Dream-like simulation abilities for automated cars

DREAMS4CARS

Grant Agreement No. 731593

Deliverable:	D3.1. – Simulation system (release 1)
Dissemination level:	CO – Confidential
Delivery date:	27/June/2018
Status:	Final

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731593

Deliverable Title	Simulation system (release 1)		
WP number and title	WP3 Dream-like states		
Lead Editor	Mauro Da Lio, UNITN		
Contributors	Mauro Da Lio, Riccardo Donà, Alice Plebe, Francesco Biral, Gastone Pietro Rosati Papini, UNITN		
	Sebastian James, Alex Blenkinsop, Sean Anderson, USFD		
	Iain Gunn, David Windridge, MU		
	Henrik Svensson, Sara Mahmoud, HIS		
Creation Date	12/April/2018	**Version number**	1.9
Deliverable Due Date	30/June/2018	**Actual Delivery Date**	27/June/2018
Nature of deliverable			
	X	DEM – Demonstrator (software prototype with report)	
Dissemination Level/ Audience			
	X	CO - Confidential, restricted under conditions set out in MGA	

Version	Date	Modified by	Comments
0.1	14/April/2018	Mauro Da Lio	Initial draft (document structure and contributions to section 1 and 5.1).
0.2	11/May/2018	Mauro Da Lio	Contribution to sections 2 and 3.
0.3	17/May/2018	Mauro Da Lio	Contribution to section 4.
0.4	22/May/2018	Sebastian James	Contribution to section 6.2.
0.5	28/May/2018	Mauro Da Lio	Contribution to section 6.1.
0.6	30/May/2018	Riccardo Donà	Contribution to sections 3.4, 4.5, 4.6.
0.7	01/June/2018	Mauro Da Lio	Review and further integration.
0.8	09/June/2018	Mauro Da Lio	Fixed formatting issues followed from contributions of other authors.
0.9	12/June/2018	Mauro Da Lio	Contribution to section 6.3.
1.0	14/June/2018	Sean Anderson	Figures added to section 6.2.

1.1	14/June/2018	Henrik Svensson	Contribution to sections 1.1, 1.1.1, and sections 4.1-4.4 and 4.7 Minor adjustments of other sections.
1.2	16/June/2018	Mauro Da Lio	Harmonization of contributions. All sections.
1.3	16/June/2018	Mauro Da Lio	Inclusion of contributions from Alex Blenkinsop and Iain Gunn (section 5.2) with additional text from David Windridge.
1.4	17/June/2018	Mauro Da Lio	Contribution to section 6.4.
1.5	18/June/2018	Alice Plebe	Contribution to section 3.5.
1.6	18/June/2018	Mauro Da Lio	Version for peer review (including Executive Summary).
1.7	25/June/2018	Mauro Da Lio	Version including reviewers' recommendations and edits.
1.8	26/June/2018	Francesco Biral	Contribution to section 6.4.6
1.9	27/June/2018	Mauro Da Lio	Final version including minor edits from Gastone Pietro Rosati Papini (mostly typos).

Executive Summary

Work Package 3 spans from month 12 to month 30. The current deliverable (D3.1) is a checkpoint, at month 18, to verify that efficient methods have been developed for dreaming (to be used in project phase 2, from month 19 to 30).

We think that we have developed a spectrum of methods that cover all aspects of the dreaming mechanism, though not all the methods presented here are equally developed at this stage.

Some approaches have produced results that go beyond the hopes (and even beyond the DoA). These include the episodic simulation machinery of sections 3 and 4 and the embodied simulation mechanisms of section 6.

We have indeed identified and developed two distinct imagery mechanisms.

The first one is referred to as "*episodic simulations*" and is related to cortical-subcortical processes in the brain. We have developed two distinct types of implementations for this mechanism.

- The former (section 3) relies on artificial neural networks that reproduce convergent divergent zones (CDz) posited to form the dorsal stream. We have significantly demonstrated and tested this mechanism in section 3, with reference to imagery of roads and imagery of other road users' behaviours.
- The second mechanism for episodic simulations (section 4) is less tied to biological inspiration but very effective and complementary. It is based on Genetic Algorithm (GA) that swaps and recombines the elements of the scenario and that can be used to set up simulation environments. We have extensively tested this mechanism with one scenario on curvy roads and another inspired by the recent UBER fatality. Furthermore, GA algorithms are potentially effective in directing the dreaming exploration towards those situations that are likely to create useful dreams (but this has not been tested yet): accordingly, the GA machinery acts as a system that is adversarial to the learning agent in a way that, while the agent improves, the dreaming machine creates more challenging situations.
- The two mechanisms here described can act in synergy, where the GA is responsible of creating discrete elements in the scenarios and the CDz model continuous items such as, e.g., other road users.

The second imagery mechanisms that have been developed are the so-called "*embodied simulation mechanisms*" which are related to the cerebellar loop (section 6).

- In sections 6.1 and 6.2 we have shown effective ways to learn *forward models* either based on carefully engineered neural networks that resembles the cerebellar adaptive filters (section 6.1) or based on more traditional control theory and parametric modelling (section 6.2).
- We then show how to derive inverse models in section 6.3 and how to use them for vehicle low-level motor control (which is important for both on the fly adaptation and interoperability).
- Finally, in section 6.4 we present a method for learning (bootstrapping) a hierarchical motor control architecture that steps from forward models to motor primitives to sequences of actions (i.e., a subsumption architecture). This has the potential for discovering and optimizing behaviours made of sequences of actions (further work is required here but a demonstration is already given in section 6.4).

Concerning learning of safe behaviours, section 5 presents an extension to the agent architecture based on the notion of frontal-cortex biasing. Here the basal-ganglia MSPRT loop (action selection mechanism based on Multi-Hypothesis Sequential Probability Ratio Test) is extended with biasing matrices that represent choices corresponding to longer-term intentions.

- The Logical Reasoning Module (LRM) implements the traffic regulations (Highway code) in a subsumptive PA (perception-action) format and is responsible (together with the main dorsal stream) for producing the various potential biases in intention.
- An algorithm implements Reinforcement learning at action-selection level, ideally allowing the agent to learn how to suppress immediately rewarding actions in favour of better longer terms rewards.

These algorithms have been coded, but extensive testing remains to be done.

While the LRM can initiate exploratory learning across the PA hierarchy as a whole (as per the project specification), a potentially limiting issue that we have realized recently concerns the fact that there is currently relatively little scope for explicit learning in the LRM. Another limitation that has emerged is related to practical limitations in the Reinforcement Learning algorithm itself at the action-selection level, where for practical reasons the number of alternatives has to be limited and this limits the learning capacity of the agent with this respect.

On the other hand, these limitations are overcome by the action sequence discovery mechanism described in section 6.4. So, while the LRM is useful to embed traffic rules (that are coded) the bootstrapping machine in section 6.4 allows to discover behaviours that might be useful in emergency situations.

Finally, concerning interactions of the frontal stream with the dreaming mechanisms themselves (section 4), the LRM is also designed to act in a generative manner, hallucinating high-level legal road configurations (and corresponding legal intentions) for the GA dreaming mechanism. Following the specification and development of the GA system, it has been determined that the LRM interface for dreaming will be required to occur at a higher level than that of the run-time system, and thus require a separate interfacing protocol at a higher level of PA subsumption. This part is under development.