

# *SalM<sup>2</sup>* : An extremely lightweight saliency mamba model for real-time cognitive awareness of driver attention

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## Abstract

Driver attention recognition in driving scenarios is a popular direction in traffic scene perception technology. It aims to understand human driver attention to focus on specific targets/objects in the driving scene. However, traffic scenes contain not only a large amount of visual information but also semantic information related to driving tasks. Existing methods lack attention to the actual semantic information present in driving scenes. Additionally, the traffic scene is a complex and dynamic process that requires constant attention to objects related to the current driving task. Existing models, influenced by their foundational frameworks, tend to have large parameter counts and complex structures. Therefore, this paper proposes a real-time saliency Mamba network based on the latest Mamba framework. Our model uses very few parameters (0.08M, only 0.09% to 11.16% of other models), while maintaining state-of-the-art (SOTA) performance or achieving over 98% of the SOTA model's performance, as shown in Figure 1. Our code is available at the anonymous link <https://anonymous.4open.science/r/aaai14329>.

## Introduction

With the rapid advancement of autonomous driving technology, understanding and predicting driver behavior has become increasingly important. Among the many factors affecting driving safety, the driver's attention state is crucial (Balasubramani et al. 2024). Distraction or insufficient attention can lead to reduced perception of the surrounding environment, increasing the risk of traffic accidents (Fang et al. 2024). Therefore, research on methods for recognizing driver attention is of great significance for enhancing road safety and advancing the development of intelligent driving assistance systems.

Given that the traffic driving scenario is dynamic and complex (Alkaabi 2023), it is unwise to analyze driver attention solely based on features from the driving scene. The driving environment contains not only rich "Bottom-up" image features (such as the sky, buildings, vehicles, etc.) but also "Top-down" information related to the current driving task (such as vehicles ahead, pedestrians crossing the road, traffic lights, etc.). Relying only on features within the driving scene to identify driver attention may cause the model

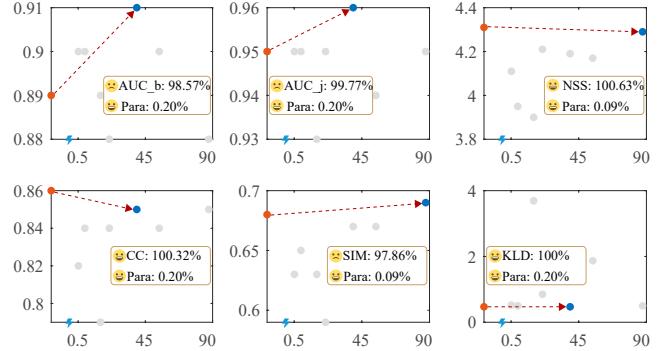


Figure 1: Comparison of Parameters and Performance. We compare our model with other state-of-the-art models on the DrFixD-rainy dataset. The horizontal axis represents the number of parameters (M), and the vertical axis represents performance. ● denotes our model, and ● denotes the best-performing model among the comparison models, and ● denotes other comparison models. ↗ denotes truncated coordinates, with the origin set to 0.08.

to overfit to the labeled driver attention data, leading to a lack of understanding of the driving context and reducing the model's generalization ability. However, within the visual attention system, relevant stimuli and cues can be selected while filtering out less relevant ones from the rich visual information around us. Attention resources are then allocated to these stimuli and cues, typically by directing gaze toward objects of interest in the visual environment (Hertz-Pannier et al. 2023; Itti and Koch 2001). This process is known as selective visual attention or selective attention allocation (Evans et al. 2011). Similarly, in specific traffic driving scenarios, a driver's visual attention, driven by the driving task, tends to focus on one or more regions or targets that are related to the task at hand. When performing a driving task, a driver's attention needs to remain highly focused, consistently allocating attention to objects or areas relevant to the current driving task. If the driving scenario or task changes, the driver's attention will also shift accordingly. Therefore, the semantic information of the current driving scene is crucial for understanding the subsequent shifts in driver attention.

Numerous researchers have studied driver attention prediction, but most of these studies focus on the overall features of the driving scene, often neglecting the understanding of semantic information present within the scene (Xia et al. 2019; Baee et al. 2021; Shen et al. 2022). Additionally, existing models tend to have large parameter counts and high computational complexity (Fang et al. 2022; Chen, Nan, and Xiang 2023). Therefore, this paper proposes a novel driver attention recognition model based on driving events, which not only has a small parameter count but also utilizes the semantic information from the driving scene to guide the recognition of current driver attention. Specifically, we employ a dual-branch structure: one “Bottom-up” branch extracts image features from the driving scene, while the other “Top-down” branch captures the semantic information of the scene. At the deepest layer of image feature extraction, we integrate the semantic information of the driving scene to guide the image features. This semantic-guided feature is then passed through a decoder module to obtain the final driver attention map. Since our driver gaze prediction is driven by the contextual information of the driving scene, the resulting attention maps align more closely with the actual distribution of driver attention. To summarize, the contributions of this work are the following:

- **We propose a driver attention prediction architecture based on the Mamba framework.** Our architecture is inspired by visual cognition, with a “Bottom-up” branch that extracts stimulus-driven image features from the driving scene, and a “Top-down” branch that extracts task-driven semantic features. The “Top-down” branch includes a novel Selective Channel Parallel Mamba (SCPM) layer, which not only addresses the parameter explosion issues caused by high-dimensional data in Mamba, but also corrects the information loss from fixed channel partitioning. [Response Q1]
- **We design a novel Cross-Modal Attention (CMA) fusion module.** This module integrates the semantic information from the cognitive process and the image features to guide the allocation of driver attention in driving scenarios. Our module adopts the idea of channel attention to address the challenge of feature dimension mismatch between semantic and image information, allowing for effective fusion. The entire module introduces only a single additional parameter.
- **We develop an extremely lightweight effective driver attention prediction network.** To the best of our knowledge, the *SalM<sup>2</sup>* network is the most lightweight model for driver saliency prediction, with only 0.08M trainable parameters. The model is trained on three popular datasets, and *SalM<sup>2</sup>* achieves SOTA performance using only a fraction (approximately 0.09% to 11.16%) of the parameters compared to other models, or reaches 98+% of the performance of the SOTA models. [Response Q2]

## Related Work

### Driver Saliency Prediction

Previous works have made notable advances in driver gaze prediction, primarily focusing on inherent visual features or

semantic information from image segmentation and optical flow. Tawari et al. pioneered first-person gaze estimation using Google Glass (Tawari et al. 2014), while Deng et al. proposed a bottom-up saliency model combining low and high-level features (Deng, Yan, and Li 2017), though limited by traditional machine learning’s feature extraction capabilities.

As research progressed, numerous datasets and deep learning algorithms emerged to address conventional limitations. The DR(eye)VE dataset by Alletto et al. covers various driving conditions but lacks scene diversity and semantic richness (Alletto et al. 2016). The BDAA dataset introduced by Xia et al. enriches the field with urban driving scenarios and emergency events (Xia et al. 2019). Fang et al. presented DADA-2000 dataset covering normal and accident scenarios with a semantic-guided attention fusion network, though limited to collision scenes and segmentation-based semantics (Fang et al. 2019). The TrafficGaze dataset by Deng et al. offers comprehensive clear-weather data with a lightweight CNN framework (Deng et al. 2019), while the DrFixD-rainy/night dataset specifically addresses adverse weather conditions (Tian, Deng, and Yan 2022; Deng et al. 2023). Nevertheless, these approaches rely on scene features or segmentation-based semantics, lacking scene understanding. Brishtel et al. demonstrated correlations in gaze patterns across driving modes (Brishtel et al. 2022). Vozniak et al. successfully incorporated semantic danger cues in attention prediction (Vozniak et al. 2023), though obtaining annotated semantic data remains challenging.

In summary, while substantial research has developed numerous models for predicting driver attention, there remains a gap in utilizing basic semantic guidance of driving scenes for driver saliency prediction. Therefore, this paper employs the CLIP (Radford et al. 2021) model to extract semantic information from driving scenes. To validate the effectiveness of our proposed method in diverse and dynamic driving scenarios, we conduct experiments across datasets with different weather conditions (TrafficGaze, DrFixD-rainy) and complex semantic information (BDAA).

### Downstream tasks

**Salient object detection.** This is an important task in computer vision aimed at detecting the most prominent object regions in an image. In the context of traffic driving scenes, drivers often automatically filter out objects unrelated to the current driving task. Therefore, some existing works use driver attention allocation as prior knowledge to detect prominent or key objects (Qin et al. 2022; Shi et al. 2023). This approach does not detect all objects in the driving scene but focuses on those most relevant to the current driving task, thereby reducing redundant information.

**Drive event recognition.** In the field of intelligent transportation systems, detecting driving events by analyzing driving scene information is one of the key tasks in preventing traffic accidents. Driver visual attention helps identify information relevant to the current driving task while suppressing irrelevant information. Du et al. (Du, Deng, and Yan 2023) established an attention-based driving event

dataset (ADED) and proposed a driver attention-guided model that uses driver attention as guidance to better recognize events that cause shifts in driver attention.

In conclusion, we believe that the semantic information of the driving scene is beneficial in identifying the driver's attention most aligned with the current driving task. Inspired by visual cognition, we have developed an attention prediction model driven by the semantic information of the current driving scene, integrating this semantic information at the deepest level of image feature extraction to guide the driver's attention effectively.

## Proposed Method

Since the traffic scene is a complex and dynamically changing setup [Response Q6], the driver requires continuous focus on objects/areas that are significantly relevant to the current driving scene. However, most of the previous work only considered spatio-temporal information in driving scenarios. In fact, solely relying on visual information from the driving scene is not sufficient to accurately identify the locations or areas that need the driver's attention (Rasouli and Tsotsos 2018) [Response Q7] — that is the “Bottom-up” image information. This is because the driver's attention is closely related to the current driving task, and it is also necessary to consider the “Top-down” semantic information related to the current driving task that is embedded in the driving scene.

**Overall network framework.** Considering these elements, we propose a saliency mamba model, named *SalM*<sup>2</sup> that uses “Top-down” driving scene semantic information to guide “Bottom-up” driving scene image information to simulate human drivers' attention allocation. The overall framework is illustrated in Figure 2, our model first utilizes an efficient network framework Mamba structure to build an extremely lightweight backbone network for extracting “Bottom-up” features from image and decoding the features. Simultaneously, a visual encoder is used to understand the “Top-down” semantic information driven by the driving task in the current traffic scene. Then, when the deepest features representing image information [Response Q8] of the driving scene is extracted from the backbone network, we utilize the “Top-down” semantic information to guide the “Bottom-up” image information. Finally, we decode the perceived information in the decoder of the backbone network to obtain the driver attention map.

**Reliable attention prediction network.** [Response Q9] Since we aim for intelligent vehicles to have the capability to focus on objects related to driving tasks in the scene, just like a driver, we need to develop a network with low computational cost [Response Q10] and deployability with lower hardware requirements [Response Q11]. To achieve this goal, we construct an extremely lightweight backbone network as the image encoding and decoding network, as shown in Figure 3. This design allows us to fully utilize the Mamba structure's efficient feature representation capability, accelerating the learning of the representation space at the channel level. Inspired by the work of Wu et al. (Wu et al. 2024), we modified it to perform high-dimensional feature representation in our selective channel parallel Mamba

(SCPM) layers. This framework contains only 0.0785M parameters, with a model size of just 1.6MB.

In this architecture, the overall backbone network is a hierarchical structure based on Mamba. We first use convolutional network layers to extract low-level features from images, and then employ SCPM layers to further extract high-level features. To leverage the efficiency of the Mamba framework and address the parameter disaster caused by high-dimensional data, a typical solution is to split the input  $X \in \mathbb{R}^{B \times C \times H \times W}$  into four parts  $x_i \in \mathbb{R}^{B \times C/4 \times H \times W}, i = 1, 2, 3, 4$  and then process them in parallel through the Mamba layers. To correct the information loss caused by fixed channel splitting, we design the SCPM layer. This layer embeds the input features into convolutional blocks in parallel and then feeds them into the Mamba layer in parallel. The output feature channels of the parallel branches differ, but the feature dimensions remain consistent. The operation of each parallel channel is as shown in Equation 1.

$$\Phi_i(X) = Conv_i(X) + \alpha \times Mamba(Conv_i(X)), \quad (1)$$

$$Y = \sum_{i=1}^{i=n} \Phi_i(X), i \in \{1, 2, 3, 4\}, n = 4, \quad (2)$$

where  $\Phi_i(X)$  represents the output of the  $i^{th}$  parallel layer,  $\alpha$  is a skip scale,  $Y \in \mathbb{R}^{B \times C' \times H \times W}$  represents the final output of the SCPM layer, and  $\sum$  represents the summation operation, which in this context is the summation along the channel dimension.

**Cross-Modal Attention mechanism (CMA).** For most models, the backbone network is used to extract “Bottom-up” image information to predict driver attention (Deng et al. 2019; Min and Corso 2019; Deng, Yan, and Yan 2021; Tian, Deng, and Yan 2022; Chen, Nan, and Xiang 2023) [Response Q12]. However, the traffic environment is a complex and dynamic process where different driving scenarios involve specific driving tasks (such as stopping at traffic lights, yielding to pedestrians crossing the road, etc.). Therefore, we need to understand the specific driving tasks in the current driving scenario. Using this “Top-down” scene information to guide the “Bottom-up” image information can better identify the driver's attention allocation. However, text data contains strong semantic and logical properties, making it difficult to match and align with image data in the feature space. To further explore how to use semantic information to guide driving scene information, this paper proposes using a cross-modal attention mechanism.

As shown in Figure 4, CMA uses the semantic information  $Info_{text}$  extracted by CLIP (Radford et al. 2021) [Response Q16] and the image information  $Info_{image}$  extracted by the backbone network as inputs. However, directly fusing these inputs leads to a dimension mismatch problem as  $Dim(Info_{text}) \neq Dim(Info_{image})$ . Therefore, we project the semantic information into the same feature channel space as the image information. Using the simple structure of the channel attention module (Fu et al. 2019) [Response Q12], we achieve cross-modal information fusion, thereby avoiding the issue of scale mismatch between different types of information.

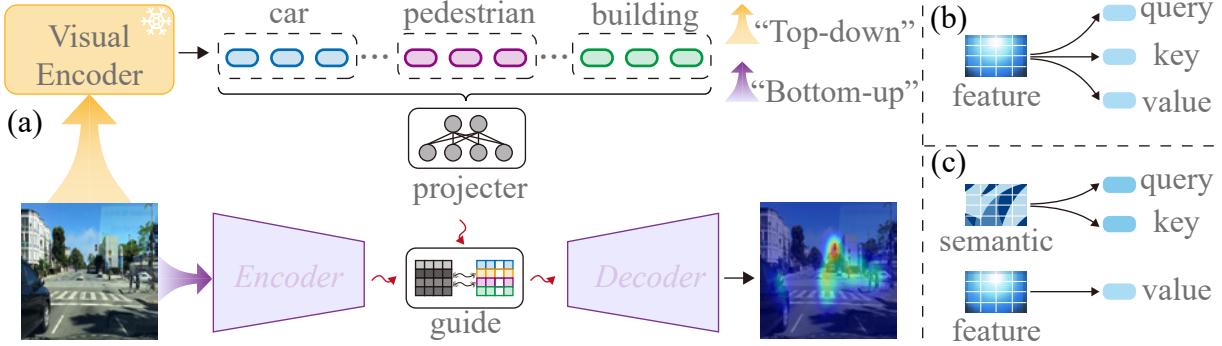


Figure 2: Overview of the proposed *SalM<sup>2</sup>* network. (a) shows the overall network framework, which includes two branches: a “Bottom-up” branch and a “Top-down” branch. (b) illustrates the principle of the self-attention mechanism. (c) illustrates the principle of our proposed cross-modal attention mechanism.

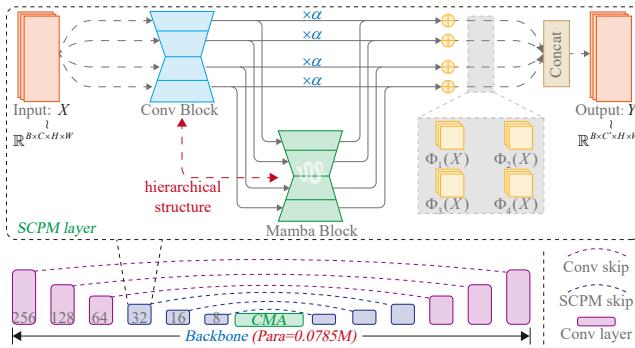


Figure 3: Illustrate of the ‘Bottom-up’ backbone network. The purple and blue dashed lines represent skip connections, which include both spatial and channel attention. The skip connections share weights.

Due to CLIP being a large model trained through contrastive learning, the extracted semantic information and image features have already been aligned in a similar feature space through contrastive training, enabling us to readily obtain the original semantic information  $Info_{text}^{ori} \in \mathbb{R}^{B \times Token}$  from images. Nevertheless, we still need to perform a easy dimensional projection on the semantic information to ensure identical channel dimensions between the two modalities while preserving all information. we map the original semantic information  $Info_{text}^{ori}$  to the image feature space, obtaining new semantic information  $Info_{text} \in \mathbb{R}^{B \times C \times \mathcal{H}_1 \times \mathcal{W}_1}$ .

$$Info_{text} = projector(Info_{text}^{ori}). \quad (3)$$

**[Response Q13]** Within the CMA module: we first reshape the semantic information  $Info_{text} \in \mathbb{R}^{B \times C \times \mathcal{H}_1 \times \mathcal{W}_1}$  to  $Q \in \mathbb{R}^{B \times C \times \mathcal{N}_1}$  as Query and transpose  $Info_{image}$  to  $K \in \mathbb{R}^{B \times \mathcal{N}_1 \times C}$  as Key. Then, we perform a matrix multiplication between the  $Q$  and the  $K$ . Finally, we apply a softmax operation to obtain the saliency semantic representation

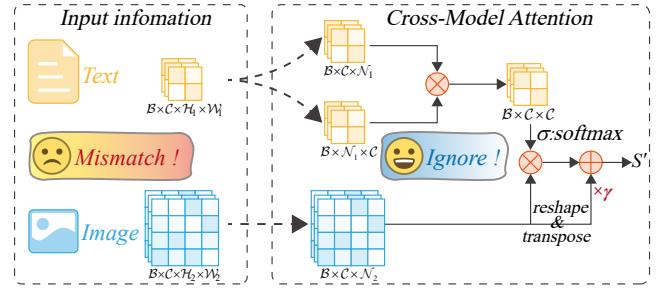


Figure 4: Illustrate of the cross-modal attention mechanism. In the figure,  $\otimes$  denotes matrix multiplication, and  $\oplus$  represents element-wise addition.

$$S \in \mathbb{R}^{B \times C \times C}.$$

$$s_{ji} = \frac{\exp(Q_i, K_j)}{\sum_{i=1}^C \exp(Q_i, K_j)}, \quad (4)$$

where  $s_{ji}$  measures the influence of the  $i^{th}$  channel on the  $j^{th}$  channel,  $C$  is the total number of channels, and  $\exp(\cdot, \cdot)$  is used to measure the similarity between two channels.

In addition, we reshape the deepest image information  $Info_{image} \in \mathbb{R}^{B \times C \times \mathcal{H}_2 \times \mathcal{W}_2}$  to  $V \in \mathbb{R}^{B \times C \times \mathcal{N}_2}$  as the Value and perform a matrix multiplication between  $S$  and  $V$ , then reshape the result to  $Info_{fusion} \in \mathbb{R}^{B \times C \times \mathcal{H}_2 \times \mathcal{W}_2}$ . Next, we multiply the attention  $S$  by a scaling parameter  $\gamma$  and add the image feature information  $Info_{image}$  to obtain the final cross-modal fused information  $S' \in \mathbb{R}^{B \times C \times \mathcal{H}_2 \times \mathcal{W}_2}$ .

$$S'_j = \gamma \sum_{i=1}^C (s_{ji} \cdot V_i) + Info_{image}^j, \quad (5)$$

where  $\gamma$  is a learnable weight and is initialized to 0,  $\mathcal{N}_1 = \mathcal{H}_1 \times \mathcal{W}_1$ ,  $\mathcal{N}_2 = \mathcal{H}_2 \times \mathcal{W}_2$ ,  $\mathcal{H}_2 = 2\mathcal{H}_1$ , and  $\mathcal{W}_2 = 2\mathcal{W}_1$ .

## Experiment

**Datasets.** In this work, we train our proposed *SalM<sup>2</sup>* model on 3 representative driver attention datasets: TrafficGaze, DrFixD-rainy, and BDD-A. Before training, we re-

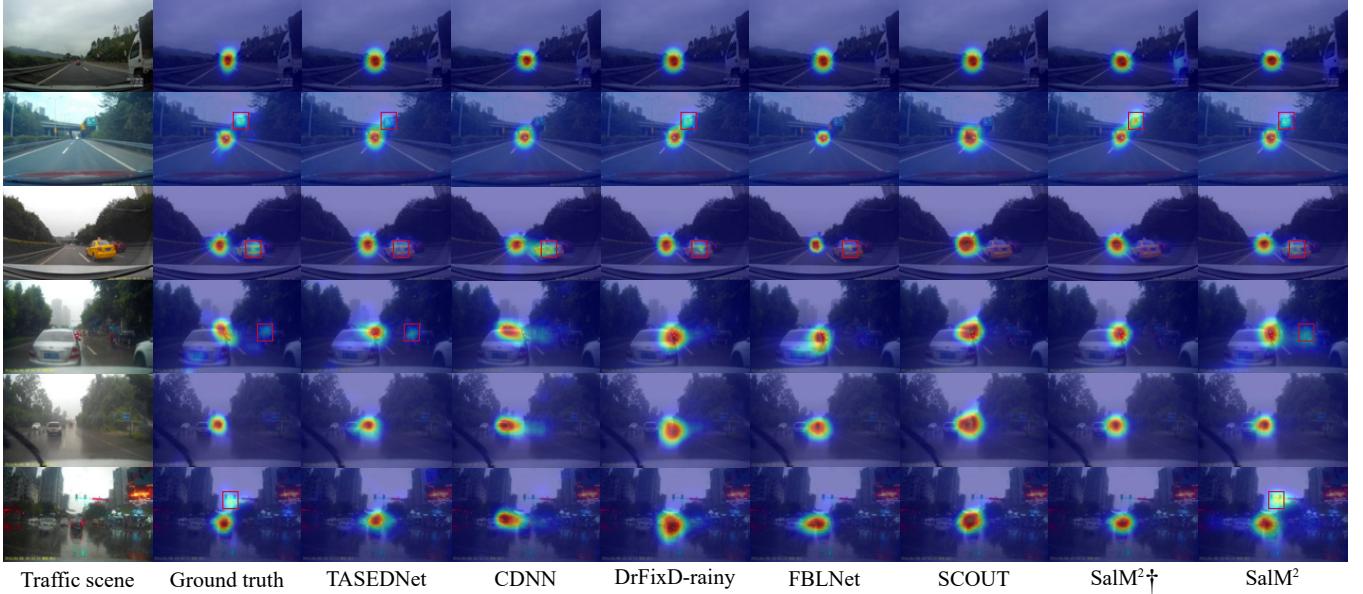


Figure 5: Qualitative evaluation comparison of our proposed model and the other state-of-the-art methods. Since the weight files of MLNet and SCAFNet are not available in original papers, we could not perform visualization comparisons under identical conditions for those methods.  $\dagger$  is  $SalM^2$  without branch of semantic.  $\square$  delineates the attention allocation regions influenced by semantic information. [Response Q19,Q20]

size the traffic images in each dataset to  $256 \times 256$  to reduce the computational load on the network. Additionally, the compared models are divided into static driver attention prediction methods and dynamic driver attention prediction methods [Response Q14]. In the static methods, the model relies on a single-frame driving scene image to predict driver attention. In the dynamic driver attention methods, we use a sequence of six consecutive frames as input.

**Implementation Details.** The “Top-down” semantic information in this work is initialized and extracted using CLIP, with the pre-trained model being RN50x16. The model parameters are entirely frozen and do not impact the actual training process, and thus are not included in the actual parameter count. We choose the Adam optimizer with a learning rate set to  $10^{-3}$ , momentum of 0.9, and weight decay of  $10^{-4}$ . The model training is conducted on a GPU server equipped with an NVIDIA GeForce RTX 4090 24GB GPU and an Intel(R) Xeon(R) Silver 4314 CPU @ 2.40GHz. It is worth noting that for the SCOUT network used in the comparison, we used the version without additional annotations as described in the original paper, since the original SCOUT network (Kotseruba and Tsotsos 2024) [Response Q16] involved extra dataset annotations.

**Loss function.** The loss function  $\mathcal{L}_{sal}$  is defined for predicting the saliency map  $\hat{S}$  [Response Q17] and the ground truth saliency map  $S$ .  $\mathcal{L}_{sal}$  is the BCE loss, which is formulated as follows. [Response Q17]

$$\mathcal{L}_{sal}(S, \hat{S}) = -\frac{1}{N} \sum_{i=1}^N S_i \log(\hat{S}_i) + (1-S_i) \log(1-\hat{S}_i) \quad (6)$$

## Results

To evaluate the performance of our proposed model, we conduct both qualitative and quantitative comparisons with 7 other popular methods. These include 4 static methods: MLNet (Cornia et al. 2016), CDNN (Deng et al. 2019), FBLNet (Chen, Nan, and Xiang 2023) and SCOUT (Kotseruba and Tsotsos 2024)) and 3 dynamic methods: TASED-Net (Min and Corso 2019), DrFixD-rainy (Tian, Deng, and Yan 2022) and SCAFNet (Fang et al. 2021). [Response Q18,Q21]

### Qualitative Evaluation

Figure 5 presents a qualitative comparison with the aforementioned models. For better visualization, we overlay the predicted saliency maps on the original images. Overall, we can conclude that the  $SalM^2$  model proposed demonstrates performance on par with existing models and is even more accurate in predicting driver gaze regions compared to current saliency models. In rows 1, 3, and 5 of Figure 5, we can see that existing saliency models exhibit good prediction performance for traffic lights, cars, and some road lanes in traffic scenes. However, these models fail to capture the most crucial “Top-down” information related to driving, and their results do not align well with standard saliency map. For example, in rows 2, 4, and 6 of Figure 5, the “Top-down” information related to the current driving task (such as road signs, nearby vehicles, and traffic lights) is better simulated by our model compared to other models in terms of capturing human driver attention.

Table 1: Performance comparison on BDDA using saliency evaluation metrics. Symbol  $\uparrow$  expects a larger value and  $\downarrow$  expects a smaller value. Best scores are shown in **bold**, the second best is underlined.

Model	CC $\uparrow$	SIM $\uparrow$	KLD $\downarrow$	Params (M)	FLOPs (G)
MLNet	0.14	0.12	2.68	15.45	34.46
TASED-Net	<u>0.55</u>	0.42	1.24	21.26	91.48
CDNN	0.31	0.22	2.10	<u>0.68</u>	<u>7.10</u>
SCAFNet	<b>0.64</b>	<b>0.48</b>	1.09	54.51	85.86
DrFixD-rainy	<b>0.64</b>	<u>0.47</u>	1.09	39.57	9.74
FBLNet	<b>0.64</b>	<u>0.47</u>	1.40	87.48	20.31
SCOUT	<u>0.63</u>	<b>0.48</b>	<b>1.04</b>	4.96	17.72
<i>SalM</i> <sup>2</sup>	<b>0.64</b>	<u>0.47</u>	<u>1.08</u>	<b>0.08</b>	<b>4.45</b>

## Quantitative Evaluation

We use six metrics to evaluate the performance of different prediction methods. These include five similarity metrics: Area Under the ROC Curve (AUC\_Borji (Judd et al. 2009) and AUC\_Judd (Borji, Sihite, and Itti 2012)), Normalized Scanpath Saliency (NSS (Peters et al. 2005)), Linear Correlation Coefficient (CC (Le Meur, Le Callet, and Barba 2007)), Similarity Metric (SIM (Borji, Sihite, and Itti 2012)) and one dissimilarity metric: Kullback-Leibler Divergence (KLD (Riche et al. 2013)).

Table 1 presents the quantitative performance metrics obtained by training the proposed model and other saliency models on the BDD-A dataset. As shown in the Table 1, the proposed model achieves SOTA performance or performance close to SOTA while using only approximately 11%, or even as little as 0.1%, of the parameters of other models. Additionally, our model exhibits significantly lower FLOPs compared to other models, resulting in lower computational costs and making it more suitable for deployment. Therefore, it can be concluded that the proposed *SalM*<sup>2</sup> prediction model demonstrates superior performance compared to other models.

Simultaneously, we further validated the model on two additional datasets, TrafficGaze and DrFixD-rainy, and compared it against the same algorithms. As shown in Tables 2 and 3, our model achieved either state-of-the-art (SOTA) or second-to-SOTA performance on all but one metric within the same dataset, while using only 11% to 0.1% of the parameters of other SOTA models.

## Ablation Study

**Reliable attention prediction network.** The driving scene is a dynamic environment that requires real-time feedback, necessitating an extremely efficient network for predicting driver attention. Inspired by the work of Wu et al. on medical image segmentation, we designed a lightweight backbone network better suited for predicting driver gaze points. To ensure fairness, we compare the backbone network of *SalM*<sup>2</sup> without the semantic information branch against the original network on the TrafficGaze, DrFixD-rainy, and BDD-A datasets.

As shown in Table 4, our model demonstrates leading performance across all three datasets. Except for the AUC\_Borji

Table 2: Performance comparison on TrafficGaze using saliency evaluation metrics. The symbol “-” indicates that this metric was not computed officially.

Model	AUC_Borji $\uparrow$	AUC_Judd $\uparrow$	NSS $\uparrow$	CC $\uparrow$	SIM $\uparrow$	KLD $\downarrow$
MLNet	0.87	0.90	5.69	0.87	0.45	0.87
TASED-Net	<u>0.92</u>	<b>0.97</b>	5.73	<u>0.94</u>	<b>0.79</b>	1.43
CDNN	<b>0.93</b>	<u>0.97</u>	5.83	<b>0.95</b>	<u>0.78</u>	0.29
SCAFNet	-	<b>0.98</b>	<u>6.10</u>	0.94	0.77	0.66
DrFixD-rainy	<u>0.92</u>	<b>0.98</b>	6.01	<u>0.94</u>	<u>0.78</u>	<b>0.28</b>
FBLNet	0.87	<u>0.97</u>	<b>6.50</b>	0.90	0.69	0.46
SCOUT	0.91	<u>0.97</u>	5.35	0.91	0.72	0.39
<i>SalM</i> <sup>2</sup>	<u>0.92</u>	<b>0.98</b>	5.90	0.94	<u>0.78</u>	<b>0.28</b>

Table 3: Performance comparison on DrFixD-rainy using saliency evaluation metrics.

Model	AUC_Borji $\uparrow$	AUC_Judd $\uparrow$	NSS $\uparrow$	CC $\uparrow$	SIM $\uparrow$	KLD $\downarrow$
MLNet	0.89	0.93	3.90	0.79	0.63	3.69
TASED-Net	0.88	<u>0.95</u>	4.21	0.84	0.59	0.85
CDNN	<u>0.90</u>	<u>0.95</u>	4.11	0.82	0.63	0.52
SCAFNet	<u>0.90</u>	0.94	4.17	0.84	0.67	1.87
DrFixD-rainy	<b>0.91</b>	<b>0.96</b>	4.19	<u>0.85</u>	0.67	<b>0.47</b>
FBLNet	0.88	<u>0.95</u>	<u>4.29</u>	<u>0.85</u>	<b>0.69</b>	<u>0.50</u>
SCOUT	0.90	0.95	3.95	0.84	0.65	0.50
<i>SalM</i> <sup>2</sup>	0.89	<u>0.95</u>	<b>4.31</b>	<b>0.86</b>	<u>0.68</u>	<b>0.47</b>

metric on the DrFix-rainy dataset, our model achieves superior performance on all other metrics. Therefore, our backbone network represents a more efficient backbone network for predicting driver gaze points.

**Effective Semantic Information.** In complex driving scene, the concentration of driver attention is a key factor in ensuring road safety. By understanding how specific tasks guide attention, we can design more effective driver assistance systems to improve road safety. In our experiments, the experimental group uses the model with driving task semantic information guidance (*SalM*<sup>2</sup>), while the control group uses the model without semantic information (Backbone network). We qualitatively compare the attention distribution predicted by different models in the same driving scenarios to determine the significant impact of driving tasks

Table 4: Ablation study of the backbone network. The symbol “-” indicates that this metric could not be computed due to reasons related to the dataset.

Dataset	Model	AUC_Borji $\uparrow$	AUC_Judd $\uparrow$	NSS $\uparrow$	CC $\uparrow$	SIM $\uparrow$	KLD $\downarrow$
TrafficGaze	Wu et al.	<b>0.93</b>	<b>0.98</b>	5.82	0.93	0.77	0.31
	Backbone	<b>0.93</b>	<b>0.98</b>	<b>5.87</b>	<b>0.94</b>	<b>0.78</b>	<b>0.28</b>
DrFixD-rainy	Wu et al.	<b>0.90</b>	<b>0.95</b>	4.21	0.85	0.67	0.47
	Backbone	0.89	<u>0.95</u>	<u>4.29</u>	<b>0.87</b>	<b>0.69</b>	<b>0.46</b>
BDDA	Wu et al.	-	-	-	0.62	0.45	1.12
	Backbone	-	-	-	<b>0.63</b>	<b>0.47</b>	<b>1.09</b>

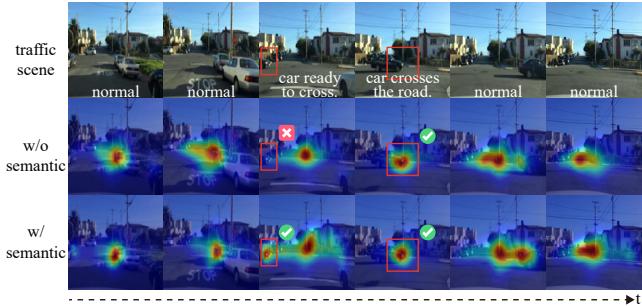


Figure 6: Visualize the driver’s attention under the semantic information of a car crossing the road. White text represents semantic information, with “normal” indicating that the driver is looking ahead and no additional information is required.

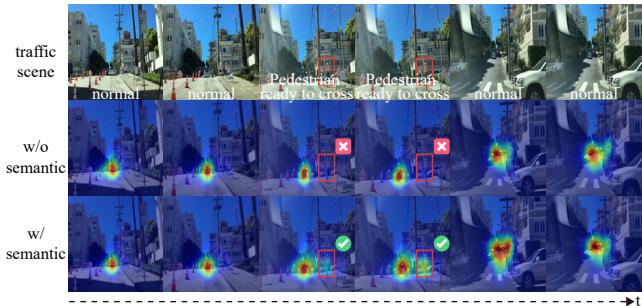


Figure 7: Visualize the driver’s attention under the semantic information of a pedestrian ready to cross the road.

on driver attention distribution.

Due to the minimal differences between consecutive frames, we applied interval sampling and selected videos with rich scene information for analysis, extracting 6 frames as a sequence (with the first two and last two frames depicting normal scenes where the driver’s attention is focused on the center of the road). Below, we analyze two such scenarios.

Scenario 1: A car crosses the road. As shown in Figure 6, when a car suddenly enters the driver’s field of view from the left, our model promptly captures this semantic information and allocates attention to the car. When the car moves to the center of the field of view, the model can still make accurate predictions even without semantic information, as the driver’s attention is typically concentrated in the center under most circumstances.

Scenario 2: A pedestrian is ready to cross the road. As shown in Figure 7, a pedestrian is positioned ahead on the right, potentially about to cross the road, requiring the driver to constantly monitor the pedestrian’s movements. With semantic information, the model can promptly allocate attention to the pedestrian, thereby enhancing the ability to avoid traffic accidents.

Overall, our model can better understand the information of the scene and adjust the driver’s attention distribution in time to improve driving safety. Meanwhile, in the scenario

where the information of the scene is single and the driver’s attention is distributed at the end of the road, our model can achieve the same or even better results than other models.

## Conclusion

In driving, a driver’s attention is predominantly focused on the area ahead, such as the road’s endpoint or the vehicle in front. However, in complex environments, this attention can shift due to sudden events in the field of view, making the semantic information of the current driving scene crucial for understanding driver attention. We have investigated driver attention through the lens of dual-process visual cognition and developed a driver attention prediction model based on driving scene information. This model integrates “Top-down” semantic information (high-level) with “Bottom-up” image information (low-level) for effective attention prediction.

Extensive experiments demonstrate that guiding model understanding of driver attention through driving scene information can be an effective approach. Our model achieves SOTA or near-SOTA performance with minimal parameters. In future work, we aim to explore more effective methods for using driving scene semantic information to guide driver attention prediction, further improving prediction accuracy.

## References

- Alkaabi, K. 2023. Identification of hotspot areas for traffic accidents and analyzing drivers’ behaviors and road accidents. *Transportation research interdisciplinary perspectives*, 22: 100929.
- Alletto, S.; Palazzi, A.; Solera, F.; Calderara, S.; and Cucchiara, R. 2016. Dr (eye) ve: a dataset for attention-based tasks with applications to autonomous and assisted driving. In *Proceedings of the ieee conference on computer vision and pattern recognition workshops*, 54–60.
- Bae, S.; Pakdamanian, E.; Kim, I.; Feng, L.; Ordonez, V.; and Barnes, L. 2021. Medirl: Predicting the visual attention of drivers via maximum entropy deep inverse reinforcement learning. In *Proceedings of the IEEE/CVF international conference on computer vision*, 13178–13188.
- Balasubramani, S.; Aravindh, J.; Renjith, P.; and Ramesh, K. 2024. DDSS: Driver decision support system based on the driver behaviour prediction to avoid accidents in intelligent transport system. *International Journal of Cognitive Computing in Engineering*, 5: 1–13.
- Borji, A.; Sihite, D. N.; and Itti, L. 2012. Quantitative analysis of human-model agreement in visual saliency modeling: A comparative study. *IEEE Transactions on Image Processing*, 22(1): 55–69.
- Brishtel, I.; Krauß, S.; Schmidt, T.; Rambach, J. R.; Vozniak, I.; and Stricker, D. 2022. Classification of Manual Versus Autonomous Driving based on Machine Learning of Eye Movement Patterns. In *2022 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, 700–705.
- Chen, Y.; Nan, Z.; and Xiang, T. 2023. FBLNet: FeedBack Loop Network for Driver Attention Prediction. In *Proceedings of the IEEE/CVF International Conference on Computer Vision*, 13371–13380.

- Cornia, M.; Baraldi, L.; Serra, G.; and Cucchiara, R. 2016. A deep multi-level network for saliency prediction. In *2016 23rd International Conference on Pattern Recognition (ICPR)*, 3488–3493. IEEE.
- Deng, T.; Jiang, L.; Shi, Y.; Wu, J.; Wu, Z.; Yan, S.; Zhang, X.; and Yan, H. 2023. Driving visual saliency prediction of dynamic night scenes via a spatio-temporal dual-encoder network. *IEEE Transactions on Intelligent Transportation Systems*.
- Deng, T.; Yan, F.; and Yan, H. 2021. Driving Video Fixation Prediction Model Via Spatio-Temporal Networks and Attention Gates. In *2021 IEEE International Conference on Multimedia and Expo (ICME)*, 1–6.
- Deng, T.; Yan, H.; and Li, Y.-J. 2017. Learning to boost bottom-up fixation prediction in driving environments via random forest. *IEEE Transactions on Intelligent Transportation Systems*, 19(9): 3059–3067.
- Deng, T.; Yan, H.; Qin, L.; Ngo, T.; and Manjunath, B. 2019. How do drivers allocate their potential attention? Driving fixation prediction via convolutional neural networks. *IEEE Transactions on Intelligent Transportation Systems*, 21(5): 2146–2154.
- Du, P.; Deng, T.; and Yan, F. 2023. What Causes a Driver’s Attention Shift? A Driver’s Attention-Guided Driving Event Recognition Model. In *2023 International Joint Conference on Neural Networks (IJCNN)*, 1–8. IEEE.
- Evans, K. K.; Horowitz, T. S.; Howe, P.; Pedersini, R.; Reijnen, E.; Pinto, Y.; Kuzmova, Y.; and Wolfe, J. M. 2011. Visual attention. *Wiley Interdisciplinary Reviews: Cognitive Science*, 2(5): 503–514.
- Fang, J.; Wang, F.; Xue, J.; and Chua, T.-S. 2024. Behavioral intention prediction in driving scenes: A survey. *IEEE Transactions on Intelligent Transportation Systems*.
- Fang, J.; Yan, D.; Qiao, J.; and Xue, J. 2019. Dada: A large-scale benchmark and model for driver attention prediction in accidental scenarios. *arXiv preprint arXiv:1912.12148*, 3.
- Fang, J.; Yan, D.; Qiao, J.; Xue, J.; and Yu, H. 2021. DADA: Driver attention prediction in driving accident scenarios. *IEEE transactions on intelligent transportation systems*, 23(6): 4959–4971.
- Fang, J.; Yan, D.; Qiao, J.; Xue, J.; and Yu, H. 2022. DADA: Driver Attention Prediction in Driving Accident Scenarios. *IEEE Transactions on Intelligent Transportation Systems*, 23(6).
- Fu, J.; Liu, J.; Tian, H.; Li, Y.; Bao, Y.; Fang, Z.; and Lu, H. 2019. Dual attention network for scene segmentation. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, 3146–3154.
- Hertz-Pannier, N.; Rozenblit, D.; Lavi, S.; Zeltser, J.; Kviatek, Y.; and Lazarov, A. 2023. Aberrant reward learning, but not negative reinforcement learning, is related to depressive symptoms: an attentional perspective. *Psychological Medicine*, 1–14.
- Itti, L.; and Koch, C. 2001. Computational modelling of visual attention. *Nature reviews neuroscience*, 2(3): 194–203.
- Judd, T.; Ehinger, K.; Durand, F.; and Torralba, A. 2009. Learning to predict where humans look. In *2009 IEEE 12th international conference on computer vision*, 2106–2113. IEEE.
- Kotseruba, I.; and Tsotsos, J. K. 2024. SCOUT+: Towards Practical Task-Driven Drivers’ Gaze Prediction. *arXiv preprint arXiv:2404.08756*.
- Le Meur, O.; Le Callet, P.; and Barba, D. 2007. Predicting visual fixations on video based on low-level visual features. *Vision research*, 47(19): 2483–2498.
- Min, K.; and Corso, J. J. 2019. Tased-net: Temporally-aggregating spatial encoder-decoder network for video saliency detection. In *Proceedings of the IEEE/CVF International Conference on Computer Vision*, 2394–2403.
- Peters, R. J.; Iyer, A.; Itti, L.; and Koch, C. 2005. Components of bottom-up gaze allocation in natural images. *Vision research*, 45(18): 2397–2416.
- Qin, L.; Shi, Y.; He, Y.; Zhang, J.; Zhang, X.; Li, Y.; Deng, T.; and Yan, H. 2022. ID-YOLO: Real-time salient object detection based on the driver’s fixation region. *IEEE Transactions on Intelligent Transportation Systems*, 23(9): 15898–15908.
- Radford, A.; Kim, J. W.; Hallacy, C.; Ramesh, A.; Goh, G.; Agarwal, S.; Sastry, G.; Askell, A.; Mishkin, P.; Clark, J.; Krueger, G.; and Sutskever, I. 2021. Learning Transferable Visual Models From Natural Language Supervision. *arXiv:2103.00020*.
- Rasouli, A.; and Tsotsos, J. K. 2018. Joint attention in driver-pedestrian interaction: from theory to practice. *arXiv preprint arXiv:1802.02522*.
- Riche, N.; Duvinage, M.; Mancas, M.; Gosselin, B.; and Dutuit, T. 2013. Saliency and human fixations: State-of-the-art and study of comparison metrics. In *Proceedings of the IEEE international conference on computer vision*, 1153–1160.
- Shen, Y.; Wijayaratne, N.; Sriram, P.; Hasan, A.; Du, P.; and Driggs-Campbell, K. 2022. CoCAtt: A cognitive-conditioned driver attention dataset. In *2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC)*, 32–39. IEEE.
- Shi, Y.; Zhao, S.; Wu, J.; Wu, Z.; and Yan, H. 2023. Fixed object detection based on saliency prior in traffic scenes. *IEEE Transactions on Circuits and Systems for Video Technology*.
- Tawari, A.; Møgelmose, A.; Martin, S.; Moeslund, T. B.; and Trivedi, M. M. 2014. Attention estimation by simultaneous analysis of viewer and view. In *17th International IEEE Conference on Intelligent Transportation Systems (ITSC)*, 1381–1387. IEEE.
- Tian, H.; Deng, T.; and Yan, H. 2022. Driving as well as on a sunny day? predicting driver’s fixation in rainy weather conditions via a dual-branch visual model. *IEEE/CAA Journal of Automatica Sinica*, 9(7): 1335–1338.
- Vozniak, I.; Müller, P.; Hell, L.; Lipp, N.; Abouelazm, A.; and Müller, C. 2023. Context-empowered visual attention prediction in pedestrian scenarios. In *Proceedings of the*

*IEEE/CVF Winter Conference on Applications of Computer Vision*, 950–960.

Wu, R.; Liu, Y.; Liang, P.; and Chang, Q. 2024. Ultra-light vm-unet: Parallel vision mamba significantly reduces parameters for skin lesion segmentation. *arXiv preprint arXiv:2403.20035*.

Xia, Y.; Zhang, D.; Kim, J.; Nakayama, K.; Zipser, K.; and Whitney, D. 2019. Predicting driver attention in critical situations. In *Computer Vision–ACCV 2018: 14th Asian Conference on Computer Vision, Perth, Australia, December 2–6, 2018, Revised Selected Papers, Part V 14*, 658–674. Springer.