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# The Smart Black Box: Capturing High-Bandwidth Data for Value-Driven Automotive Insights

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**ABSTRACT:**The Smart Black Box (SBB) for autonomous vehicles is implemented using MATLAB to enhance low-bandwidth data logging with high-bandwidth data capture. The SBB uses a deterministic Mealy machine to cache short-term data histories as buffers based on data value and similarity. The implementation optimizes the compression quality of each frame to balance value and storage cost. Low-value buffers are discarded to make room for new data, using a constrained multi-objective optimization problem with novel value metrics and filtering. The performance of the SBB is evaluated on a traffic simulator, where MATLAB is utilized to generate trajectories with events of interest (EOIs) and capture first-person-view videos. This implementation demonstrates the storage efficiency of the SBB with different compression quality levels and event capture ratios, comparing it to a traditional first-in-first-out recording scheme. By incorporating MATLAB, the SBB provides prioritized, efficient, and value-driven data recording, which is critical for validating and improving autonomous vehicles.

**KEYWORDS:**Smart Black Box, Events of Interest, Value-driven data recording, Discrete mealy machine, MATLAB.

## I. INTRODUCTION

Smart Black Box (SBB) for autonomous vehicles that can enhance traditional low-bandwidth data logging with high-bandwidth data capture based on data value and similarity. The SBB is designed to cache short-term histories of data as buffers through a deterministic Mealy machine and determine the compression quality for each frame by optimizing the trade-off between value and storage cost. To evaluate the performance of the SBB, a traffic simulator has been used that generates trajectories containing events of interest (EOIs) and corresponding first-person-view videos. The compression efficiency of SBB is assessed by comparing storage requirements with different compression quality levels and event capture ratios. Performance is evaluated by comparing results with a traditional first-in-first-out (FIFO) recording scheme. SBB compression decision-making as a constrained multi-objective optimization problem with novel value metrics and filtering. The system is designed to capture critical data during events, providing a comprehensive view of what happened before, during, and after the event [3]. Overall, this paper aims to provide value-driven, efficient, and prioritized data recording, which is critical for validating and improving autonomous vehicles.

## II. RELATED WORK

Traditional Event Data Recorders (EDRs) have limitations in terms of the types of data they can capture, the quality of the data, and the way the data is used [1]. The proposed paper aims to overcome these limitations by incorporating a broader range of sensors and using a value-driven approach to data collection and analysis. Lane-changing is one of the most complex and risky maneuvers for autonomous vehicles, and it is important to evaluate their safety in these scenarios. In [2], the authors explain the importance of sampling to estimate the probability of a safety event, such as collision or close proximity, occurring during a lane-change maneuver. Automatic smart black box system based on IoT (Internet of Things) technology to detect accidents in vehicles. The system uses various sensors such as an accelerometer, gyroscope, GPS, and camera to collect data related to vehicle dynamics, location, and environment [4]. The data is processed using machine learning algorithms to detect different types of accidents



such as collision, rollover, and sudden stop. In this paper, we are going to collect data from sensors (i.e., Camera, Lidar, and Radar) and collect data when events of interest (cut-in, conflict, and crash) events occur.

### III. SYSTEM DESIGN AND WORKFLOW

The high-bandwidth automotive event data recorder is designed to provide reliable and resilient sensor suites and ongoing validation through fleet-wide data collection. The system is designed to augment traditional low-bandwidth data logging with value-driven high-bandwidth data capture.

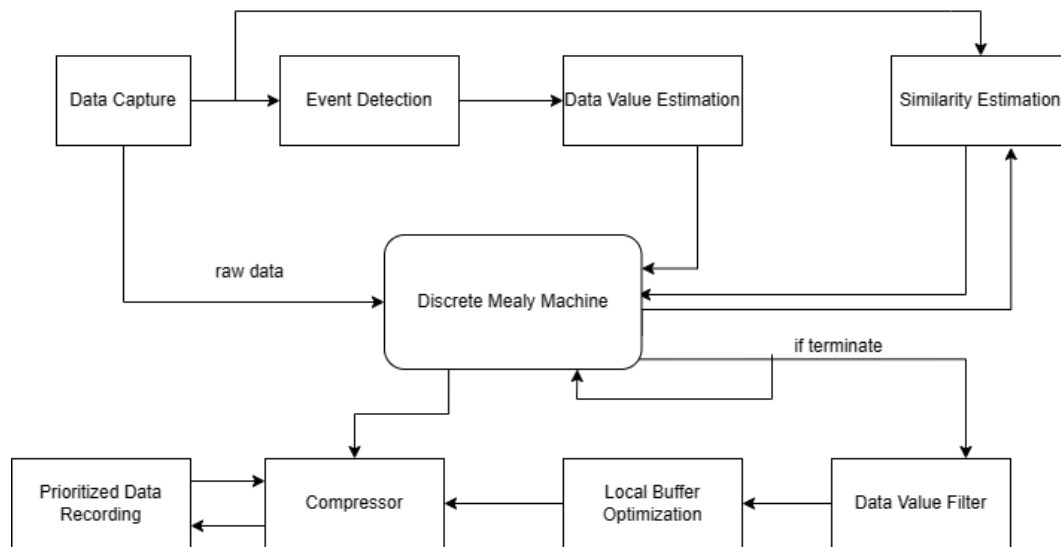


Fig. 2. Flow chart of the data recording

The system design includes several key components, including:

- Data Capture:** The SBB captures data from various sensors in the vehicle, such as cameras and lidar. The data is captured at a high bandwidth to provide a detailed record of the vehicle's surroundings and actions.
- Event Detection:** The process of identifying events of interest (EOIs) from the captured data. The SBB is designed to detect events of interest (EOIs) that are relevant to the safety and performance of the vehicle. EOIs can include hard braking, conflict, crash, and cut-in.
- Data Value Estimation:** The SBB evaluates the value of each frame of data based on its relevance to EOIs and other factors. Frames with higher values are prioritized for storage and compression.
- Similarity Estimation:** The SBB also evaluates the similarity between frames of data to identify redundant information. The process of identifying the degree of similarity between two data buffers. The SBB uses a similarity metric to determine if two buffers contain similar data. Similar frames can be compressed or discarded to optimize storage.
- Discrete Mealy Machine:** A type of finite-state machine that takes input from the sensors and generates output based on the state of the machine. The SBB uses a deterministic Mealy machine to decide whether to store or discard a buffer based on its value and similarity. The machine is designed to optimize storage and compression by balancing value and cost.
- Local Buffer Optimization:** The SBB optimizes the buffer by prioritizing data recording based on data value and similarity. The SBB discards low-value buffers to make room for new data.
- Buffer:** A temporary storage area is used to store data before it is processed. The SBB uses buffers to store short-term histories of sensor data.
- Multi-Objective Optimization:** The SBB formulates the compression decision-making process as a constrained multi-objective optimization problem. This optimization problem uses novel value metrics and filtering to optimize storage and compression while maximizing the relevance of data to EOIs and other factors.
- Data Value Filter:** The SBB includes a data value filter to remove data that is not relevant to EOIs or other factors. This filter helps to reduce storage requirements and optimize compression.

10. **Compressor:** The SBB compresses data based on the trade-off between value and storage cost. Frames with a higher value are compressed with higher quality to ensure their fidelity.
11. **Prioritized Data Recording:** The process of recording high-value data while discarding low-value data to optimize storage. The SBB uses prioritized data recording

#### IV. EVENTS OF INTEREST

In a smart black box in a vehicle, events of interest typically refer to specific driving behaviors or incidents that could potentially impact safety or indicate risky driving habits. Some common events of interest that are often recorded by a smart black box include:

- **Cut-in:** This event occurs when a vehicle changes lanes in front of another vehicle without sufficient distance or warning, causing the other vehicle to brake suddenly or take respective action. In the simulation, this could be detected by measuring the distance between the two cars and their relative velocities. This can be a common cause of rear-end collisions.
- **Conflict:** A conflict can occur when two or more vehicles come into close proximity to each other, which can be a potential hazard or precursor to a collision. This can happen when vehicles are changing lanes, merging onto a highway, or when one vehicle is following another too closely. This can be detected by measuring the distance between the cars and their relative velocities and could trigger an alert for the driver to take evasive action.
- **Crash:** A crash event occurs when two or more cars collide with each other. This can be detected by measuring the distance between the cars and their relative velocities. A crash event could trigger an emergency response and stop the simulation. This event occurs when two or more vehicles collide with each other, resulting in damage to the vehicles and potentially causing injuries or fatalities to the passengers.
- **Hard braking:** Hard braking occurs when a vehicle decelerates rapidly or comes to a sudden stop. This can be an indication of an emergency stop, such as to avoid a collision or to allow pedestrians to cross the road. It can also indicate that the driver is distracted or unaware of the traffic ahead. In the simulation, this could be detected by measuring the car's velocity and acceleration.

#### V. DISCRETE MEALY MACHINES DATA VALUE AND SIMILARITY METRICS

To calculate the data value and similarity metrics the Mealy machine and local buffer optimization are used in this paper. The mealy machine is used to capture frames, add frames to a buffer, and update the buffer based on the current state and input symbol. For example, in the event that a conflict is detected with another vehicle, the Mealy machine transitions from the "Idle" state to the "Capture Frame" state and captures a frame to add to the buffer. The output of the system, in this case, is "Capture Frame".

##### ❖ States:

- **Idle:** The initial state of the machine, where it waits for an event of interest to occur.
- **Capture Frame:** The state where the machine captures a frame and compresses it. If an event of interest occurs, the machine transitions to the Event Occurred state.
- **Event Occurred:** The state where the machine detects an event of interest and adds the compressed frame to the buffer. If no further events occur, the machine transitions back to Idle. Otherwise, it transitions to Capture Frame again.

##### ❖ Input symbols:

- **Event Occurred:** This input signal indicates that an event of interest has occurred.
- **Frame Captured:** This input signal indicates that a frame has been captured and compressed.
- **Buffer Updated:** This input signal indicates that the buffer has been updated with a new frame.

##### ❖ Outputs:

- **Capture Frame:** This output signal indicates that the machine should capture a new frame.
- **Add Frame to Buffer:** This output signal indicates that the compressed frame should be added to the buffer.





The mealy machine uses the transition and output tables to determine the next state and output based on the current state and input symbol.

State	Input	Next state
Idle	Event Occurred	Event Occurred
Capture Frame	Event Occurred	Event Occurred
Capture Frame	Frame Captured	Idle
Capture Frame	Buffer Updated	Capture Frame
Event Occurred	Event Occurred	Event Occurred
Event Occurred	Frame Captured	Idle
Event Occurred	Buffer Updated	Capture Frame

Table 1. Transition table

State	Input	Output
Idle	Event Occurred	-
Capture Frame	Event Occurred	[0, 0]
Capture Frame	Frame Captured	[1, 0]
Capture Frame	Buffer Updated	[0, 1]
Event Occurred	Event Occurred	-
Event Occurred	Frame Captured	[1, 0]
Event Occurred	Buffer Updated	[0, 1]

Table 2. Output table

The mealy machine has two output signals:

- [1 0] when the Mealy machine is in the Capture Frame state, indicating that a frame should be captured
- [0 1] when the Mealy machine is in the Event Occurred state, indicating that a compressed frame should be added to the buffer

The output table is a matrix with each row corresponding to a state and each column corresponding to an input symbol. The entries in the matrix represent the output signal produced by the Mealy machine in response to a particular input symbol in a particular state. In this case, the output signal is a binary vector indicating whether or not to capture a frame and whether or not to add a frame to the buffer.

#### VI. LOCAL BUFFER OPTIMIZATION AND LONG-TERM STORAGE MANAGEMENT:

Local buffer optimization and long-term storage management are two important components of a smart black box (SBB) system. Local buffer optimization refers to the process of optimizing the buffer capacity of the SBB system so that it can effectively store and manage video footage. In an SBB system, the local buffer is a temporary storage space that holds recently captured data. The buffer is designed to ensure that the data is available when needed, but it has limited capacity. Therefore, it is important to optimize the buffer capacity so that it can hold enough footage to capture critical events, such as accidents or other road incidents. Long-term storage management, on the other hand, refers to the process of managing the storage of video footage in the long term. The SBB system needs to store a large amount of video footage for an extended period of time. However, storing all the footage can be expensive and impractical. Therefore, the system needs to manage the storage efficiently. To manage long-term storage, the SBB system may employ various techniques such as data deduplication, data compression, and data encryption. Data deduplication identifies and removes duplicate data to save storage space. Data compression reduces the size of the data while maintaining its quality. Data encryption secures the data from unauthorized access. Local buffer optimization and long-term storage management are critical techniques in data management. These techniques help to optimize data storage and retrieval, improve system performance, and ensure data availability and security.



VII. IMPLEMENTATION AND RESULTS

Cut-inis detected when the distance between the target vehicle and another vehicle in front of it becomes less than a certain threshold distance. When this happens, the simulation checks if the two vehicles are going to collide based on their current positions and velocities. If a collision is likely, the simulation triggers a conflict or crash event.

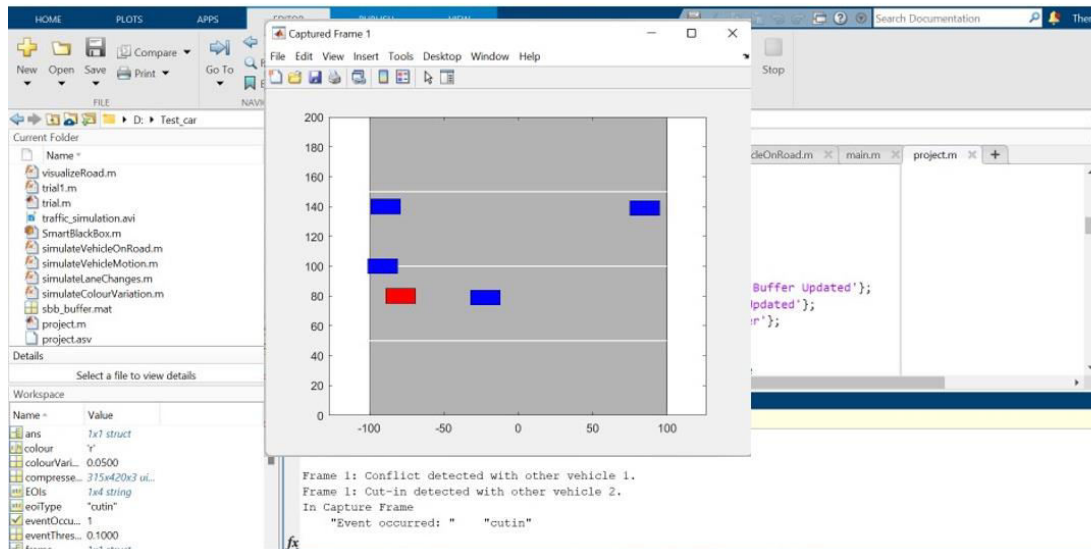


Fig. 2. Cut-in event occurred

A conflict event occurs when one of the other vehicles cuts in front of the target vehicle and occupies its safe following distance. In this situation, there is a risk of collision or unsafe driving conditions.

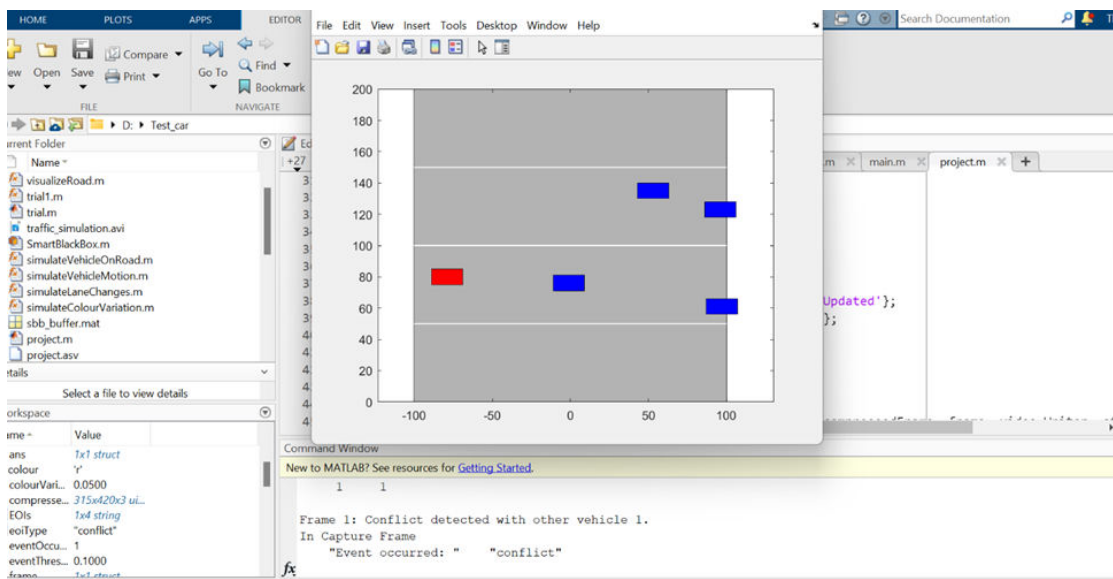


Fig. 3. Conflict event occurred



A crash event occurs when a vehicle collides with another vehicle on the road. If a crash occurs, both vehicles involved in the collision have their velocities set to 0, effectively bringing them to a stop. The hard braking event occurs when the target vehicle detects that another vehicle is too close and there is a risk of collision. In this event, the target vehicle needs to rapidly reduce its speed to avoid a collision.

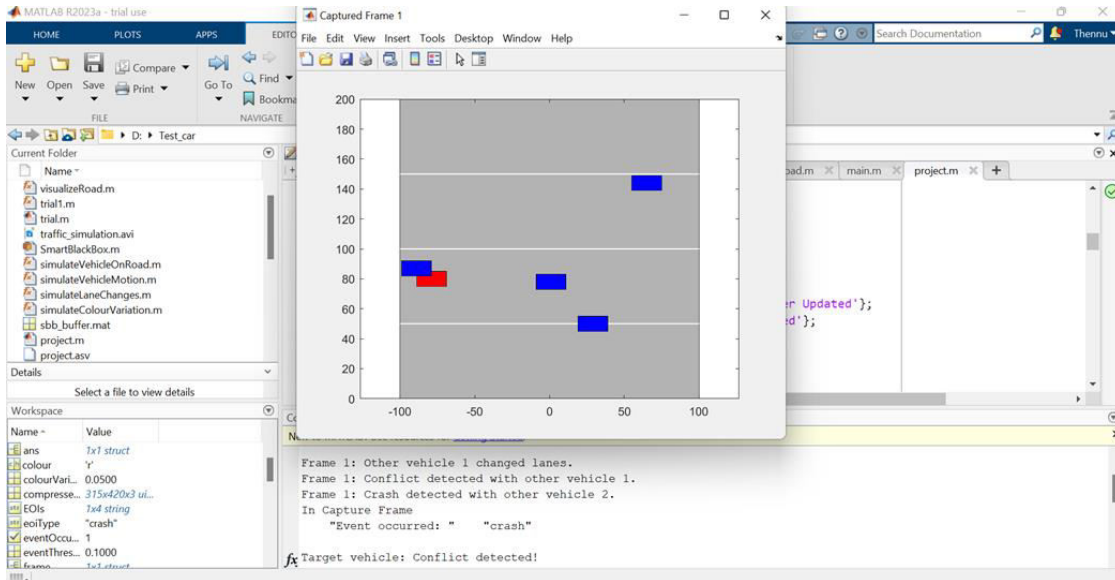


Fig. 4. Crash event occurred

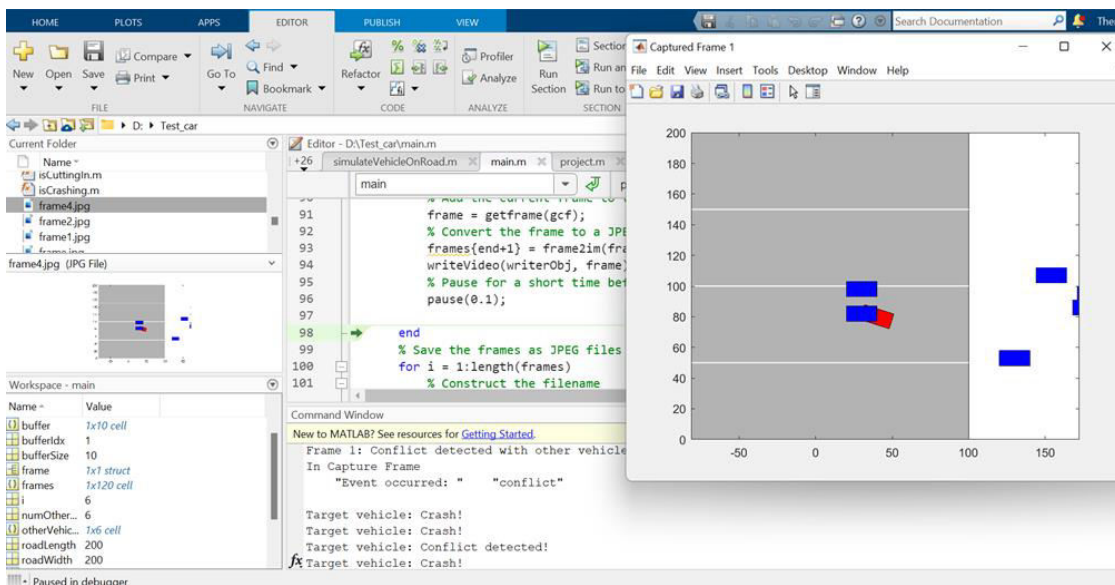


Fig. 5. Captured frame stored in the buffer



The below table shows the values for each term. The target vehicle color is 'red' and the other vehicles color is 'blue'. In this, the conflict event occurs and the current state of the mealy machine is the 'capture frame' and the next state of the mealy machine is the 'eventoccurred'. The original size of the frame is 630x840x3 and the frame compressed to the size of 315x420x3.

Name ^	Value
colour	'r'
colourVariationProb	0.0500
compressedFrame	315x420x3 uint8
EOIs	1x4 string
eoiType	"conflict"
eventOccurred	1
eventThresholds	0.1000
frame	1x1 struct
frameNum	1
input	1x3 cell
input_symbols	1x3 cell
laneChangeProb	0.1000
mealy_machine	1x1 mealyMachine
nextState	'Event Occurred'
numFrames	10
numVehicles	6
otherVehicleColor	'blue'
otherVehicles	1x2 struct
output_symbols	1x2 cell
output_table	3x1 cell
roadLength	200
roadWidth	200
sbb	1x1 SmartBlackBox
state	'Capture Frame'
states	1x3 cell
targetVehicle	1x1 struct

Fig.6.Final output

## VII. CONCLUSION

This paper appears to be a MATLAB simulation of vehicle traffic on a road, with the goal of detecting and recording events of interest using a Smart Black Box. The events of interest include hard braking, conflicts, crashes, and cut-ins. The simulation includes parameters such as the number of vehicles, the road dimensions, the probability of lane changes and color variations, and the color of the target and other vehicles. The simulation is implemented using a Mealy machine to control the flow of the simulation and detect events of interest. The Mealy machine has three states:





Idle, Capture Frame, and Event Occurred. The Smart Black Box is used to store compressed frames of the simulation and to detect and record events of interest. The simulation includes visualizations of the vehicles on the road and can output a video file of the simulation. The MATLAB simulation could be further improved by adding more parameters and features, such as different types of vehicles with varying speeds, more complex road layouts, and more sophisticated event detection algorithms. Overall, this paper demonstrates the use of a Mealy machine and a Smart Black Box to simulate and detect events of interest in a vehicle traffic scenario.

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