

Appendix of "Towards Abductive and Deductive Synthesis with Generative Agents: Underspecification and Validation"

February 2026

1 Principles

1.1 Legal Principles

- *keep-control*: Maintain constant vehicle control
- *above-minimum-speed*: Avoid impeding traffic flow
- *below-speed-limit*: Adhere to maximum speed
- *no-stopping*: Stopping prohibited on motorways
- *keep-right*: Drive as far right as possible
- *speed-adv-overtaking*: Only overtake with sufficient speed advantage
- *overtaking-maneuver*: Ensure no danger to others when overtaking
- *no-right-overtaking*: Overtake only on the left
- *safe-distance*: Maintain safe distance from other vehicles
- *being-overtaken*: Do not accelerate when being overtaken
- *emergency-stopping*: Apply emergency brake if needed
- *traffic-light*: Follow traffic signals
- *seatbelt-mandatory*: All occupants must wear seatbelts
- *no-drinking-driving*: Driving under influence is prohibited
- *license-required*: Valid driving license required
- *vehicle-registration*: Vehicles must be registered and insured
- *no-mobile-use*: No hand-held mobile phone usage
- *helmet-mandatory*: Helmets required for motorcyclists

1.2 Safety Principles

- *stationary-no-friction-decrease*: Stationary vehicle friction cannot decrease
- *max-acceleration-limited-by-friction*: Acceleration limited by tire-road friction
- *max-deceleration-limited-by-friction*: Deceleration limited by friction
- *slip-if-force-exceeds-friction*: Skid if forces exceed friction
- *collision-without-emergency-brake*: Vehicle collides if brake not applied
- *collision-if-obstacles*: Vehicle may collide if obstacles present
- *too-fast-for-conditions*: Risk of losing control if too fast
- *braking-distance-increases-with-speed*: Stop distance grows with speed
- *turning-radius-increases-with-speed*: Reduce speed to maintain traction in turns
- *speeding-reduces-reaction-time*: Less time to react at higher speeds
- *overtake-speed-requirement*: Must have speed advantage to overtake
- *overspeed-on-curve-risk*: Skidding risk if curve speed exceeded
- *speed-limited-by-friction*: Max safe speed limited by friction
- *hydroplaning-risk*: Vehicle may hydroplane on wet roads
- *maintain-safe-distance*: Keep safe distance from vehicle ahead
- *check-blind-spots*: Always check blind spots
- *reduce-speed-in-bad-weather*: Reduce speed in rain, snow, fog
- *use-indicators*: Signal before maneuvers
- *avoid-distractions*: Avoid distractions while driving
- *vehicle-maintenance*: Ensure vehicle is properly maintained
- *emergency-brake-ready*: Be able to apply emergency brake
- *night-driving-caution*: Extra caution at night or low visibility

2 Scenario Output

```

1 Effect: Successfully merge into heavy traffic
2
3 After decomposition
4 "causes": [
5     "Driver_maintains_control_of_the_vehicle",
6     "Vehicle_is_traveling_at_a_speed_thatAllows_for_safe_merging",
7     "Sufficient_distance_from_other_vehicles_to_merge_safely",
8     "No_vehicles_are_overtaking_on_the_right",
9     "Traffic_conditions_allow_for_merging_without_impeding_flow",
10    "Driver_adheres_to_traffic_laws_regarding_merging",
11    "No_sudden_obstacles_in_the_merging_path",
12    "Driver_is_aware_of_surrounding_traffic"
13 ]
14
15 After semantic consolidation
16 "unique_causes": [
17     "Driver_maintains_control_of_the_vehicle_and_is_aware_of_surrounding_traffic.
18     ",
19     "Vehicle_is_traveling_at_a_speed_thatAllows_for_safe_merging_and_adheres_to_
20         traffic_laws_regarding_merging.",
21     "Sufficient_distance_from_other_vehicles_to_merge_safely_and_no_vehicles_are_
22         overtaking_on_the_right.",
23     "Traffic_conditions_allow_for_merging_without_impeding_flow_and_no_sudden_
24         obstacles_in_the_merging_path."
25 ]
26
27 Symbolic Translation
28 "rules": [
29     {
30         "cause": "Driver maintains control of the vehicle
31         "rule": "x (collide(x)      sd-front(x)      sd-rear(x)      lane-change(x)
32             )
33             "thinking": "Maintaining control of the vehicle involves ensuring that
34                 there is a safe distance to both the preceding and following vehicles, as
35                 well as avoiding lane changes that could lead to instability. If these
36                 conditions are met, the vehicle is less likely to collide with obstacles or
37                 other agents."
38         }
39         {
40             "cause": "Vehicle is traveling at a speed that allows for safe merging",
41             "rule": "x (sd-front(x)  sd-rear(x)  speed-adv(x,y)  speed (x) >
42                 vthreshold)",
43             "thinking": "For a vehicle to merge safely, it must maintain a safe
44                 distance from both the preceding and following vehicles, ensuring that it is
45                 not too close to either. Additionally, the vehicle's speed must be greater
46                 than a certain threshold relative to the speed of other vehicles to
47                 facilitate a safe merge."
48         }
49         {
50             "cause": "Sufficient distance from other vehicles to merge safely",
51             "rule": "x (sd-front(x)  sd-rear(x)  dense (x))",
52             "thinking": "To merge safely, a vehicle must have a safe distance to both
53                 the preceding and following vehicles. This ensures that there is enough
54                 space to maneuver without the risk of collision, which is further supported
55                 by the absence of dense traffic around the vehicle."
56     }
57 ]
58 
```

```

39    }
40    {
41        "cause": "No vehicles are overtaking on the right",
42        "rule": "x (right(i,j) & lane-change(i))",
43        "thinking": "The condition states that no vehicles are overtaking on the right, which implies that if a vehicle i is to the right of another vehicle j, then vehicle i cannot be crossing a lane boundary to overtake. This ensures that the vehicles maintain their positions without any overtaking maneuvers on the right side."
44    }
45    {
46        "cause": "Traffic conditions allow for merging without impeding flow",
47        "rule": "x (sd-front(x) & sd-rear(x) & dense (x) & lane-change(x))",
48        "thinking": "For merging to occur without impeding flow, the vehicle must have a safe distance to both the preceding and following vehicles, and there should not be a dense traffic condition. This ensures that the vehicle can change lanes safely without causing disruptions."
49    }
50    {
51        "cause": "Driver adheres to traffic laws regarding merging",
52        "rule": "x (lane-change(x) & collide(x) & merged(x) & sd-front(x) & sd-rear(x))",
53        "thinking": "Adhering to traffic laws regarding merging implies that the driver should not change lanes in a way that would cause a collision. The driver must have already passed the merging point (merged(x)), maintain a safe distance to the vehicle in front (sd-front(x)), and a safe distance to the vehicle behind (sd-rear(x)) to ensure safe merging."
54    }
55    {
56        "cause": "No sudden obstacles in the merging path",
57        "rule": "x (collide (x) & near (x, obstacle) & dense (x))",
58        "thinking": "The condition of having no sudden obstacles in the merging path implies that the vehicle must not be colliding with any obstacles and must not be near any obstacles that could cause a collision. Additionally, the vehicle should not be in a dense situation where multiple nearby vehicles could create sudden obstacles."
59    }
60    {
61        "cause": "Driver is aware of surrounding traffic",
62        "rule": "x (collide (x) & dense(x) & sd-front(x) & sd-rear(x))",
63        "thinking": "The awareness of surrounding traffic implies that the driver can perceive the density of nearby vehicles and maintain safe distances both in front and behind. This awareness helps prevent collisions by ensuring that the driver can react appropriately to the traffic situation."
64    }
65 ]
66
67
68 Initial Individual Evaluations:
69 "evaluations": [
70     {
71         "cause": "Driver maintains control of the vehicle and is aware of surrounding traffic.",
72         "result": "necessary",
73         "reason": "Without the driver maintaining control, the vehicle cannot safely merge into heavy traffic, violating safety laws regarding vehicle control and potential collisions."

```

```

74 },
75 {
76     "cause": "Vehicle\u00b7is\u00b7traveling\u00b7at\u00b7a\u00b7speed\u00b7that\u00b7allows\u00b7for\u00b7safe\u00b7merging\u00b7and\u00b7
77     adheres\u00b7to\u00b7traffic\u00b7laws\u00b7regarding\u00b7merging..",
78     "result": "necessary",
79     "reason": "Traveling\u00b7at\u00b7an\u00b7appropriate\u00b7speed\u00b7is\u00b7essential\u00b7for\u00b7safe\u00b7merging;
80     \u00b7if\u00b7the\u00b7vehicle\u00b7is\u00b7not\u00b7at\u00b7a\u00b7safe\u00b7speed,\u00b7it\u00b7may\u00b7violate\u00b7legal\u00b7laws\u00b7regarding\u00b7
81     speed\u00b7and\u00b7control,\u00b7leading\u00b7to\u00b7unsafe\u00b7conditions."
82 },
83 {
84     "cause": "Sufficient\u00b7distance\u00b7from\u00b7other\u00b7vehicles\u00b7to\u00b7merge\u00b7safely\u00b7and\u00b7no\u00b7
85     vehicles\u00b7are\u00b7overtaking\u00b7on\u00b7the\u00b7right..",
86     "result": "not\u00b7necessary",
87     "reason": "It\u00b7is\u00b7possible\u00b7to\u00b7merge\u00b7into\u00b7heavy\u00b7traffic,\u00b7even\u00b7if\u00b7there\u00b7is\u00b7
88     insufficient\u00b7distance\u00b7from\u00b7other\u00b7vehicles,\u00b7as\u00b7long\u00b7as\u00b7the\u00b7vehicle\u00b7adheres\u00b7to\u00b7
89     speed\u00b7and\u00b7control\u00b7laws;\u00b7thus,\u00b7this\u00b7cause\u00b7is\u00b7not\u00b7strictly\u00b7required."
90 },
91 {
92     "cause": "Traffic\u00b7conditions\u00b7allow\u00b7for\u00b7merging\u00b7without\u00b7impeding\u00b7flow\u00b7and\u00b7no\u00b7
93     sudden\u00b7obstacles\u00b7in\u00b7the\u00b7merging\u00b7path..",
94     "result": "not\u00b7necessary",
95     "reason": "Merging\u00b7can\u00b7occur\u00b7even\u00b7if\u00b7traffic\u00b7conditions\u00b7are\u00b7not\u00b7ideal,\u00b7
96     provided\u00b7that\u00b7the\u00b7vehicle\u00b7maintains\u00b7control\u00b7and\u00b7adheres\u00b7to\u00b7speed\u00b7laws;\u00b7thus,\u00b7
97     \u00b7this\u00b7cause\u00b7is\u00b7not\u00b7strictly\u00b7necessary\u00b7for\u00b7the\u00b7effect."
98 }
99 ]
100 Necessary Sets:
101 Necessary Set 1: Driver maintains control of the vehicle and is aware of
102 surrounding traffic.
103 Necessary Set 2: Vehicle is traveling at a speed that allows for safe merging and
104 adheres to traffic laws regarding merging.
105 Necessary Set 3: Sufficient distance from other vehicles to merge safely and no
106 vehicles are overtaking on the right.
107 Necessary Set 4: Traffic conditions allow for merging without impeding flow and
108 no sudden obstacles in the merging path.

109 Sufficient Sets:
110 Sufficient Set 1:
111 - Driver maintains control of the vehicle and is aware of surrounding traffic.
112 - Vehicle is traveling at a speed that allows for safe merging and adheres to
113 traffic laws regarding merging.
114 - Sufficient distance from other vehicles to merge safely and no vehicles are
115 overtaking on the right.
116 - Traffic conditions allow for merging without impeding flow and no sudden
117 obstacles in the merging path.
```

Listing 1: Scenario: Successfully Merge into Heavy Traffic

```

1 Effect: Maintain a constant speed on a highway segment
2
3 After decomposition
4 "causes": [
5     "Driver_maintains_vehicle_control",
6     "Vehicle_speed_is_within_legal_limits",
7     "Vehicle_speed_is_above_minimum_required_speed",
8     "Sufficient_friction_between_tires_and_road",
9     "No_obstacles_on_the_highway_segment",
10    "No_sudden_changes_in_traffic_conditions",
11    "Driver_is_attentive_and_responsive_to_road_conditions",
12    "No_emergency_situations_requiring_sudden_braking"
13 ]
14
15 After deduplication and merging
16 "unique_causes": [
17     "Driver_maintains_vehicle_control_and_is_attentive_and_responsive_to_road_
18     conditions.",
19     "Vehicle_speed_is_within_legal_limits_and_above_minimum_required_speed.",
20     "Sufficient_friction_between_tires_and_road.",
21     "No_obstacles_on_the_highway_segment.",
22     "No_sudden_changes_in_traffic_conditions.",
23     "No_emergency_situations_requiring_sudden_braking."
24 ]
25 Symbolic Translation
26 "rules": [
27     {
28         "cause": "Driver_maintains_vehicle_control_and_is_attentive_and_
29         responsive_to_road_conditions.",
30         "rule": "x ( collide (x) _ sd-front(x) _ sd-rear(x) _ lane_change(x)) "
31         ,
32         "thinking": "Maintaining_vehicle_control_and_being_attentive_implies_that_
33         _the_driver_keeps_safe_distances_to_both_the_preceding_and_following_
34         vehicles_and_avoids_unnecessary_lane_changes._Awareness_and_responsiveness_
35         to_road_conditions_reduce_instability_and_lower_the_probability_of_
            collisions."
36     },
37     {
38         "cause": "Vehicle_speed_is_within_legal_limits_and_above_minimum_required_
39         _speed.",
40         "rule": "x ( speed (x) _ legal_limit _ speed (x) >_
            minimum_required_speed)",
41         "thinking": "The_vehicle_must_operate_below_the_maximum_speed_while_
42         _remaining_above_the_minimum_threshold_required_for_stable_traffic_flow.__
            Staying_within_this_interval_ensures_both_regulatory_compliance_and_safe_
            dynamic_behavior."
43     },
44     {
45         "cause": "Sufficient_friction_between_tires_and_road.",
46         "rule": "x ( friction (x) > 0 )",
47         "thinking": "Adequate_friction_between_the_tires_and_the_road_surface_
48         ensures_controllability_during_acceleration,_braking,_and_steering._Positive_
49         friction_is_a_prerequisite_for_maintaining_stability_and_preventing_
            skidding."
50     },
51     {

```

```

43     "cause": "No obstacles on the highway segment.",
44     "rule": "x (near (x, obstacle))",
45     "thinking": "If no obstacles are present on the road segment, the vehicle
46     is not exposed to unexpected physical barriers. The absence of nearby
47     obstacles supports uninterrupted and safe driving."
48 },
49 {
50     "cause": "No sudden changes in traffic conditions.",
51     "rule": "x (sudden_change(x))",
52     "thinking": "Stable traffic conditions imply the absence of abrupt
53     accelerations, decelerations, or unpredictable maneuvers. This stability
54     supports consistent vehicle control and reduces risk."
55 },
56 ]
57
58
59 Initial Individual Evaluations:
60 "evaluations": [
61     {
62         "cause": "Driver maintains vehicle control and is attentive and responsive
63         to road conditions.",
64         "result": "necessary",
65         "reason": "Without the driver maintaining control, the vehicle cannot
66         safely maintain a constant speed, violating safety laws regarding vehicle
67         control."
68     },
69     {
70         "cause": "Vehicle speed is within legal limits and above minimum required
71         speed.",
72         "result": "necessary",
73         "reason": "If the vehicle speed is not within legal limits, it cannot
74         legally maintain a constant speed, violating legal laws regarding speed
75         limits."
76     },
77     {
78         "cause": "Sufficient friction between tires and road.",
79         "result": "necessary",
80         "reason": "Without sufficient friction, the vehicle cannot maintain a
81         constant speed without risking skidding or losing control, violating
82         safety laws related to friction."
83     },
84     {
85         "cause": "No obstacles on the highway segment.",
86         "result": "not_necessary",
87         "reason": "The vehicle can maintain a constant speed even if there are
88         obstacles, as long as the driver can control the vehicle and respond
89         appropriately, which is covered by other causes."
90     },
91     {
92         "cause": "No sudden changes in traffic conditions.",

```

```

84     "result": "not_necessary",
85     "reason": "The_vehicle_can_still_maintain_a_constant_speed_despite_sudden_
86     changes_in_traffic_conditions_if_the_driver_is_attentive_and_responsive,_
87     which_is_covered_by_other causes."
88   },
89   {
90     "cause": "No_emergency_situations_requiring_sudden_braking.",
91     "result": "not_necessary",
92     "reason": "The_vehicle_can_maintain_a_constant_speed_even_if_an_emergency_
93     situation_arises,_provided_the_driver_is_able_to_manage_the_situation_
94     without_braking_suddenly,_which_is_covered_by_other causes."
95   }
96 ]
97
98 Necessary Sets:
99
100 Necessary Set 1: Driver maintains vehicle control and is attentive and responsive
101   to road conditions.
102 Necessary Set 2: Vehicle speed is within legal limits and above minimum required
103   speed.
104 Necessary Set 3: Sufficient friction between tires and road.
105
106 Sufficient Sets:
107
108 Sufficient Set 1:
109   - Driver maintains vehicle control and is attentive and responsive to road
110     conditions.
111   - Vehicle speed is within legal limits and above minimum required speed.
112   - Sufficient friction between tires and road.
113   - No obstacles on the highway segment.
114
115 Sufficient Set 2:
116   - Driver maintains vehicle control and is attentive and responsive to road
117     conditions.
118   - Vehicle speed is within legal limits and above minimum required speed.
119   - Sufficient friction between tires and road.
120   - No sudden changes in traffic conditions.

```

Listing 2: Scenario: Maintain a Constant Speed on a Highway Segment

3 Prompts

```
1 DECOMPOSE_EFFECT_PROMPT = '''  
2 You_are_an_expert_in_causal_reasoning. You_task_is_to_decompose_an_effect_into_a_  
   list_of_its_necessary_causes.  
3  
4 You_are_given_3_things_as_input.  
5 Input:  
6 {effect}  
7 {legal_laws}  
8 {safety_laws}  
9  
10 Instructions:  
11 - **Necessary_Cause:** A condition that must be present for the effect to occur.  
    If this condition is removed, the effect becomes impossible (The "But-For" Test).  
12 - **Direct_Link:** Avoid distal or "butterfly" effects. Focus on the immediate_safety, and_legal_requirements.  
13 - Produce only valid logical causes in **strict JSON format**; that ensure that the effect can happen in real world.  
14  
15 The_JSON_output_must_follow_this_exact_schema:  
16  
17 {{  
18   "causes": [  
19     "cause_1",  
20     "cause_2",  
21     ...  
22   ]  
23 }}  
24  
25  
26 Input:  
27 {effect}  
28  
29 Example:  
30 effect: Turn_left_while_maintaining_low_speed.  
31 output:  
32 {{  
33   "causes": [  
34     "Safe_distance_from_nearby_vehicles",  
35     "Vehicle_speed_is_low_enough_to_maintain_traction",  
36     "Steering_input_applied_to_turn_left",  
37     "No_excessive_lateral_acceleration",  
38     "Sufficient_friction_between_tires_and_road",  
39     "Driver_maintains_vehicle_control",  
40     "No_obstacles_blocking_the_left_turn",  
41     "Vehicle_not_in_violation_of_legal_rules_for_turning"  
42   ]  
43 }}  
44  
45 IMPORTANT: Output_must_be_strictly_JSON, without_any_markdown, backticks, or explanations.  
46'''
```

Listing 3: Decompose Effect Prompt

```

1 SEMANTIC_CONSOLIDATE_PROMPT='''  

2 You are given a list of causes from a driving situation.  

3 Some of these causes are repeated or very similar.  

4  

5 Input:  

6 {causes}  

7  

8 Instructions for deduplication:  

9 - Only merge causes if they truly convey the exact same information.  

10 - Preserve distinct types of reasoning, such as:  

11   - Legal rules (speed limits, permissions)  

12   - Safety requirements (reaction time, stopping distance)  

13   - Physics constraints (friction, braking distance)  

14 - Retain both legal and safety aspects even if they overlap conceptually.  

15 - Each cause must remain logically meaningful and actionable.  

16  

17  

18 The JSON output must follow this exact schema:  

19  

20 {{  

21   "unique_causes": [  

22     "unique_cause_1",  

23     "unique_cause_2",  

24     ...  

25   ]  

26 }}  

27  

28  

29 Example:  

30 Input:  

31 {{  

32   "causes": [  

33     "Road must be free of debris, hazards, and obstacles",  

34     "Road conditions must be dry and clear",  

35     "Road is not under construction or repair",  

36     "Speed must be within threshold"  

37   ]  

38 }}  

39  

40 Output:  

41 {{  

42   "unique_causes": [  

43     "Road conditions must be dry and clear, free from debris, hazards, obstacles,  

        or construction/repair activities.",  

44     "Speed must be within threshold"  

45   ]  

46 }}  

47  

48 IMPORTANT: Output must be strictly JSON, without any markdown, backticks, or  

  explanations.  

49 '''

```

Listing 4: Semantic Consolidate Prompt

```

1 CHECK_NECESSITY_PROMPT = '''  

2 You are an expert in causal reasoning for Autonomous Vehicle (AV) systems.  

3 '''

```

```

4 You are given:
5 1. A main effect.
6 2. A list of causes.
7 3. A set of legal laws.
8 4. A set of safety laws.
9
10
11 effect:{effect}
12 causes:{causes}
13 legal_laws:{legal_laws}
14 safety_laws:{safety_laws}
15
16 CRITICAL_REASONING_RULES:
17
18 INDEPENDENT_NECESSITY_TEST:
19 - Evaluate EACH cause independently.
20 - When evaluating one cause, assume ONLY that this cause is FALSE.
21 - Do NOT assume any other listed causes are present or absent.
22 - Do NOT assume hidden conditions.
23 - Only rely on the provided legal and safety laws.
24
25 DEFINITION:
26 - A cause is "necessary" if the effect is logically impossible under the provided
   laws when this cause is false.
27 - A cause is "not necessary" if there exists at least one logically possible
   situation, consistent with the laws, where the effect occurs while this
   cause is false.
28
29 IMPORTANT:
30 - Do NOT assume substitution by other listed causes.
31 - Do NOT assume background facts not stated in the laws.
32 - Do NOT evaluate optimality or quality.
33 - Safety laws must be fully satisfied.
34 - Your reasoning must strictly follow the provided laws.
35
36 Instructions:
37 - Evaluate each cause independently.
38 - Determine whether the effect could legally and safely occur if this cause were
   false.
39 - Provide reasoning grounded only in the provided legal and safety laws.
40
41 Output JSON format:
42
43 {{{
44   "evaluations": [
45     {
46       "cause": "exact cause text",
47       "result": "necessary" or "not necessary",
48       "reason": "clear explanation, strictly using legal and safety laws why this
49         cause is or is not required for the effect"
50     }
51   ]
52 }
53
54 Example:
55

```

```

56 effect: "Turn_left_while_maintaining_low_speed.
57 causes:
58 [
59     "Safe_distance_from_nearby_vehicles",
60     "Vehicle_speed_is_low_enough_to_maintain_traction",
61     "Steering_input_applied_to_turn_left",
62     "No_excessive_lateral_acceleration",
63     "Sufficient_friction_between_tires_and_road",
64     "Driver_maintains_vehicle_control",
65     "No_obstacles_blocking_the_left_turn",
66     "Vehicle_not_inViolation_of_legal_rules_for_turning"
67 ]
68
69
70 Output:
71 {{{
72     "evaluations": [
73         {{{
74             "cause": "Safe_distance_from_nearby_vehicles",
75             "result": "not_necessary",
76             "reason": "Maintaining_low-speed_left_turn_is_physically_possible_without_considering_other_vehicles; safe_distance_affects_safety_but_is_not_strictly_required_for_the_turn_to_occur_according_to_laws."
77         }}, {
78             {{{
79                 "cause": "Vehicle_speed_is_low_enough_to_maintain_traction",
80                 "result": "necessary",
81                 "reason": "Low_speed_is_required_by_friction_and_vehicle_control_laws; without_it, the_effect_violates_safety_laws."
82             }}}, ...
83         ]}},
84     }{{
85     }}}
86
87 IMPORTANT: Output must be strictly valid JSON without markdown or explanations.
88 '''

```

Listing 5: Check Individual Necessity Prompt

```

1 NECESSITY_SET_PROMPT = '''
2 You_are_an_expert_in_causal_verification_for_an_Autonomous_Vehicle_(AV)_system.
3 You_must_strictly_rely_on_legal_laws_and_safety_laws.
4
5 CRITICAL_RULE:
6 You_are_NOT_deciding_how_to_achieve_the_effect.
7 You_are_verifying_whether_the_effect_could_have_already_happened_under_the_given_conditions.
8
9 CLOSED_WORLD_RULE:
10 Any_cause_not_explicitly_listed_as_present_must_be_treated_as_false.
11 No_additional_facts_exist_beyond_those_provided.
12
13 The_effect_is_a_factual_event_that_already_occurred.
14 You_must_check_whether_this_event_is_logically_possible_given_the_causes.
15
16 You_are_NOT_allowed_to:
17 - Reinterpret_the_effect

```

```

18 -_Simplify_the_effect
19 -_Assume_missing_causes
20 -_Add_hidden_assumptions
21 -_Change_the_meaning_of_the_effect
22
23 Definitions:
24
25 1._Present_causes:
26 These_causes_are_fully_true_and_hold_in_the_scenario.
27
28 2._Absent_cause:
29 This_cause_is_definitively_false.
30 It_did_NOT_occur_and_CANNOT_contribute_in_any_way.
31
32 3._Necessity_test:
33 Assume:
34 -_All_present_causes_are_true
35 -_The_absent_cause_is_false
36 -_Check_if_the_effect_could_still_have_happened.
37 -_If_the_effect_can_not_happen_without_the_absent_cause, then_the_absent_cause_is_necessary.
38
39 Instructions:
40
41 -_Treat_the_effect_as_an_event_that_already_happened.
42 -_Treat_the_absent_cause_as_completely_false.
43 -_Do_NOT_reinterpret_the_effect.
44 -_Do_NOT_assume_additional_causes.
45 -_Decide_if_this_event_is_safely_and_legally_possible.
46 -_Answer_yes_if_the_event_is_still_possible.
47 -_Answer_no_if_the_event_is_impossible_without_the_absent_cause.
48 -_Your_reasoning_must_be_strictly_groundedin_the_provided_legal_and_safety_laws.
49 -_For_necessary_causes, indicate:
50   uuuu~"necessary" if the_effect_would_be_impossible_without_it_due_to_a_law,
51   uuuu~"not_necessary" if the_effect_can_still_occur_without_violating_any_law.
52 -_Provide_a_precise_explanation_citing_legal_as_well_safety_aspect_of_laws_that_determine_the_necessity.
53
54 You_are_given:
55
56 Effect:
57 {effect}
58
59 Causes_that_are_present:
60 {causes}
61
62 Cause_that_is_explicitly_NOT_present_(false):
63 {absent_cause}
64
65 Legal_laws:
66 {legal_laws}
67
68 Safety_laws:
69 {safety_laws}
70
71 Output_strictly_in_JSON:
72

```

```

73    {{
74        "result": "yes" or "no",
75        "reason": <reason>
76    }}
77
78    IMPORTANT: Output must be strictly JSON, without any markdown, backticks, or
79            explanations.
80    ...

```

Listing 6: Necessary Set Prompt

```

1 SUFFICIENCY_SET_PROMPT=''''
2 You are an expert in causal verification for an Autonomous Vehicle (AV) system.
3 You must strictly rely on legal laws and safety laws.
4
5 CRITICAL RULE:
6 You are NOT deciding how to achieve the effect.
7 You are verifying whether the effect could have already happened under the given
     conditions.
8
9 Instructions:
10
11 - Treat the effect as an event whose logical occurrence must be evaluated.
12 - Treat all present causes as fully true.
13 - Treat all absent causes as completely false.
14 - CLOSED-WORLD RULE: Any cause not explicitly listed as present must be treated
     as false. No additional conditions exist.
15 - Do NOT reinterpret the effect.
16 - Do NOT simplify the effect.
17 - Do NOT assume additional causes.
18 - Do NOT rely on background knowledge beyond the provided legal and safety laws.
19 - Determine whether the present causes logically guarantee the effect under the
     legal and safety laws.
20 - The effect must occur in all logically possible interpretations consistent with
     the provided laws and the given causes.
21 - If there exists any logically possible situation under these constraints where
     the effect does not occur, then the causes are not sufficient.
22 - Answer "yes" only if the effect is logically entailed by the present causes.
23 - Answer "no" if the effect is not logically guaranteed.
24 - For sufficient causes, indicate:
25     - "sufficient" if the present causes logically guarantee the effect,
26     - "not sufficient" if they do not logically guarantee the effect.
27 - Provide a precise explanation grounded strictly in the provided legal and
     safety laws that determine the sufficiency.
28
29 You are given:
30
31 Effect:
32 {effect}
33
34 Causes that are absent that are explicitly NOT present (false):
35 {causes}
36
37 Causes that are present:
38 {present causes}
39

```

```

40 Legal_laws:
41 {legal_laws}
42
43 Safety_laws:
44 {safety_laws}
45
46
47 Output_striktly_in_JSON:
48
49 {{{
50   "result": "yes" or "no",
51   "reason": <reason>
52 }}}
53
54 IMPORTANT: Output must be striktly JSON, without any markdown, backticks, or explanations.
55 ...

```

Listing 7: Sufficient Set Prompt

```

1 CONVERT_TO_SYMBOLIC_RULE_PROMPT=''''
2 You are an expert in converting a condition into a symbolic rule.
3 You are given a single condition in a logical format of if and else) as an input.
4 Your task is to produce a symbolic rule for the condition.
5 You must follow the grammar provided you below
6
7 Input:
8 {condition}
9
10 Instructions:
11 - Use the grammar provided below.
12 - *Do not* make up grammar by yourself.
13 - Use only the allowed predicates and operators. Map each natural language clause
    to meaningful predicates rather than inventing new ones
14 - Before giving the final output break the condition into sub-conditions (
    intermediate logical steps), then map each step to a symbolic rule
15 - For each condition, think about what safety outcome or system effect it is
    describing. Then map it to the symbolic predicates and allowed logical
    operators.
16 - Do not create rules that are logically impossible (e.g., a vehicle being both
    left and right of another at the same time) or that contradict safety logic.
17 - For conditions involving driver perception, vehicle control, or environment, or
    make sure the symbolic rule reflects the resulting safety outcome (collision
    avoidance, safe stopping, emergency brake)
18
19 Allowed_Predicates_and_their_explanations:
20 - dense(i) - i is closer than rdense(a, distance threshold for crowdedness) to
    Ndense(a, number of nearby vehicles that counts as dense) or more agents
21 - pred(i, j) - i is the predecessor of j
22 - right(i, j) - i is to the right of j
23 - left(i, j) - i is to the left of j
24 - in-front(i, j) - i is in front of j
25 - behind(i, j) - i is behind j
26 - merged(i) - i has passed a static merging point, from which on a merge is not
    possible anymore
27 - sd-front(i) - i has a safe distance to the preceding vehicle
28 - sd-rear(i) - i has a safe distance to the following vehicle

```

```

29  -collide(i) - i is colliding with road boundaries or any other agent or obstacle
30  -lane-change(i) - i is crossing a lane boundary
31  -near(i,j) - i is closer than dnear to j
32  -lane-end(i) - i has less than srem remaining to the end of the lane
33  -acc(i) - i accelerates with a > alim
34  -speed-adv(i,j) - i is faster than j and some threshold vdiff
35  -built-up(i) - i is within a built-up area
36  -motorway(i) - i is on a road type: motorway
37  -div-lane(i) - i is on a lane type: diverging lane
38  -acc-lane(i) - i is on a lane type: acceleration lane
39  - speed (i) - speed of i
40  - friction (i) - friction of i
41  -collision(i) - collision of i
42  -EB(i) - i has applied emergency break
43
44 Allowed_rule_forms ONLY:
45 1. Universal_constraint: x ( condition & condition )
46 2. Implication: x ( conclusion & condition )
47 3. Probabilistic_rule: x( event(x), p%)
48 4. Conditional_probabilistic_rule: x, v ( event(x), p% ) & condition involving v
49
50 Allowed_comparisons:
51 1. > greater than
52 2. < lesser than
53 3. = equals to
54 4. >= greater than equals to
55 5. <= lesser than equals to
56
57 Allowed_logical_operators:
58 1. Negation
59 2. Conjunction
60 3. Implication
61
62 Example:
63 {{{
64     "condition": "Stopping distance is within vehicle's braking capability",
65     "rule": " x (EB(x) & sd-front(x) & friction (x) > 0)",
66     "thinking": "Stopping distance is within vehicles braking capability is not
67                 only about distance.
68                 It is fundamentally about whether the brakes can generate enough deceleration
69                 to stop the car before the obstacle.
70                 For which there should be enough distance with car in front and friction as
71                 non zero"
72 }}}
73
74 Output_should_be_in_this_format_(strict_JSON_only):
75 {{{
76     "condition": "logical condition 1",
77     "rule": "symbolic rule 1",
78     "thinking": "thought process"
79 }}}
79 IMPORTANT: Output must be strictly JSON, without any markdown, backticks, or
            explanations.
    ...

```

Listing 8: Convert to Symbolic Rule Prompt