Highway simulator: Monitoring update

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Federico Massa, Adriano Fagiolini

Why we needed an update

What we were doing

- We were trying to monitor the behaviour of a vehicle with a discrete states automaton running different controllers.
- The recognition of the discrete state was made via a forward prediction of the vehicle's continuous state, that was compared with the controller model that we supposed to know (first mayor problem)
- The monitoring itself was achieved by evaluating the rules (that we also supposed to know from the constructor, second mayor problem) that determined the transition between discrete states. Uncertain cases were due to the partial vision of the observer with respect to the monitored vehicle's surroundings.

Why we needed an update

What we do now

- We monitor the behaviour of a vehicle based on the abstract features of its movements. This way, we can monitor a vehicle regardless of the dynamic model (it could also be manually-driven)
- Instead of the recognition of the discrete state, we try to recognize the abstract **action** that the vehicle is pursuing.
- The monitoring is now based on the definition of some basic **social rules**, that are defined in an abstract way as the list of conditions that make a certain action forbidden.

To achieve this, we only need:

- The sensor data of all the vehicles visible to the observer (x, y on the highway plane, at least) + some kind of vehicle ID to follow its trajectory.
- A list of possible actions that the monitored vehicle can do.
- The implementation of the social rules that are being monitored.

Configuration

In the configuration file it is possible to choose, for every vehicle in the environment:

- Initial continuous and discrete state;
- Geometrical parameters (Type of vehicle);
- Dynamic model (Physical Layer type);
- Automaton type;
- Sensor errors.

The action recognition and rule monitor systems are very general and should work in any realistic case (if correctly tuned...see later on).

First step: the action recognition

An action is abstractly defined as a vehicle behaviour. Examples of it include

- *left/right lane change*
- *overtake*
- *brake*
- ...

We could also imagine a more sophisticated action recognition system to include nuances of these basic actions, like *slow left lane change* or *abrupt left lane change*.

What the observer need to know:

The observer vehicle should have a list of possible actions that the monitored vehicle can do. The action recognition system is now *independent* from the monitored vehicle's model.

How the action recognition works

In order to recognize an action, the observer needs to:

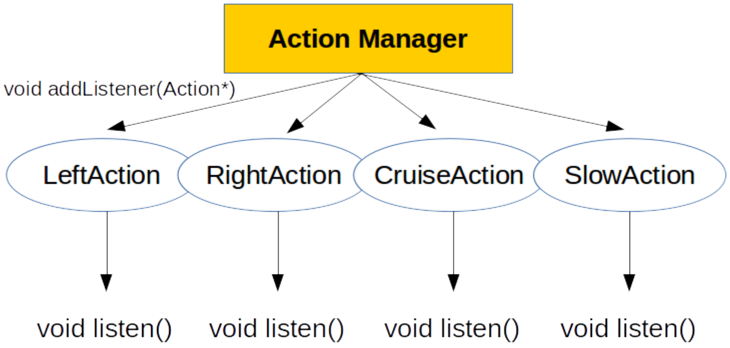
- Identify the monitored vehicle;
- Keep track of the visible vehicles' sensor data for a finite interval of time.

Each action is recognized independently $\rightarrow$ concurrent actions are possible.

An **Action Manager** continuously listens to each action and verifies if the trajectory of the monitored vehicle is compatible with that action. If it is, the action is successfully recognized.

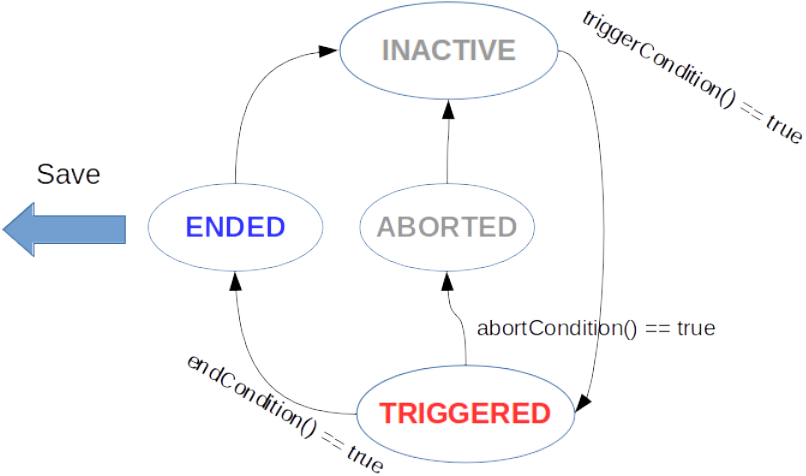
The Action Manager structure

Specific actions (LeftAction, RightAction...) inherit from abstract class Action. The ActionManager initializes several *listeners*, i.e. actions that the system can recognize.



listen() cycle

If an action is registered in the ActionManager listener list, it enters a cycle:



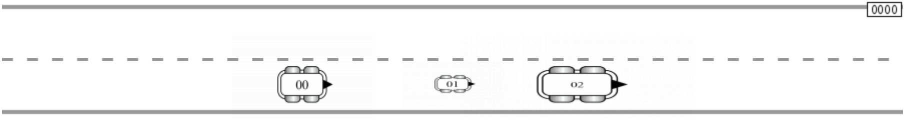
LeftAction example

We use the following parameters (also using the N-points trajectory):

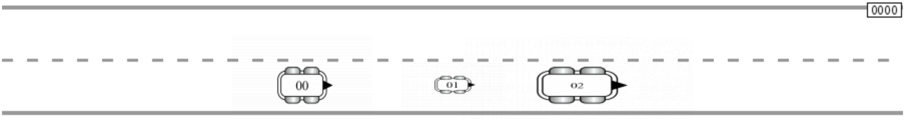
- Δy: Transversal distance covered in the recorded trajectory (last y - initial y);
- μ_y: Average transversal position;
- σ_y: Standard deviation of transversal position.
- f: constant between 0 and 1 (needs tuning);
- $\Delta y_{tolerance}$: transversal position tolerance on central position (needs tuning);
- ϵ_y: transverse position sensor error.

triggerCondition()	$\Delta y > f \cdot v_{max}$
	$\lvert y_{init} - y_{initLane} \rvert < \Delta y_{tolerance} + 3 \cdot \epsilon_y$
endCondition()	$\lvert \mu_y - y_{targetLane} \rvert < \Delta y_{tolerance} + 3 \cdot \epsilon_y / \sqrt{N}$
	$\sigma_y < \epsilon_y$
abortCondition()	After trigger time, the vehicle has disappeared.

LeftAction video



Complete action example




```
TRAVEL        from 149 to -1  TRIGGERED
RIGHT         from 123 to 147 ENDED
LEFT_OVERTAKE         from 41 to 80   ENDED
TRAVEL        from 28 to 129  ENDED
LEFT from 1 to 31     ENDED
TRAVEL        from 0 to 7     ENDED
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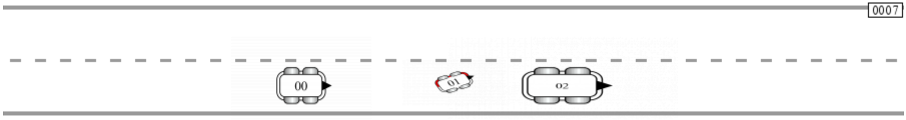


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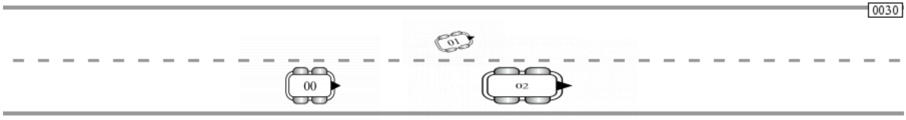


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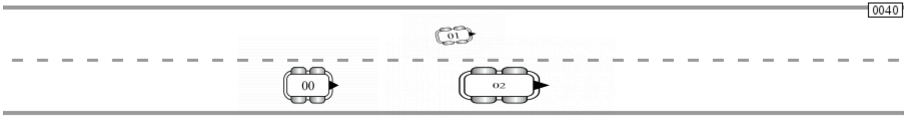


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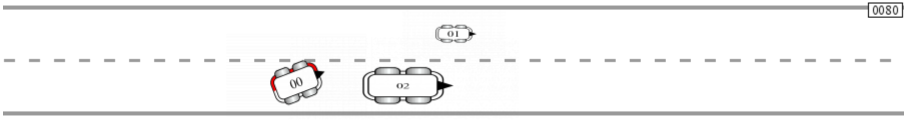


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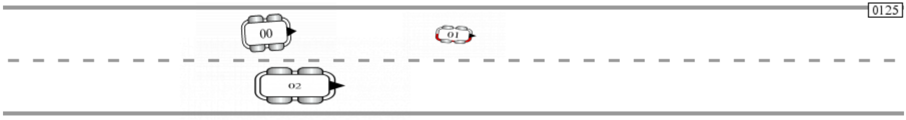


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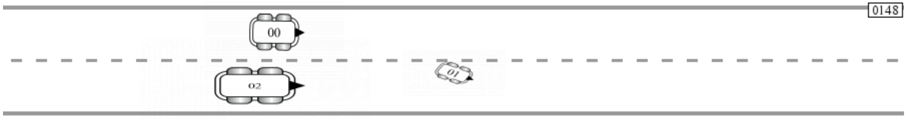


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- Evaluation mode: See after.

Example: Italian-like highway rules

Safety rules

- Safety distance, 1 event: "Someone is in front of the monitored vehicle at less than x meters";
- Maximum speed, 1 event: "The monitored vehicle is faster than x km/h"

Left lane change rules

- 1 event: "Nobody is in front of the monitored vehicle";
- 1 event: "Left lane is occupied";
- 1 event: "The monitored vehicle is on the maximum lane".

Right lane change rules

- 1 event: "Right lane is occupied";
- 1 event: "The monitored vehicle is on the minimum lane".

Travel rules

- 1 event: "Right lane is free";

Left overtake allowed, **Right overtake** forbidden.

Action Manager and Rule Monitor

An object called **Rule Monitor** is used to check if the rules are violated, as the Action Manager “listens” to each action.

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- Keeps the action and the rule systems well separated;
- Different actions can share some rule categories.

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$\rightarrow$ This also allow to make complex action managers without changing the rule system.

Action and rules

Action	Rule categories
LeftAction	Safety Left Lane Change
RightAction	Safety Right Lane Change
TravelAction	Safety Cruise
LeftOvertakeAction	Safety Cruise
RightOvertakeAction	Safety Right Overtake

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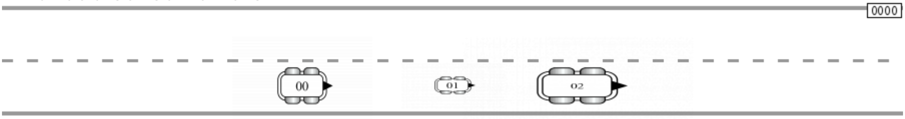
5. A rule is **true** if a wrong behaviour was spotted (at least one of the events is true), **uncertain** if the observer cannot tell if a rule is verified or not due to hidden areas (no events are true, at least one uncertain), **false** if the behaviour is correct (all events are false).

LeftAction example

Without sensor errors:



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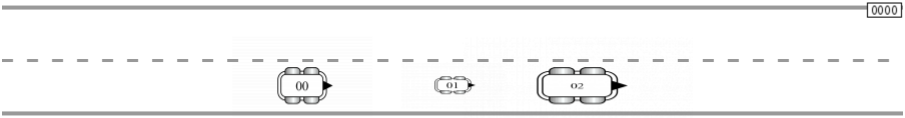

Remarks on the C++ code

The C++ code is mostly written using polymorphism, so that it is very easy to make a more complex system without having to understand the underlying code:

- Specific actions inherit from the Action class. To add a new action, it is only necessary to manually write the trigger, end and abort conditions.
- Specific set of rules inherit from the SocialRules class. After manually writing a new set of rules it is possible to change the monitored rules by changing a single line of code.

A similar concept applies when wanting to change the vehicle geometry, dynamics or automaton. The code is written keeping flexibility in high regard.

Summing up

The simulator should now be able to:

- Recognize and record list of actions done by the monitored vehicles;
- Verify, if possible, if the monitored vehicle is following the rules;
- Do this no matter the vehicle size, dynamic model, state transition rules (could also be manually driven in theory).

Critical point:

Action parameters tuning

Further studies:

- Use of consensus to improve the observer dataset (both to reduce sensor errors and to reveal the content of the hidden areas);
- Reputation system: how to deal with infractions?
- Roomba?
- Possible application in Roborace?
- Besides highways?