

CLAIMS

1. A method comprising
autonomously driving a vehicle within an environment to a destination by actions that
include:

5 generating a finite set of candidate trajectories of the vehicle that begin at a
location of the vehicle as of a given time, the candidate trajectories each being based on a
sequence of world states at successive times and on transitions between successive states
of the sequence, each of the world states comprising a state of the vehicle and a state of
the environment as of the location of the vehicle and the corresponding time, the state of
10 the environment comprising states of at least one of another vehicle, a cyclist, a
pedestrian, or another obstacle,

 selecting a putative optimal trajectory from among the candidate trajectories
based on costs associated with the candidate trajectories, including costs associated with
violations of rules of operation of the vehicle, the costs associated with a given trajectory
15 being evaluated based on costs associated with sequences of two or more of the
transitions between successive states of the trajectory, and

 based on the selected putative optimal trajectory, commanding actuators of the
vehicle to engage in control actions to drive the vehicle autonomously within the
environment toward the destination.

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2. The method of claim 1 in which the facilitating of the operation related to control
of the vehicle comprises applying a feedback control policy associated with the putative optimal
trajectory to control elements of the vehicle, the application of the feedback control policy being
based on the states of the vehicle and of the environment.

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3. The method of claim 1 comprising applying one or more constraints to the finite
set of candidate trajectories, the constraints being applied based on the sequence of world states
at the successive times.

4. The method of claim 1 in which the putative optimal trajectory is associated with both speed and direction of the vehicle and selecting the putative optimal trajectory comprises determining a minimum-cost path through a directed graph of which the candidate trajectories comprise edges, the cost of the minimum-cost path comprising a penalty associated with violation of a constraint.

5. The method of claim 1 in which generating a finite set of candidate trajectories of the vehicle comprises applying a model that represents the vehicle's expected response to a given control policy as of the location of the vehicle and the given time, the model representing responses of elements of the environment to the given control policy and the vehicle's expected response as of the location of elements of the environment vehicle.

6. The method of claim 1 in which the costs associated with a given trajectory are based on costs associated with interactions between the states of the vehicle and the states of the environment and the costs are expressed as cost rules in a formal language that enables expression of the cost rules that are interpreted over sequences of two or more world states of a trajectory over time.

7. A method comprising evaluating driving performance for a vehicle being driven within an environment to a destination, by actions that include:

generating a finite set of candidate trajectories of the vehicle that begin at a location of the vehicle as of a given time, the candidate trajectories each being based on a sequence of world states at successive times and on transitions between successive states of the sequence, each of the world states comprising a state of the vehicle and a state of the environment as of the location of the vehicle and the corresponding time, the environment comprising at least one of another vehicle, pedestrians, cyclists, or other obstacle,

selecting a putative optimal trajectory from among the candidate trajectories based on costs associated with the candidate trajectories, including costs associated with

violations of rules of operation of the vehicle, the candidate trajectories taking account of locations of elements of the environment,

monitoring an actual trajectory of the vehicle for a given time period, and

comparing the actual trajectory of the vehicle with the putative optimal trajectory

as an indication of the driving performance.

8. The method of claim 7 in which the driving performance comprises a human driver's performance.

9. The method of claim 8 comprising evaluating the driver's performance based on one or more performance metrics.

10. A method comprising autonomously driving a vehicle within an environment to a destination by actions that include:

generating a finite set of candidate trajectories of the vehicle as of a given time, the finite set of candidate trajectories belonging to a trajectory space of all possible trajectories of the vehicle,

assessing costs of each of the candidate trajectories, the costs comprising one or more of the following: length, turning angle, or other geometry related costs; acceleration, jerk, control effort, or other dynamic costs; and rule or constraint violations or other logical costs, the costs comprising a total order, and the putative optimal trajectory is selected as one with minimum cost according to the total order,

selecting a putative optimal trajectory from among the candidate trajectories of the finite set based on costs associated with the candidate trajectories, the selected putative optimal trajectory is associated with both speed and direction of the vehicle,

the space of all possible trajectories of the vehicle being sufficiently covered by the generated finite set of candidate trajectories so that the putative optimal trajectory comprises an arbitrarily close approximation to an actual optimal trajectory, and

based on the selected putative optimal trajectory commanding actuators of the vehicle to engage in control actions to drive the vehicle within the environment toward the destination.

5 11. The method of claim 10 comprising applying one or more constraints to the finite set of candidate trajectories.

12. The method of claim 10 in which generating a finite set of candidate trajectories of the vehicle comprises applying a model that represents the vehicle's and the environment's
10 expected response to a given control policy as of the location of the vehicle and a given time.

13. A method comprising
evaluating driving performance for a vehicle being driven within an environment to a destination, by actions that include:
15 generating a finite set of candidate trajectories of the vehicle as of a given time, the finite set of candidate trajectories belonging to a trajectory space of all possible trajectories of the vehicle,
 assessing costs of each of the candidate trajectories,
 selecting a putative optimal trajectory from among the candidate trajectories of
20 the finite set based on costs associated with the candidate trajectories,
 the space of all possible trajectories of the vehicle being sufficiently covered by the generated finite set of candidate trajectories so that the putative optimal-trajectory comprises an arbitrarily close approximation to an optimal trajectory,
 monitoring an actual trajectory of the vehicle for a given time period, and
25 comparing the actual trajectory of the vehicle with the putative optimal trajectory as an indication of the driving performance.

14. The method of claim 13 in which evaluating driving performance comprises monitoring a human driver's performance.

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15. The method of claim 13 comprising evaluating the driver's performance based on one or more performance metrics.

5 16. The method of claim 13 comprising assessing the likelihood of an accident occurring.

17. An apparatus comprising
an autonomous vehicle comprising
controllable devices configured to cause the vehicle to traverse at least part of an
10 optimal trajectory in a manner consistent with control policies and with cost rules that
apply to sequences of transitions between successive world states along a world
trajectory,
a controller to provide commands to the controllable devices in accordance with
the world trajectory,
15 sources of information about world states at successive times, and
a computational element to
iteratively update (a) a set of world states, each of the world states
representing a combination of a state of the vehicle, a state of an environment of
the vehicle, and a state of at least one other object in the environment based at
20 least in part on the information about world states, and (b) a set of world
trajectories, each of the world trajectories representing a sequence of temporal
transitions each transition being between one of the world states and another of
the world states,
each of the iterations of the updating comprising
25 for each of one or more of the world states and for a corresponding
vehicle control policy, simulating a candidate trajectory from the world
state to a subsequent world state,
if the simulated candidate trajectory does not violate a constraint,
adding the trajectory to the set of world trajectories to form an updated set
30 of world trajectories,

if necessary, adding a new world state to the set of world states corresponding to the transition represented by the simulated candidate trajectory to form an updated set of world states, and

determining a minimum-cost path through the updated set of world states and the updated set of world trajectories, the determining including applying cost rules to a sequence of two or more successive transitions of each of the world trajectories, and

deliver to the controller information representing a next transition from the current world state to a next world state along the minimum-cost path, for autonomous control of the vehicle.

18. The method of claim 1 in which the costs associated with a given trajectory are based on costs associated with interactions between the states of the vehicle and the states of the environment.

19. The method of claim 1 in which the selected putative optimal trajectory is associated with both speed and direction of the vehicle.

20. The method of claim 1 in which the state of the environment comprises the states of other vehicles, pedestrians, and obstacles as of the corresponding time.