information of the robot as a first step in the implementation of this system. It should be replace by a sensory information simulator of an specific robot, i.e. Nao robot. But for the purpose of validating the Reactive subsystem the GUI is an equally good option.

On the other hand, this system uses actual actuators to show its outputs. This implementation has been done in a Nao Robot using different layers of Yarp, see [16], keeping its platform-independent flavor.

It also includes an Actuation subsystem simulator which receives the outputs of the Reactive subsystem and provides the corresponding action primitives.

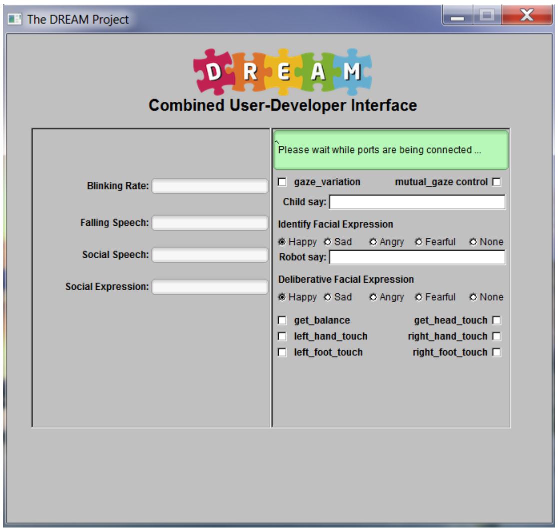


Figure 5: Graphical User Interface of the Reactive subsystem.

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