ACAV: A Framework for Automatic Causality Analysis in Autonomous Vehicle Accident Recordings

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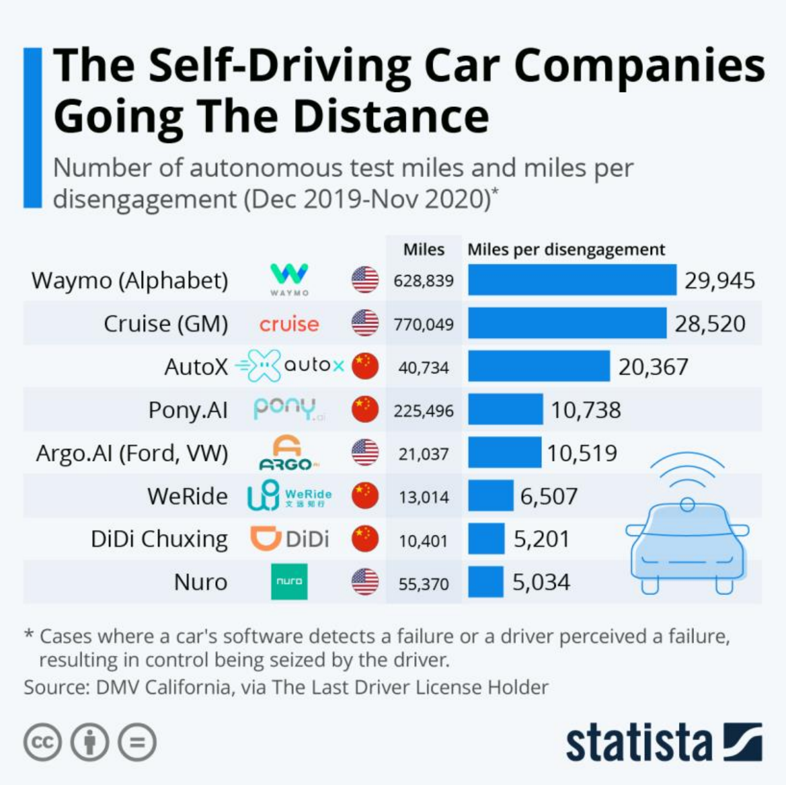
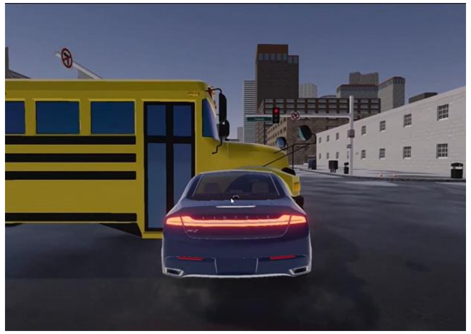
Autonomous Vehicle (AV)

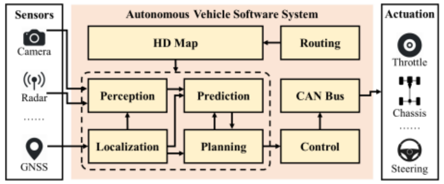


https://www.statista.com/chart/17144/test-miles-and-reportable-miles-per-disengagement/

Causality Analysis of AV Accidents



Autonomous Driving Crashes



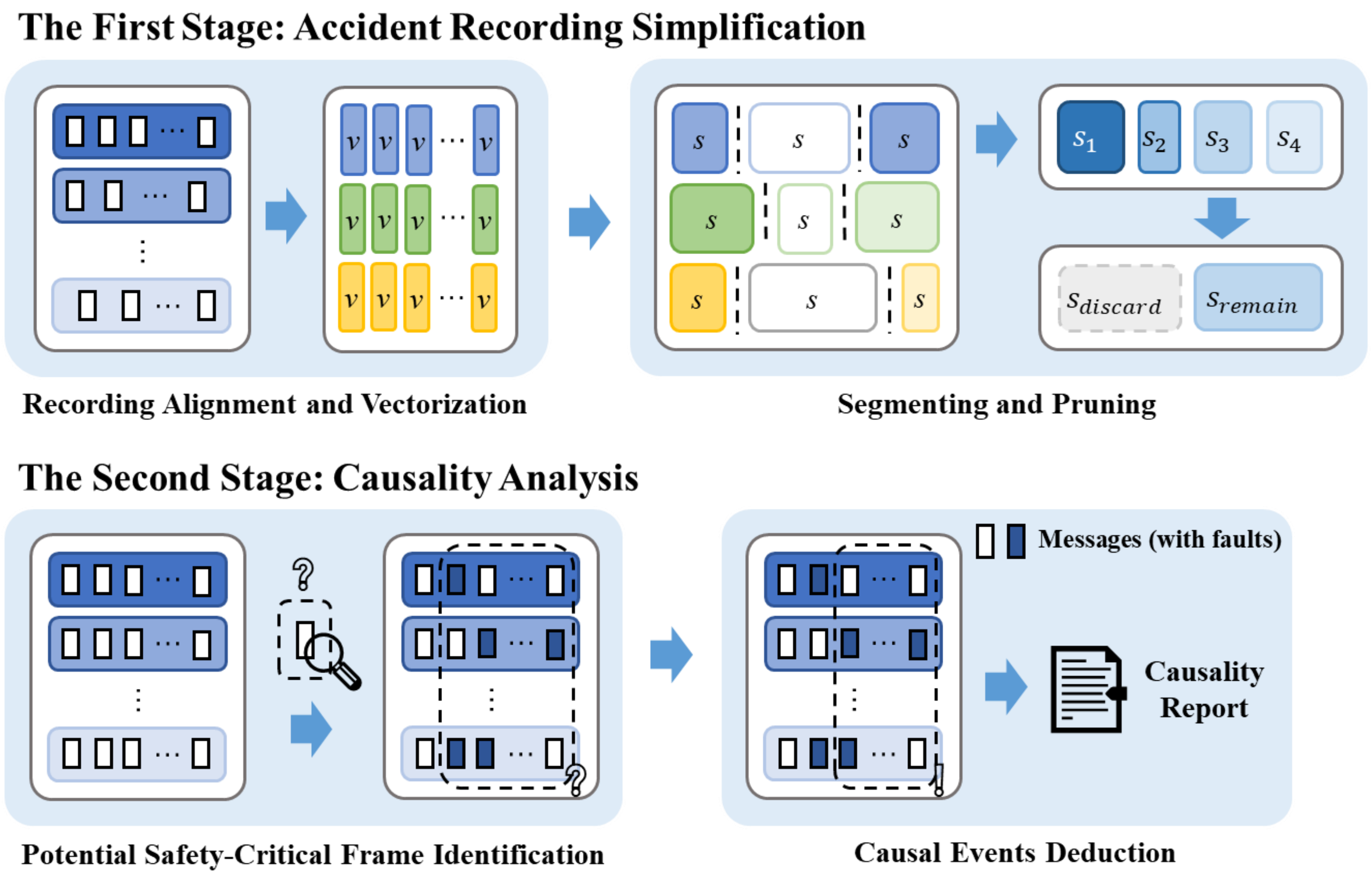
Use a recorder to obtain recordings

Vast amounts of driving recordings

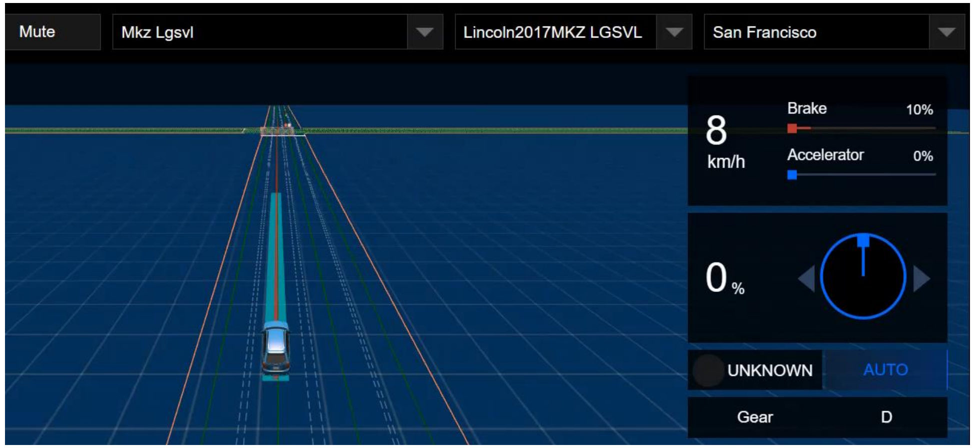
Causality Reports Of Accident

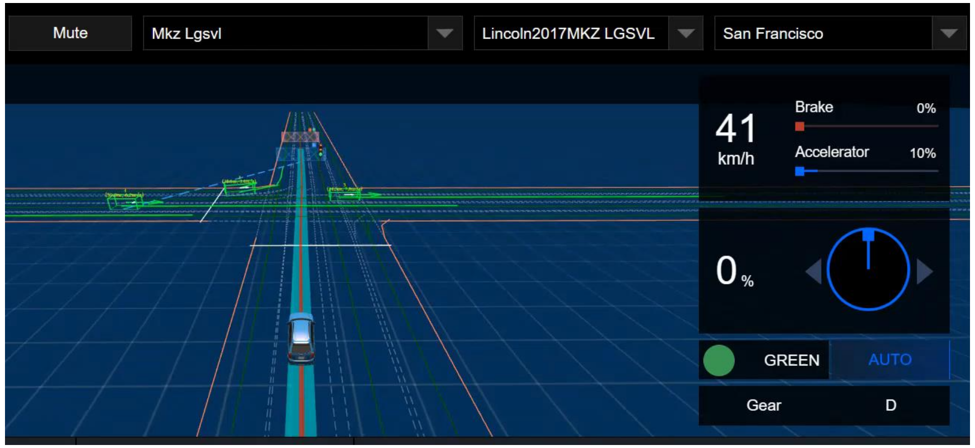
Data Labeling & Explanation

Overview of ACAV



Motivating Example

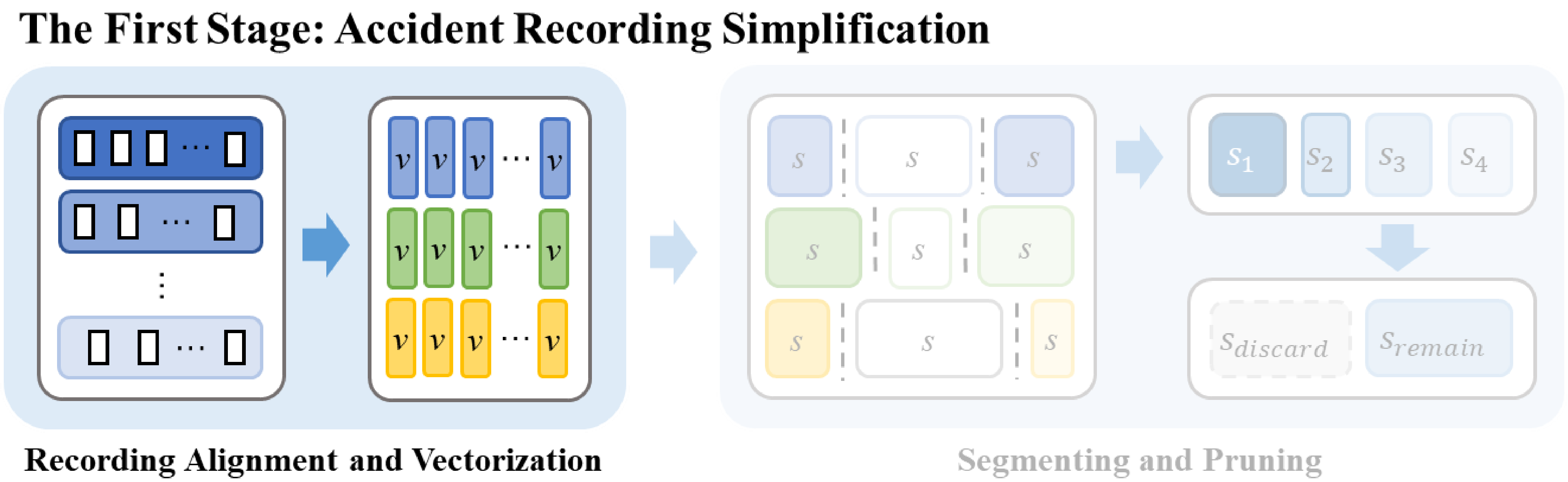




Time	Accident causal events	Details
0s	AV keeps safe distance from NPCs	--
0.4s	**Wrong motion planning**; AV **skidding** sometimes	Too fast or too slow **planning speed**
0.8s	**Wrong planning** caused by the wrong prediction; AV **skidding** sometimes	**For NPC 2**: wrong priority prediction; **For NPC 4**: improper ‘overtake’ decision; Too fast or too slow **planning speed**
2.6s	**Wrong motion planning**; AV **skidding** sometimes	Too fast or too slow **planning speed**
4.3s	Accident!	

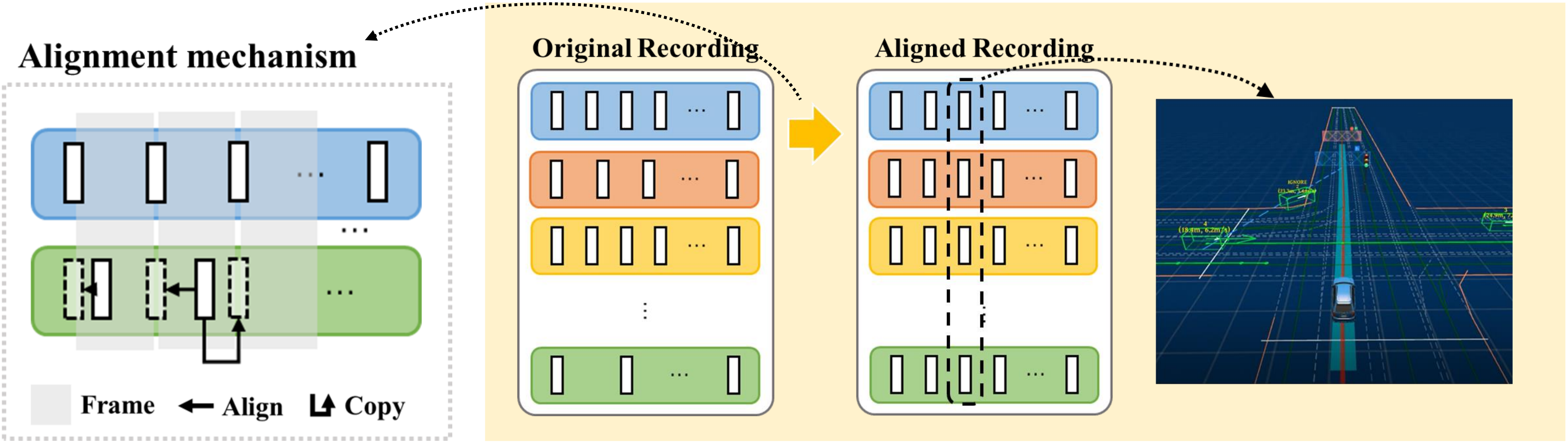
ACAV https://acav2023.github.io/merging1.html

ACAV Framework: Stage #1



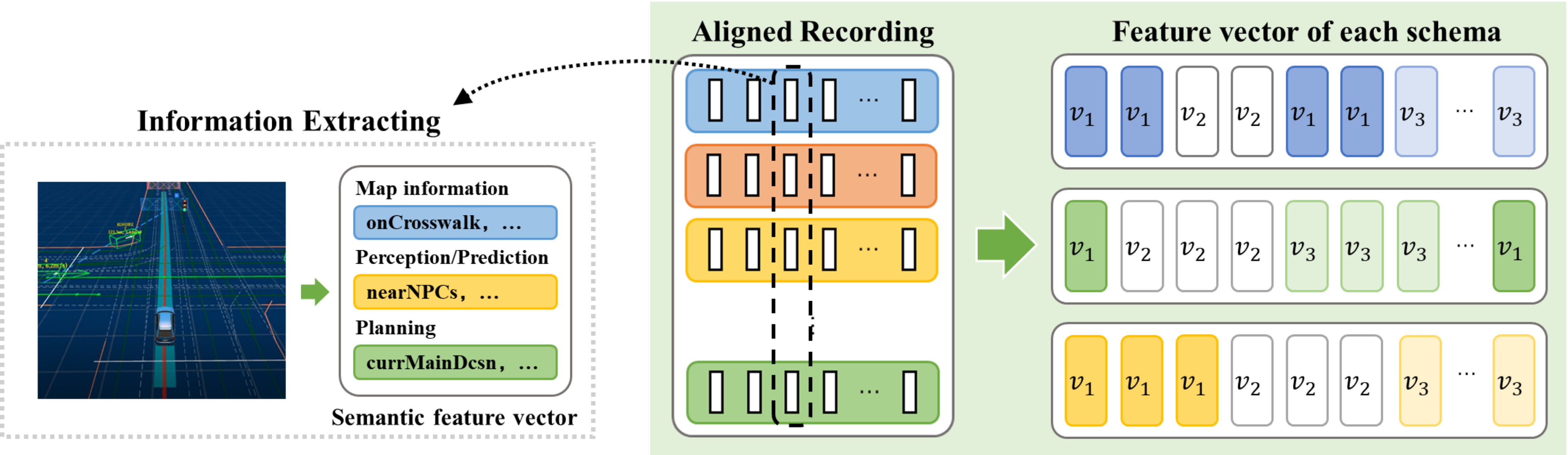
Stage #1: Alignment and Vectorization

- Consider five channels: map, localization, perception, prediction, planning.
- Divide the recording into a list of frames.

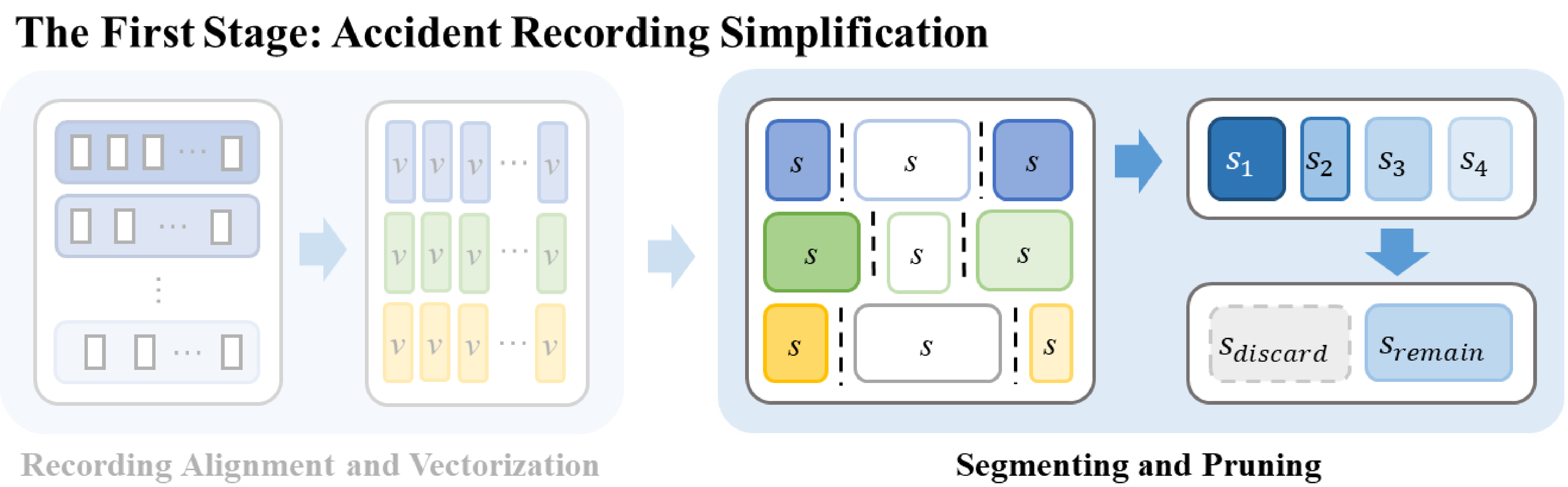


Stage #1: Alignment and Vectorization

- Extract semantic information according to three feature extraction schemas.



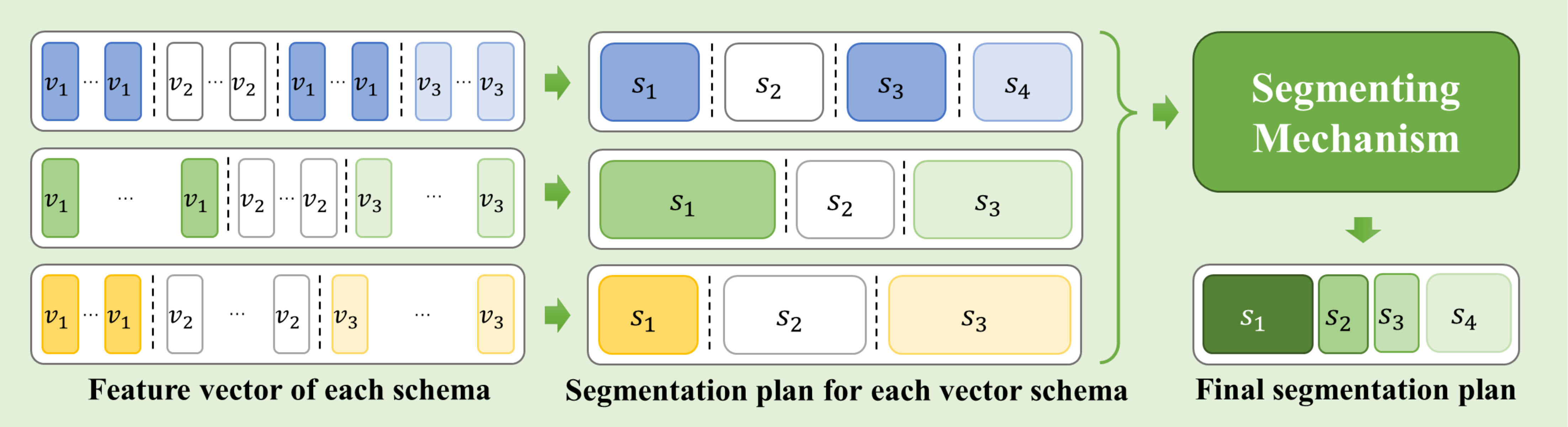
ACAV Framework: Stage #1



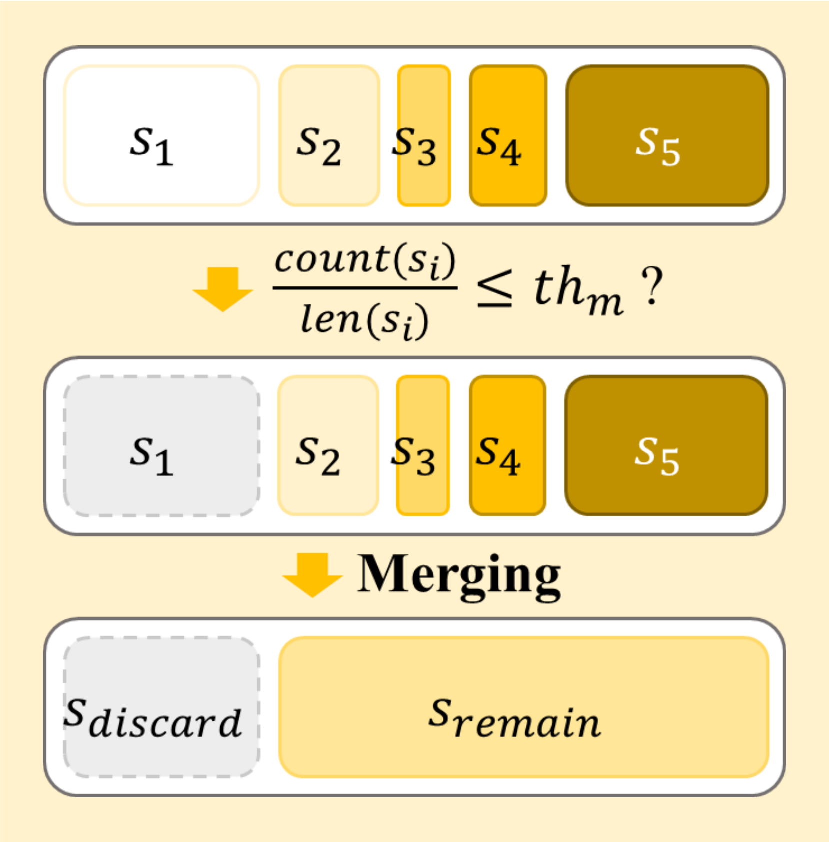
Stage #1: Segmenting and Pruning

- Segmenting Mechanism:

$$voting(v_{map}, v_{perc}, v_{pred}) \coloneqq \sum_{c \in C} w_c \times v_c \geq \frac{1}{2} \sum_{c \in C} w_c \,, \qquad C = \{map, perc, pred\}$$



Stage #1: Segmenting and Pruning



Irrelevant Frame:

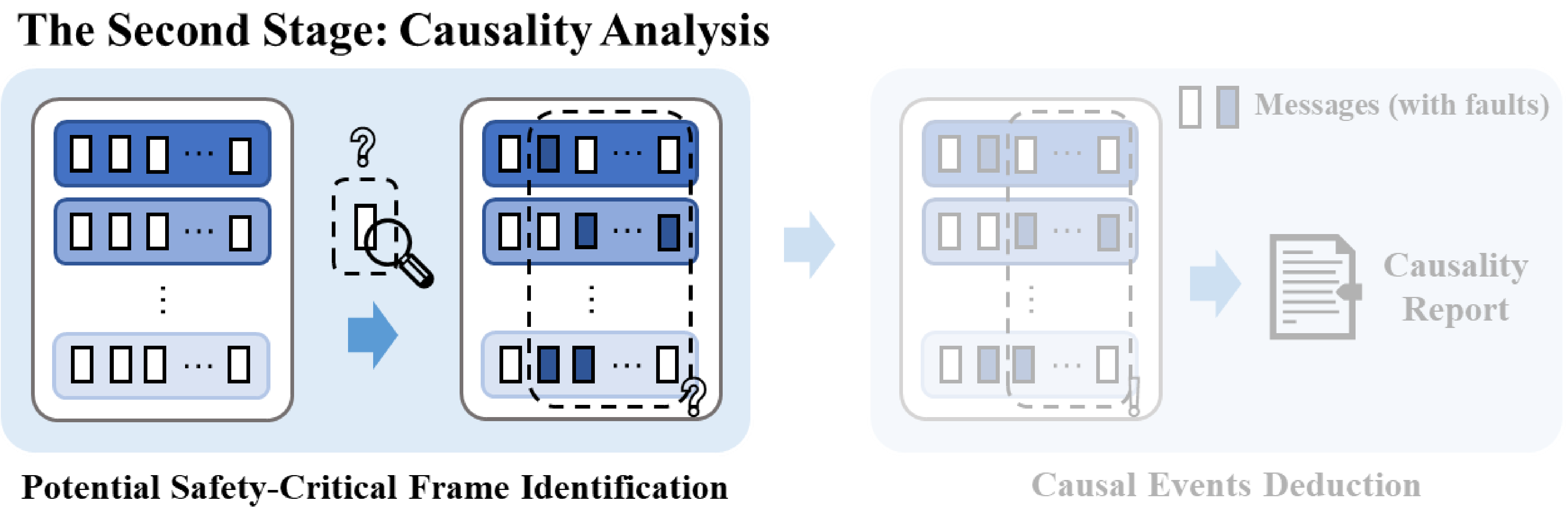
- Road Area
- Not near a stop sign
- No NPCs

Relevant Frame:

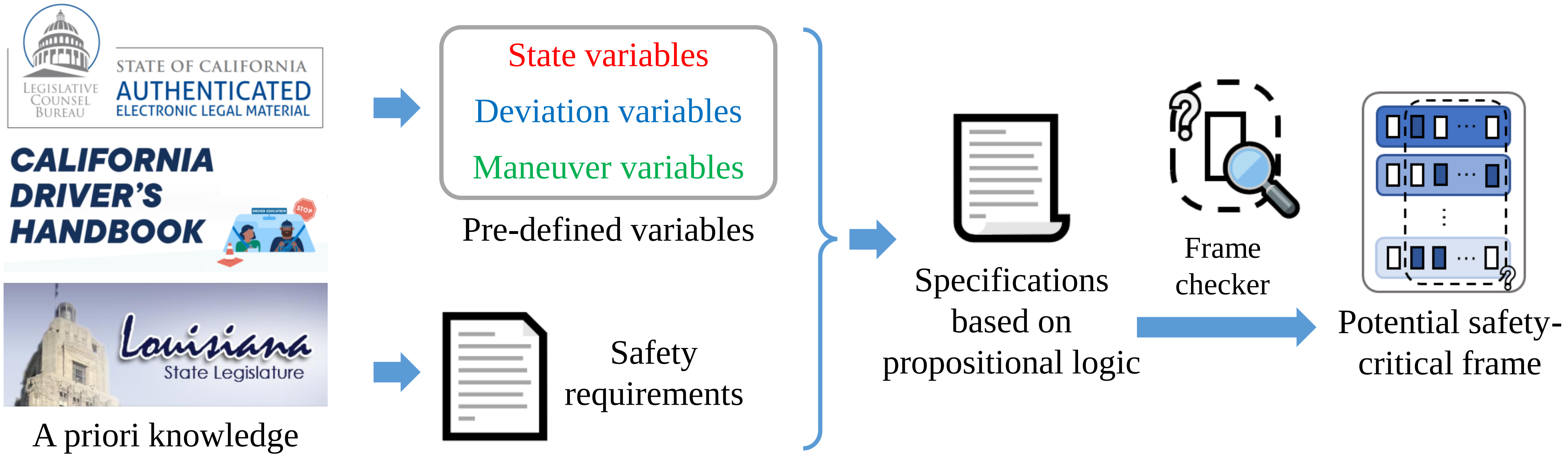
- Junction/Crosswalk area
- Near NPCs
- Interact with NPCs

$count(S)$: compute the irrelevant frame ratio for a segment S

ACAV Framework: Stage #2



Stage #2: Potential Frame Identification



Stage #2: Potential Frame Identification

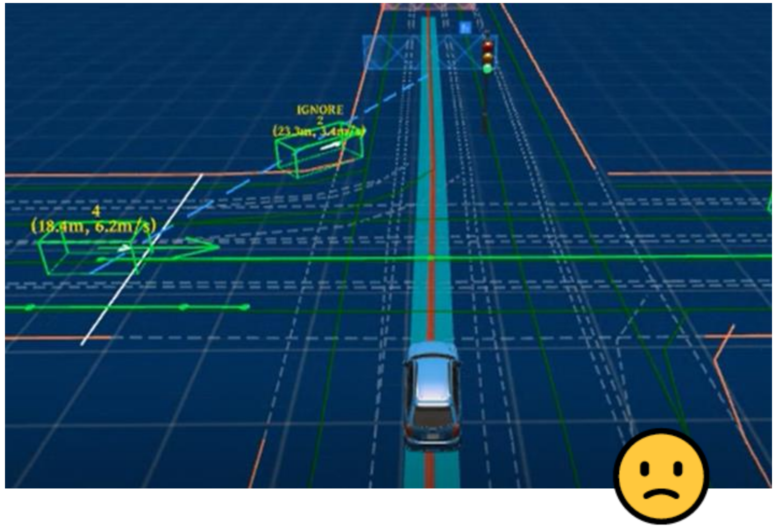
- Example

Navigating the Roads (*Section 9, Navigating the Roads, California Driver's Handbook*):

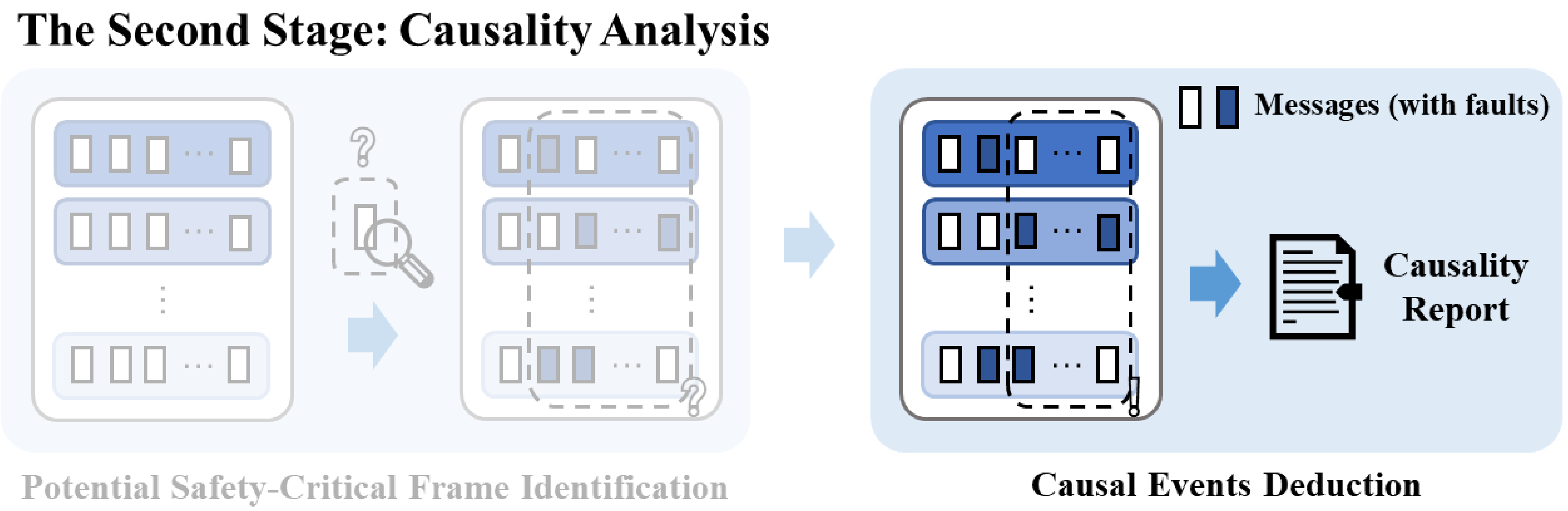
Before you pass, look ahead for road conditions and traffic that could cause other vehicles to move into your lane. Only pass when it is safe. Do not pass:

- Within 100 feet of or in an intersection, bridge, tunnel, railroad crossing, or other hazardous area.
- At crossroads and driveways.

$$ImpropOvtkDecn(x) :=$$
$$(av.onJct \lor av.OnCswk) \land DecnOvtk(x)$$

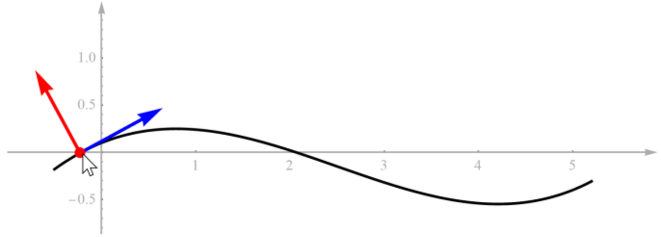


ACAV Framework: Stage #2

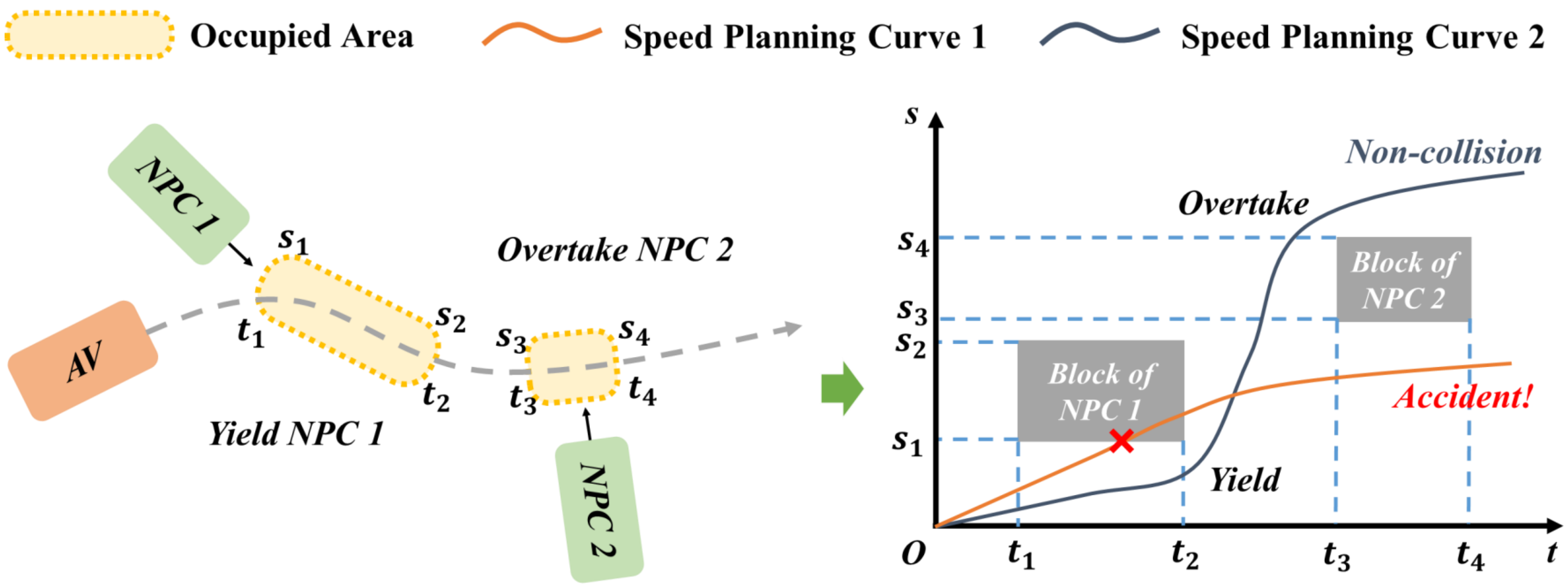


Stage #2: Causal Events Deduction

For a vehicle: motions = longitudinal motions + lateral motions



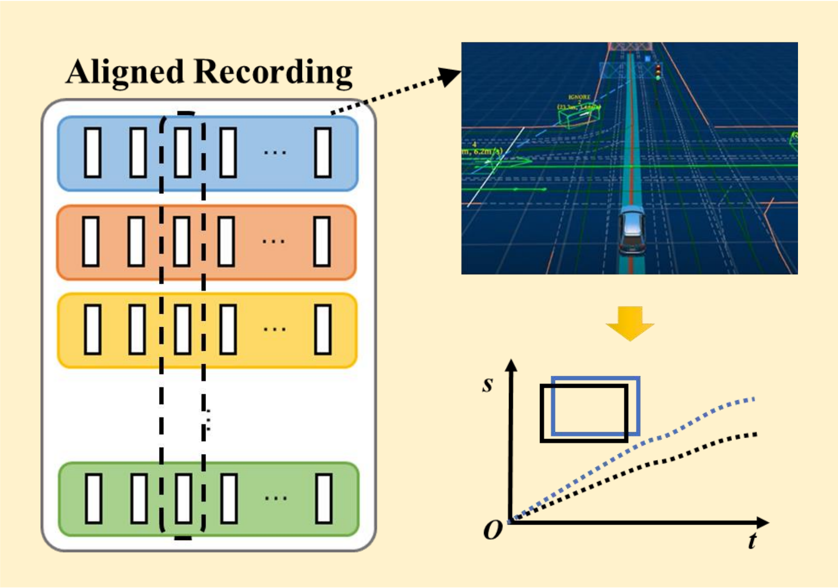
Depicting the AV's longitudinal planning states with Station-Time graph (ST graph)

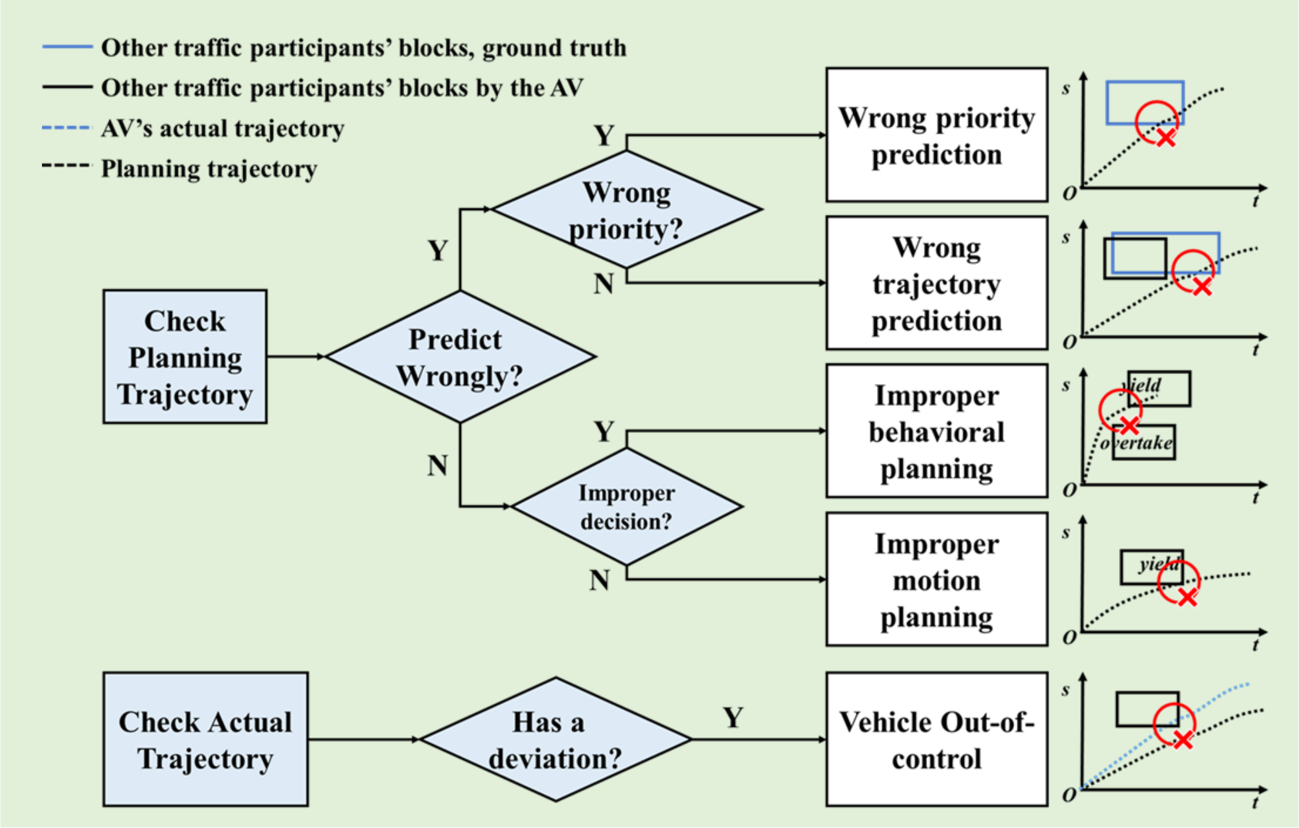


Stage #2: Causal Events Deduction

- Restore ST graph + Causality Analysis Tool (CAT)

CAT compare and analyze the ST graph from the AV perspective against the ground truth, frame by frame.

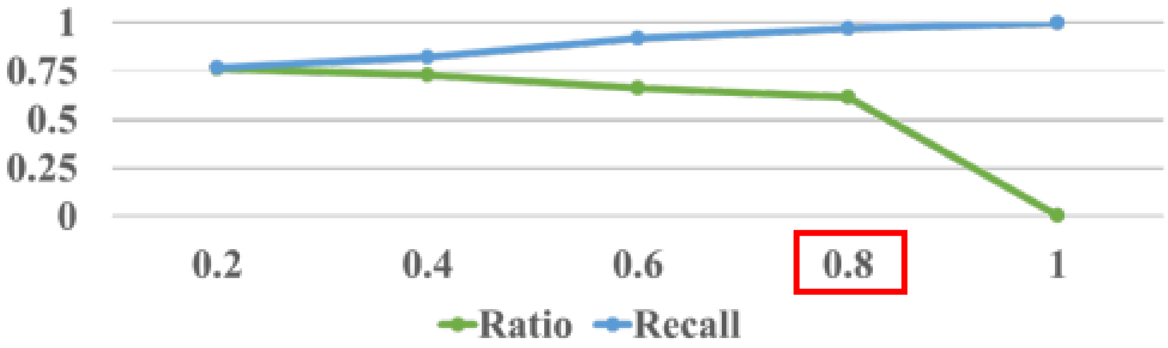




Evaluation

RQ1: Which combination of weights for feature vector categories and which threshold in the "segmenting and pruning" phase is the most **effective**?

Weight Ratio (map:perc:pln)	1:1:0	1:0:1	0:1:1	**1:1:1**	2:1:1	1:2:1	**1:1:2**
Ratio	74.64%	96.43%	74.64%	**50.03%**	60.26%	74.64%	**62.23%**
Recall	79.62%	11:06%	79.62%	**93.01%**	89.19%	79.62%	**94.41%**



Evaluation

RQ2: Does the ACAV **effectively** simplify accident recording compared to other approaches?

RQ3: How many **different causal events** can the causality analysis of ACAV automatically identify?

	ACAV	STRaP	Length: 4s	Length: 8s	Length: 12s	Length: 16s
Ratio	62.23%	60.57%	76.74%	54.40%	32.64%	16.29%
Recall	94.41%	30.81%	72.26%	82.92%	86.85%	91.35%

	Wrong Priority Prediction	Wrong Trajectory Prediction	Wrong Behavioral Planning	Wrong Motion Planning	Vehicle Out-of-control
Total	**26**	**51**	**17**	**67**	**103**
Intersection	0	0	6	27	39
Merging	20	27	4	23	30
Tailgating	6	24	7	17	34

Evaluation

RQ4: To what extent can the ACAV **accurately** identify causal events?

Location	Prediction Module			Planning Module						
Fault Types	F1	F2	Total	F3	F4	F5	F6	F7	F8	Total
Numbers	155	126	281	132	146	202	166	145	134	925
Precision (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Recall (%)	100.00	90.00	95.97	87.61	73.98	89.70	86.72	77.19	77.19	82.56
Accuracy (%)	100.00	92.06	**96.44**	89.39	**78.08**	91.58	89.76	82.07	80.60	**85.73**

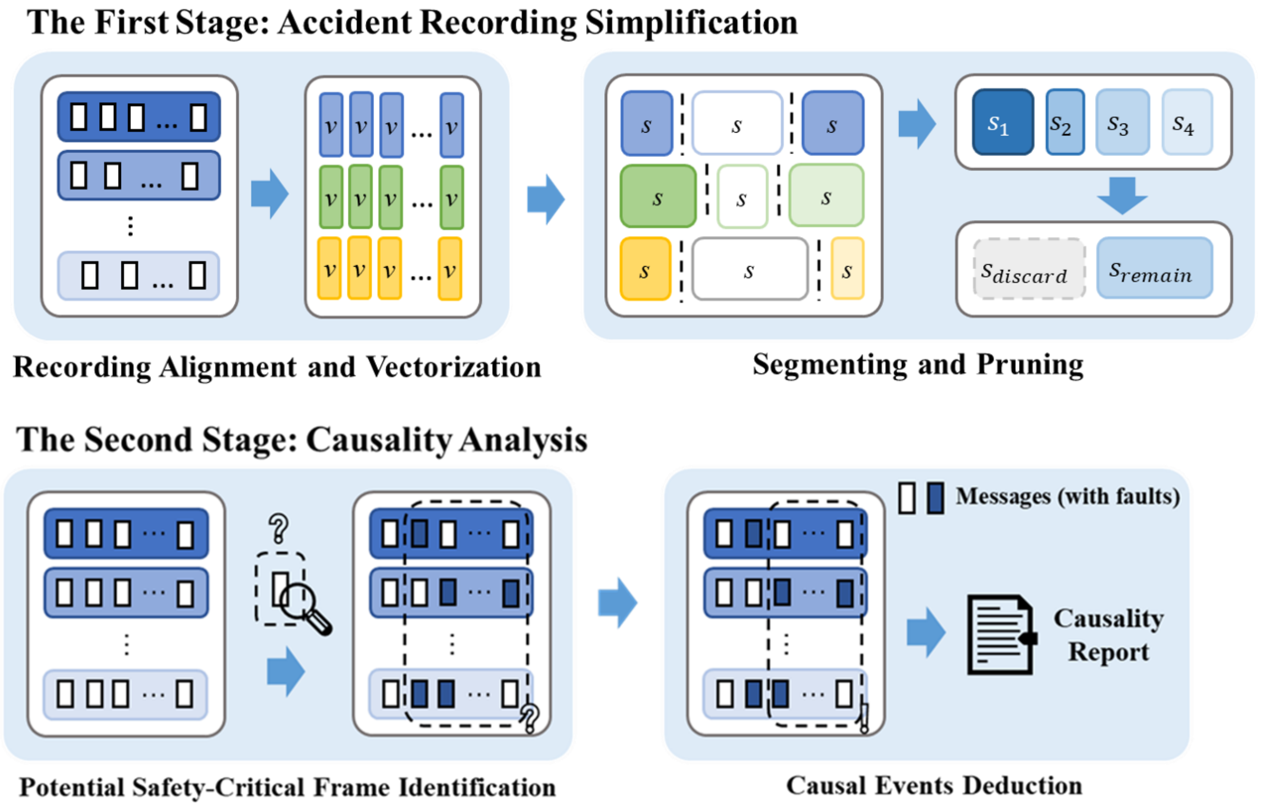
Fault Type	Location	Description
F1	`AssignIgnoreLevel()@obstacle_prioritizer.cc`	Assign 'ignore' priority to all the detected NPCs by default.
F2	`PredictObstacle()@predictor_manager.cc`	Assign improper trajectory prediction models to NPCs to get erroneous trajectory prediction.
F3	`MakeStaticObstacleDecision()@path_decider.cc`	Make 'ignore' decisions to all the static NPCs near the AV's planned trajectory.
F4	`MakeObjectDecision()@speed_decider.cc`	Make 'follow' decisions to any NPCs in front of the AV which tend to stop, instead of 'stop' decisions or changing lanes.
F5	`MakeObjectDecision()@speed_decider.cc`	Make 'ignore' decisions to an NPC ahead of the AV, if the AV is not following or keeping distance from it.
F6	`MakeObjectDecision()@speed_decider.cc`	Make 'yield' decisions to a high-speed NPC accelerating ahead of the AV, which leads to AV's low speed in a fast lane.
F7	`MakeObjectDecision()@speed_decider.cc`	Make 'overtake' decisions to any NPC if it is near the AV.
F8	`GetSpeedLimits()@speed_limit_decider.cc`	Keep a high speed even being close to NPCs.

Conclusion

- ACAV, an automated framework for determining the causal events in AV accidents

- Implementation ACAV in both Apollo and Autoware.universe

- Causal events identification in 103 of 110 accident recordings



Main Contributions:

- A mechanism for identifying recording segments related to the accident
- A tool for identifying safety-critical frames by leveraging ST graphs
- The first framework for AV accident analysis and explanation

Thank You for Listening!