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Model-based software design assignment:
CROSS-TRAFFIC ASSIST

Item definition

- **Item:** Cross-Traffic Assist (CTA) which informs the driver about hidden obstacles on each side of the vehicle during backward maneuvers
- **Elements of the item:**
  - rear left radar
  - rear right radar
  - microcontroller
    - comparator unit
    - enable/disable unit
  - CAN interface

Interactions of the item with other items

vehicle CAN network for reading current gear and transmitting warning left and warning right lamp on/off signals

Identification of functionalities

- **Provided functionalities:**
  - rear left radar: detects distances of vehicles on the left side which are closer than a certain threshold
  - rear right radar: detects distances of vehicles on the right side which are closer than a certain threshold
  - comparator unit: compares distances over time to determine whether the vehicle is approaching
  - enable/disable unit: automatically switches the item on when the reverse gear is engaged, and switches it off when the reverse gear is released
- **Functionalities provided to other items:**
  - issuing warning left lamp on/off signals via the CAN network
  - issuing warning right lamp on/off signals via the CAN network
- **Functionalities required from other items:**
  - the current gear shall be provided via the CAN network

Hazard analysis

- **Situational analysis:**
  - OS1: current gear is reverse, no approaching vehicle
  - OS2: current gear is reverse, vehicle approaching at low speed, no covered view
  - OS3: current gear is reverse, vehicle approaching at middle speed, no covered view
  - OS4: current gear is reverse, vehicle approaching at high speed, no covered view
  - OS5: current gear is reverse, vehicle approaching at low speed, covered view
  - OS6: current gear is reverse, vehicle approaching at middle speed, covered view
  - OS7: current gear is reverse, vehicle approaching at high speed, covered view
- **Hazard identification:**
  - H1: the item is not able to issue warning lamp on signal when there are approaching vehicles
    - radar failure: missed detection of vehicles closer than the threshold
    - radar failure: the radar provides increasing distance values for approaching vehicles
    - comparison unit failure: missed detection of approaching vehicles
  - H2: the item is not able to issue warning lamp off signal when there are no approaching vehicles
    - radar failure: unintended detection of vehicles closer than the threshold
    - radar failure: the radar provides decreasing distance values for departing vehicles
    - comparison unit failure: unintended detection of approaching vehicles
  - H3: the item is not able to issue warning lamp signals
    - enable/disable unit failure: missed switch on of the item
    - enable/disable unit failure: unintended switch off of the item
    - CAN interface failure: send/receive error

- **Risk assessment:**

	H1	H2	H3	notes
OS1	S=0 E=3 C=0 **QM**	S=0 E=3 C=0 **QM**	S=0 E=3 C=0 **QM**	No crash can happen since there is no approaching car.
OS2	S=1 E=3 C=1 **QM**	S=1 E=3 C=1 **QM**	S=1 E=3 C=1 **QM**	This is simply controllable for the driver by looking outside through the side window to check whether a car is approaching.
OS3	S=2 E=3 C=1 **QM**	S=2 E=3 C=1 **QM**	S=2 E=3 C=1 **QM**	
OS4	S=3 E=2 C=2 **ASIL A**	S=3 E=2 C=2 **ASIL A**	S=3 E=2 C=2 **ASIL A**	The driver may not have enough time to move his head to look outside. Parking lots are less likely to be on high-speed roads.
OS5	S=1 E=3 C=3 **ASIL A**	S=1 E=3 C=3 **ASIL A**	S=1 E=3 C=3 **ASIL A**	The driver can not look outside through the side window because the view is covered by another car parked next to him, a wall, etc.
OS6	S=2 E=3 C=3 **ASIL B**	S=2 E=3 C=3 **ASIL B**	S=2 E=3 C=3 **ASIL B**	
OS7	S=3 E=2 C=3 **ASIL B**	S=3 E=2 C=3 **ASIL B**	S=3 E=2 C=3 **ASIL B**	
notes	The lamp is always off → it is useless for the driver.	The lamp is always on → it is useless for the driver.	The item can't communicate at all with other items.	

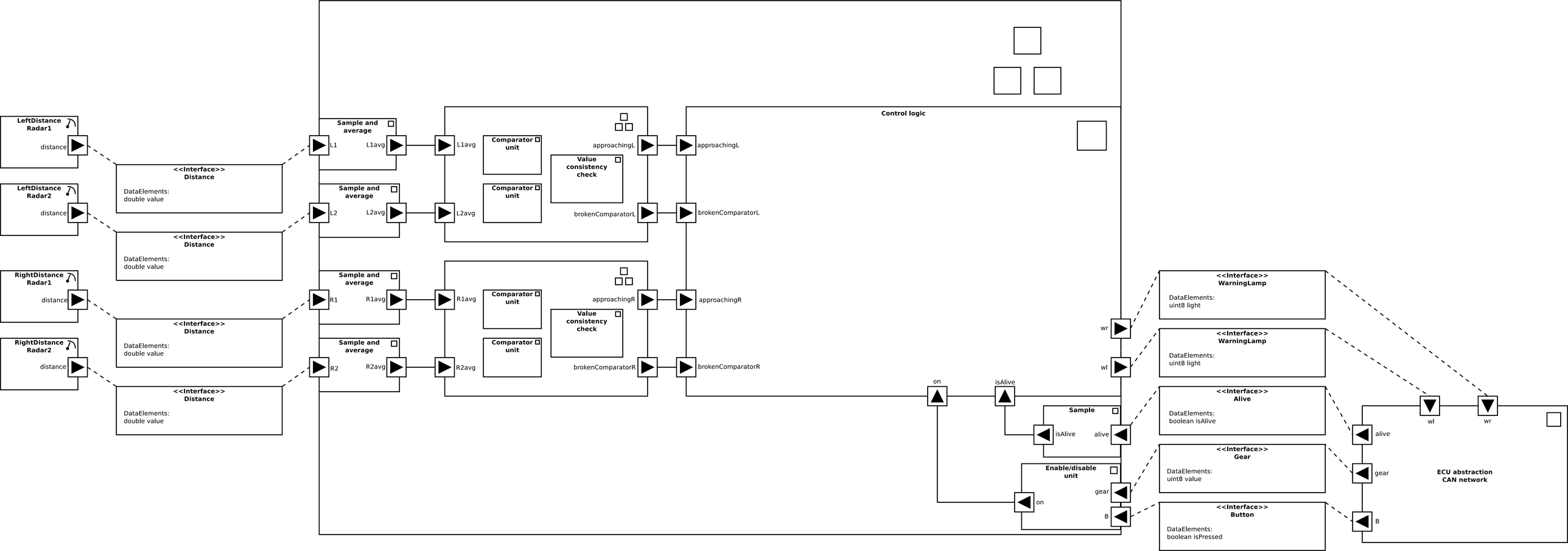
Safety goals and functional safety concept

- H1/H2 ➔ SG1: the item shall be able to detect whether the radars are operating correctly and, if not so, the driver shall be informed
  - FSC1: two[1] redundant radars per side, and if distance values are different the corresponding lamp flashes
- H1/H2 ➔ SG2: the item shall be able to detect whether the comparison unit is operating correctly and, if not so, the driver shall be informed
  - FSC2: redundant code in the comparator unit, and if outputs are different the lamps flash
- H3 ➔ SG3: the driver shall be informed whether the item is on and, if not so, he shall be able to manually force the item to switch on
  - FSC3: when the item is operating the lamps are always on (the light is green when there are no approaching vehicles, or red when there are approaching vehicles), otherwise the lamps are off
  - FSC4: a button can be pressed by the driver to manually force the item to switch on
- H3 ➔ SG4: the driver shall be informed whether the item is connected to the CAN network
  - FSC5: ping-alive protocol should be implemented on the CAN bus, and if no answer received the lamps flash

Software architecture:

The software architecture was described by means of an AUTOSAR diagram (page 3).
Each radar provide the microcontroller, through the "Distance" interface, with distance values, then filtered by a sample and average component. Each comparator unit determines whether the vehicle is approaching. The radar and the comparator unit are redundant, so the inputs from the former and the outputs from the latter are checked for consistency.
The enable/disable unit receives from the CAN network the gear value through the "Gear" interface and the button state through the "Button" interface, and determines whether the item should be switched on.
The ping-alive protocol consists in periodic alive messages coming from the CAN network through the "Alive" interface.
Information about warning lamp lights are sent by the item through the "WarningLamp" interface to the CAN network.

1 no forward recovery as a tradeoff between cost and safety (since the ASIL is not so high).


LeftDistance Radar1
distance
LeftDistance Radar2
distance
RightDistance Radar1
distance
RightDistance Radar2
distance
<<Interface>> Distance
DataElements: double value
<<Interface>> Distance
DataElements: double value
<<Interface>> Distance
DataElements: double value
<<Interface>> Distance
DataElements: double value
Control logic
Sample and average
L1
L1avg
Sample and average
L2
L2avg
Sample and average
R1
R1avg
Sample and average
R2
R2avg
L1avg
L2avg
R1avg
R2avg
Comparator unit
Comparator unit
Comparator unit
Comparator unit
Value consistency check
Value consistency check
approachingL
brokenComparatorL
approachingR
brokenComparatorR
approachingL
brokenComparatorL
approachingR
brokenComparatorR
on
isAlive
Sample
isAlive
alive
Enable/disable unit
on
gear
B
wr
wl
<<Interface>> WarningLamp
DataElements: uint8 light
<<Interface>> WarningLamp
DataElements: uint8 light
<<Interface>> Alive
DataElements: boolean isAlive
<<Interface>> Gear
DataElements: uint8 value
<<Interface>> Button
DataElements: boolean isPressed
wl
wr
alive
gear
B
ECU abstraction CAN network

Software implementation
The controller code was automatically generated by a Simulink model, having a fixed-step size equal to 0.1 seconds. For the sake of simplicity, just the left side of the vehicle was considered in the model. A testbench was also provided.

The controller block (page 5) is characterized by the following inputs:
- `L1` (double): the distance value received from the first distance radar;
- `L2` (double): the distance value received from the second distance radar;
- `gear` (uint8): the gear value (value 0 = reverse gear, value 6 = neutral gear);
- `B` (boolean): specifies whether the button is pressed;
- `alive` (boolean): specifies whether an alive message has been received.

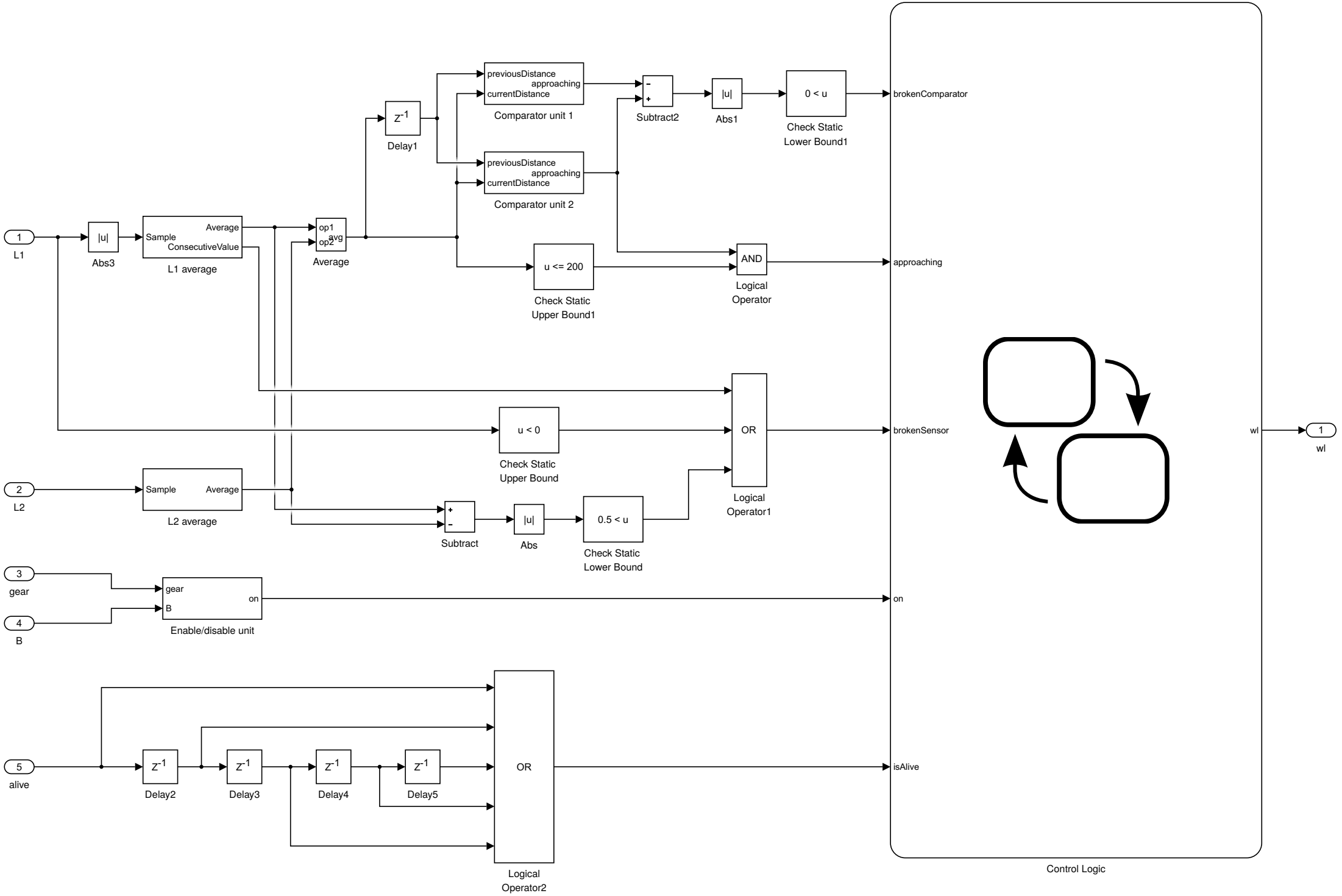
and by the following output:
- `wl` (uint8): specifies whether the light of the warning lamp should be off (value 0), red (value 1) or green (value 2).

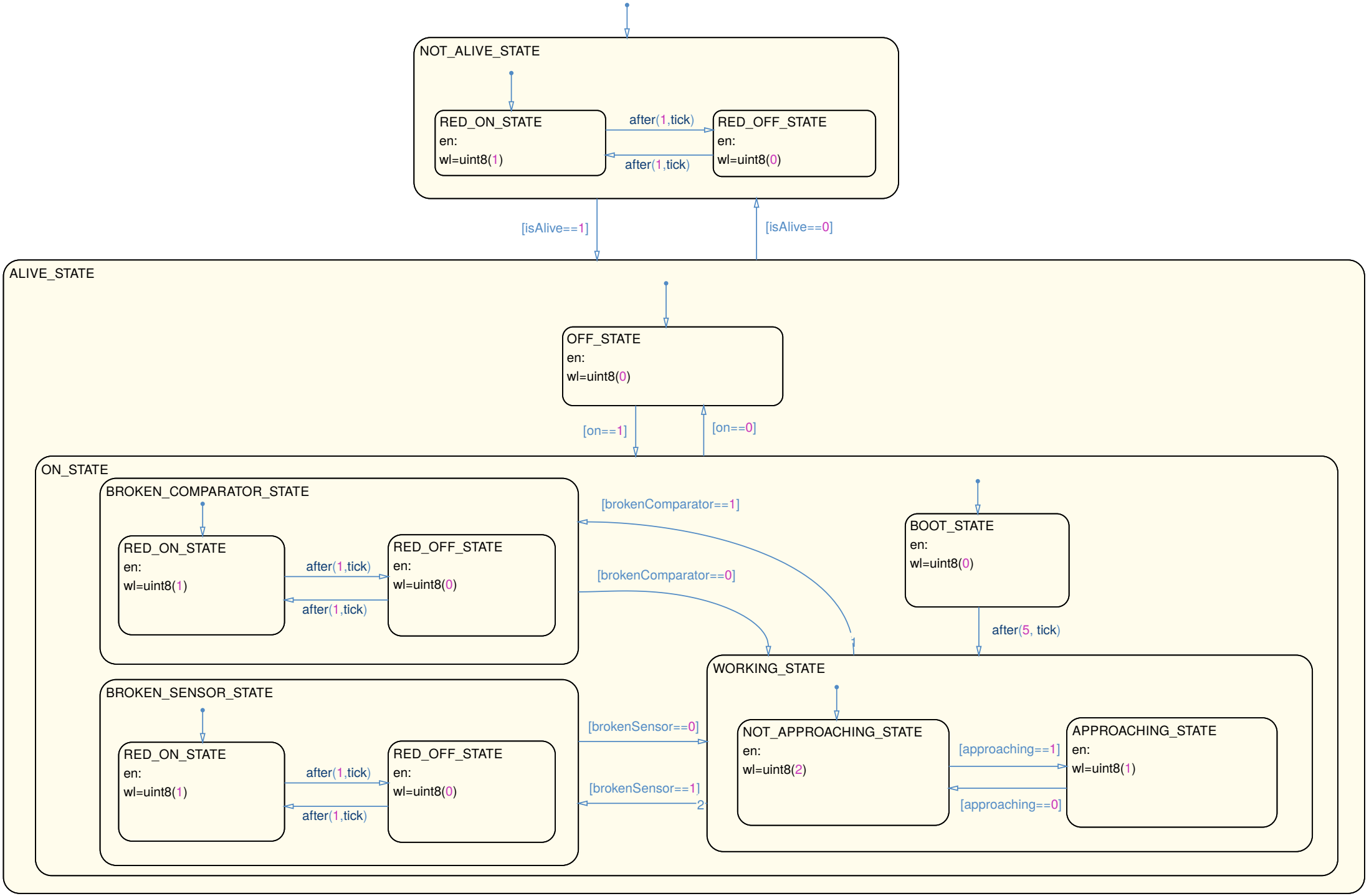
In order to remove the noise from distance inputs, each sample and average block computes the average of the last 5 distance samples. In addition, it compares the current sample with the previous 4 samples: if the same distance value has been received in the last 5 instances of time, the radars are considered as broken.
Distance values higher than 200 m are ignored. The average distance values are compared to check whether they differ beyond a threshold equal to 0.5 m, meaning that the radars are considered as broken.
Each comparator unit compares the current average distance sample to the previous one in order to determine whether the vehicle is approaching. The outputs from the comparator units are compared: if they are different, the comparator units are considered as broken.
The enable/disable unit block switches the item on when the gear is reverse or the button is pressed.
Each alive message is delayed 4 times and, if in the last 5 instants of time no alive message is received, the item is considered as not being connected to the CAN network.

The control logic, modelized by means of a stateflow (page 6), is characterized by the following inputs:
- `brokenComparator` (boolean): specifies whether the comparator units are broken;
- `approaching` (boolean): specifies whether a vehicle is approaching;
- `brokenSensor` (boolean): specifies whether the distance radars are broken;
- `on` (boolean): specifies whether the item should be switched on;
- `isAlive` (boolean): specifies whether the item is not connected to the CAN network;

and by the following main states:
- `NOT_APPROACHING_STATE`: no vehicle is approaching → the green lamp is still;
- `APPROACHING_STATE`: a vehicle is approaching → the red lamp is still;
- `BROKEN_COMPARATOR_STATE`: the comparator units are broken → the red lamp flashes;
- `BROKEN_SENSOR_STATE`: the distance radars are broken → the red lamp flashes;
- `OFF_STATE`: the item is switched off → the lamp is off;
- `NOT_ALIVE_STATE`: the item is not connected to the CAN network → the red lamp flashes.

The auto-generated code consists of the following files: `controller.c`, `controller.h`, `rtwtypes.h`.
The following functions are automatically generated:
- `controller_initialize()`: initializes the controller;
- `controller_step()`: is called on every controller step.


1
L1
|u|
Abs3
Sample
Average
ConsecutiveValue
L1 average
op1
avg
op2
Average
Z-1
Delay1
previousDistance
approaching
currentDistance
Comparator unit 1
previousDistance
approaching
currentDistance
Comparator unit 2
Subtract2
|u|
Abs1
0 < u
Check Static
Lower Bound1
brokenComparator
u <= 200
Check Static
Upper Bound1
AND
Logical
Operator
approaching
2
L2
Sample
Average
L2 average
u < 0
Check Static
Upper Bound
OR
Logical
Operator1
brokenSensor
Subtract
|u|
Abs
0.5 < u
Check Static
Lower Bound
3
gear
4
B
gear
B
on
Enable/disable unit
on
5
alive
Z-1
Delay2
Z-1
Delay3
Z-1
Delay4
Z-1
Delay5
OR
Logical
Operator2
isAlive
wl
1
wl
Control Logic


NOT_ALIVE_STATE
RED_ON_STATE
en:
wl=uint8(1)
after(1,tick)
after(1,tick)
RED_OFF_STATE
en:
wl=uint8(0)
[isAlive==1]
[isAlive==0]
ALIVE_STATE
OFF_STATE
en:
wl=uint8(0)
[on==1]
[on==0]
ON_STATE
BROKEN_COMPARATOR_STATE
RED_ON_STATE
en:
wl=uint8(1)
after(1,tick)
after(1,tick)
RED_OFF_STATE
en:
wl=uint8(0)
[brokenComparator==1]
[brokenComparator==0]
BOOT_STATE
en:
wl=uint8(0)
after(5, tick)
1
BROKEN_SENSOR_STATE
RED_ON_STATE
en:
wl=uint8(1)
after(1,tick)
after(1,tick)
RED_OFF_STATE
en:
wl=uint8(0)
[brokenSensor==0]
[brokenSensor==1]
2
WORKING_STATE
NOT_APPROACHING_STATE
en:
wl=uint8(2)
[approaching==1]
[approaching==0]
APPROACHING_STATE
en:
wl=uint8(1)

Hardware/software integration

Some C++ code in mbed was written in order to integrate the model with the evaluation board.

- **Inputs:**
  - `D4`: the `InterruptIn` interface of the board used to receive echo signals from the sensor;
  - `USBRX`: the `Serial` interface of the board simulating the input CAN interface, used to receive the gear value, the button state and alive messages.
- **Outputs:**
  - `D2`: the `DigitalOut` interface of the board used to send trigger signals to the sensor;
  - `LED_RED` and `LED_GREEN`: the `DigitalOut` interfaces of the board simulating the output CAN interface, used to send the warning lamp on/off signals.

Test plan

Boundary value analysis has been performed for the model inputs:

- `L1`: $x < 0$; $0 \leq x \leq 200$; $x > 200$
- `L2`: $x < 0$; $0 \leq x \leq 200$; $x > 200$
- `gear`: $x < 0$; $x = 0$; $x > 0$
- `B`: x = false; x = true
- `alive`: x = false; x = true