

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_that_allows_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     "Vehicle_is_traveling_at_a_speed_that_allows_for_safe_merging_and_adheres_to_traffic_laws_regarding_merging.",
19     "Sufficient_distance_from_other_vehicles_to_merge_safely_and_no_vehicles_are_overtaking_on_the_right.",
20     "Traffic_conditions_allow_for_merging_without_impeding_flow_and_no_sudden_obstacles_in_the_merging_path."
21 ]
22
23 Symbolic Translation
24 "rules": [
25     {
26         "cause": "Driver maintains control of the vehicle
27         "rule":    x ( collide (x)    sd-front(x)    sd-rear(x)    lane -change(x)
28     )
29     "thinking": "Maintaining control of the vehicle involves ensuring that
30     there is a safe distance to both the preceding and following vehicles, as
31     well as avoiding lane changes that could lead to instability. If these
32     conditions are met, the vehicle is less likely to collide with obstacles or
33     other agents."
34     }
35     {
36         "cause": "Vehicle is traveling at a speed that allows for safe merging",
37         "rule":  " x (sd-front(x)    _sd-rear(x)    _speed-adv(x,y)    _speed (x)>_
38         vthreshold)",
39         "thinking": "For a vehicle to merge safely, it must maintain a safe
40         distance from both the preceding and following vehicles, ensuring that it is
41         not too close to either. Additionally, the vehicle's speed must be greater
42         than a certain threshold relative to the speed of other vehicles to
43         facilitate a safe merge."
44     }
45     {
46         "cause": "Sufficient distance from other vehicles to merge safely",
47         "rule":  " x (sd-front(x)    _sd-rear(x)    _dense (x))",
48         "thinking": "To merge safely, a vehicle must have a safe distance to both
49         the preceding and following vehicles. This ensures that there is enough
50         space to maneuver without the risk of collision, which is further supported
51         by the absence of dense traffic around the vehicle."

```

```

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 Initial Individual Evaluations:
68 "evaluations": [
69     {
70         "cause": "Driver maintains control of the vehicle and is aware of
surrounding traffic.",
71         "result": "necessary",
72         "reason": "Without the driver maintaining control, the vehicle cannot
safely merge into heavy traffic, violating safety laws regarding vehicle
control and potential collisions."
73     }

```

```

74     },
75     {
76         "cause": "Vehicle is traveling at a speed that allows for safe merging and
adheres to traffic laws regarding merging.",
77         "result": "necessary",
78         "reason": "Traveling at an appropriate speed is essential for safe merging;
if the vehicle is not at a safe speed, it may violate legal laws regarding
speed and control, leading to unsafe conditions."
79     },
80     {
81         "cause": "Sufficient distance from other vehicles to merge safely and no
vehicles are overtaking on the right.",
82         "result": "not necessary",
83         "reason": "It is possible to merge into heavy traffic even if there is
insufficient distance from other vehicles, as long as the vehicle adheres to
speed and control laws; thus, this cause is not strictly required."
84     },
85     {
86         "cause": "Traffic conditions allow for merging without impeding flow and no
sudden obstacles in the merging path.",
87         "result": "not necessary",
88         "reason": "Merging can occur even if traffic conditions are not ideal,
provided that the vehicle maintains control and adheres to speed laws; thus,
this cause is not strictly necessary for the effect."
89     }
90 ]
91
92 Necessary Sets:
93
94 Necessary Set 1: Driver maintains control of the vehicle and is aware of
surrounding traffic.
95 Necessary Set 2: Vehicle is traveling at a speed that allows for safe merging and
adheres to traffic laws regarding merging.
96 Necessary Set 3: Sufficient distance from other vehicles to merge safely and no
vehicles are overtaking on the right.
97 Necessary Set 4: Traffic conditions allow for merging without impeding flow and
no sudden obstacles in the merging path.
98
99
100 Sufficient Sets:
101
102 Sufficient Set 1:
103 - Driver maintains control of the vehicle and is aware of surrounding traffic.
104 - Vehicle is traveling at a speed that allows for safe merging and adheres to
traffic laws regarding merging.
105 - Sufficient distance from other vehicles to merge safely and no vehicles are
overtaking on the right.
106 - Traffic conditions allow for merging without impeding flow and no sudden
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
26 Symbolic Translation
27 "rules": [
28     {
29         "cause": "Driver_maintains_vehicle_control_and_is_attentive_and_
30         responsive_to_road_conditions.",
31         "rule": "x ( collide (x) _ _sd-front(x) _ _sd-rear(x) _ _ lane -change(x))"
32     },
33     {
34         "cause": "Vehicle_speed_is_within_legal_limits_and_above_minimum_required
35         speed.",
36         "rule": "x ( speed (x) _ _legal_limit _ _ speed (x) > _
37         minimum_required_speed)",
38         "thinking": "The_vehicle_must_operate_below_the_legal_maximum_speed_while
39         _remaining_above_the_minimum_threshold_required_for_stable_traffic_flow._
40         Staying_within_this_interval_ensures_both_regulatory_compliance_and_safe_
41         dynamic_behavior."
42     },
43     {
44         "cause": "Sufficient_friction_between_tires_and_road.",
45         "rule": "x ( friction (x) > 0)",
46         "thinking": "Adequate_friction_between_the_tires_and_the_road_surface_
47         ensures_controllability_during_acceleration,_braking,_and_steering._Positive
48         _friction_is_a_prerequisite_for_maintaining_stability_and_preventing_
49         skidding."
50     },
51     {
52

```

```

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

```

```

84     "result": "not_necessary",
85     "reason": "The_vehicle_can_still_maintain_a_constant_speed_despite_sudden_
changes_in_traffic_conditions_if_the_driver_is_attentive_and_responsive,_
which_is_covered_by_other_causes."
86 },
87 {
88     "cause": "No_emergency_situations_requiring_sudden_braking.",
89     "result": "not_necessary",
90     "reason": "The_vehicle_can_maintain_a_constant_speed_even_if_an_emergency_
situation_arises,_provided_the_driver_is_able_to_manage_the_situation_
without_braking_suddenly,_which_is_covered_by_other_causes."
91 }
92 ]
93
94 Necessary Sets:
95
96 Necessary Set 1: Driver maintains vehicle control and is attentive and responsive
to road conditions.
97 Necessary Set 2: Vehicle speed is within legal limits and above minimum required
speed.
98 Necessary Set 3: Sufficient friction between tires and road.
99
100 Sufficient Sets:
101
102 Sufficient Set 1:
103     - Driver maintains vehicle control and is attentive and responsive to road
conditions.
104     - Vehicle speed is within legal limits and above minimum required speed.
105     - Sufficient friction between tires and road.
106     - No obstacles on the highway segment.
107
108 Sufficient Set 2:
109     - Driver maintains vehicle control and is attentive and responsive to road
conditions.
110     - Vehicle speed is within legal limits and above minimum required speed.
111     - Sufficient friction between tires and road.
112     - 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 effect" causes. 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 maintaing 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,
44       or construction/repair activities.",
45     "Speed must be within threshold"
46   ]
47 }}
48
49 IMPORTANT: Output must be strictly JSON, without any markdown, backticks, or
    explanations.
    '''

```

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
42 Output JSON format:
43
44 {{
45   "evaluations": [
46     {{
47       "cause": "exact cause text",
48       "result": "necessary" or "not necessary",
49       "reason": "clear explanation, strictly using legal and safety laws why this
        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_in_violation_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
40 Instructions:
41
42 -_Treat_the_effect_as_an_event_that_already_happened.
43 -_Treat_the_absent_cause_as_completely_false.
44 -_Do_NOT_reinterpret_the_effect.
45 -_Do_NOT_assume_additional_causes.
46 -_Decide_if_this_event_is_safely_and_legally_possible.
47 -_Answer_"yes"_if_the_event_is_still_possible.
48 -_Answer_"no"_if_the_event_is_impossible_without_the_absent_cause.
49 -_Your_reasoning_must_be_strictly_grounded_in_the_provided_legal_and_safety_laws.
50 -_For_necessary_causes,_indicate:
51     _"necessary"_if_the_effect_would_be_impossible_without_it_due_to_aLaw,
52     _"not_necessary"_if_the_effect_can_still_occur_without_violating_anyLaw.
53 -_Provide_a_precise_explanation_citing_legal_as_well_safety_aspect_of_Laws_that
   _determine_the_necessity.
54
55 You_are_given:
56
57 Effect:
58 {effect}
59
60 Causes_that_are_present:
61 {causes}
62
63 Cause_that_is_explicitly_NOT_present(false):
64 {absent_cause}
65
66 Legal_laws:
67 {legal_laws}
68
69 Safety_laws:
70 {safety_laws}
71
72 Output_strictly_in_JSON:

```

```

73  {{
74  {{
75  _"result":_"yes"_"or_"no",
76  _"reason":_<reason>
77  }}
78
79  IMPORTANT:_Output_must_be_strictly_JSON,_without_any_markdown,_backticks,_or_
      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_strictly_in_JSON:
48
49 {{
50   "result": "yes" or "no",
51   "reason": <reason>
52 }}
53
54 IMPORTANT: Output must be strictly JSON, without any markdown, backticks, or
55   explanations.
56 ''

```

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 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
14   to meaningful predicates rather than inventing new ones
15 - Before giving the final output, break the condition into sub-conditions (
16   intermediate logical steps), then map each step to a symbolic rule
17 - For each condition, think about what safety outcome or system effect it is
18   describing. Then map it to the symbolic predicates and allowed logical
19   operators.
20 - Do not create rules that are logically impossible (e.g., a vehicle being both
21   left and right of another at the same time) or that contradict safety logic.
22 - For conditions involving driver perception, vehicle control, or environment,
23   make sure the symbolic rule reflects the resulting safety outcome (collision
24   avoidance, safe stopping, emergency brake)
25
26 Allowed Predicates and their explanations:
27 - dense(i) - i is closer than rdense(a distance threshold for crowdedness) to
28   Ndense(a number of nearby vehicles that counts as dense) or more agents
29 - pred(i,j) - i is the predecessor of j
30 - right(i,j) - i is to the right of j
31 - left(i,j) - i is to the left of j
32 - in-front(i,j) - i is in front of j
33 - behind(i,j) - i is behind j
34 - merged(i) - i has passed a static merging point, from which on a merge is not
35   possible anymore
36 - sd-front(i) - i has a safe distance to the preceding vehicle
37 - 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 d near 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
        only about distance.
        It is fundamentally about whether the brakes can generate enough deceleration
        to stop the car before the obstacle.
        For which there should be enough distance with car in front and friction as
        non zero"
67 }}
68
69 }}
70
71
72 Output should be in this format (strict JSON only):
73 {{
74     "condition": "logical condition 1",
75     "rule": "symbolic rule 1",
76     "thinking": "thought process"
77 }}
78 IMPORTANT: Output must be strictly JSON, without any markdown, backticks, or
    explanations.
79 '''

```

Listing 8: Convert to Symbolic Rule Prompt