GFR-CAM: Gram-Schmidt Feature Reduction for Hierarchical Class Activation Maps

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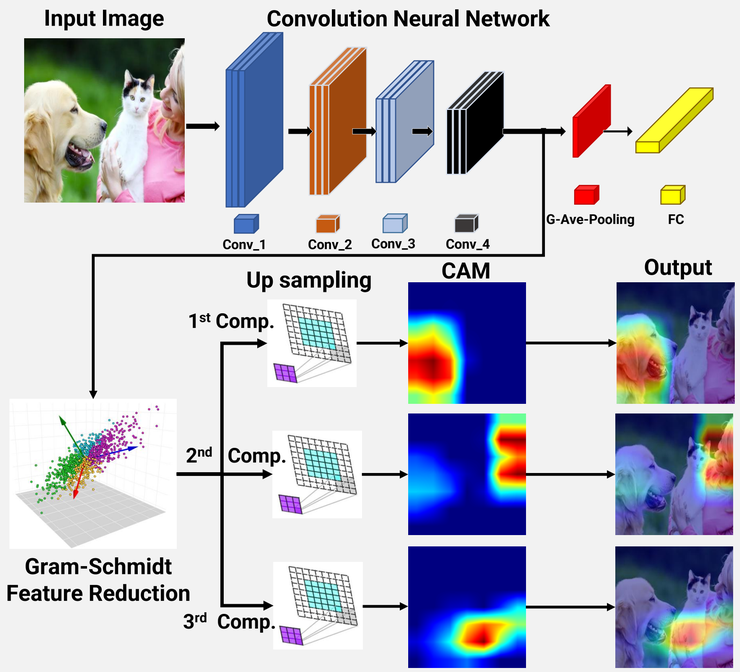
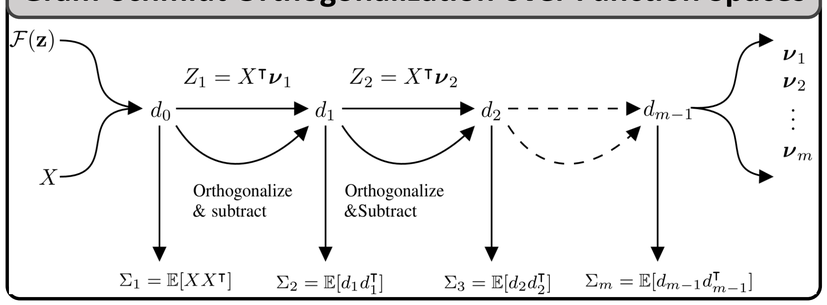
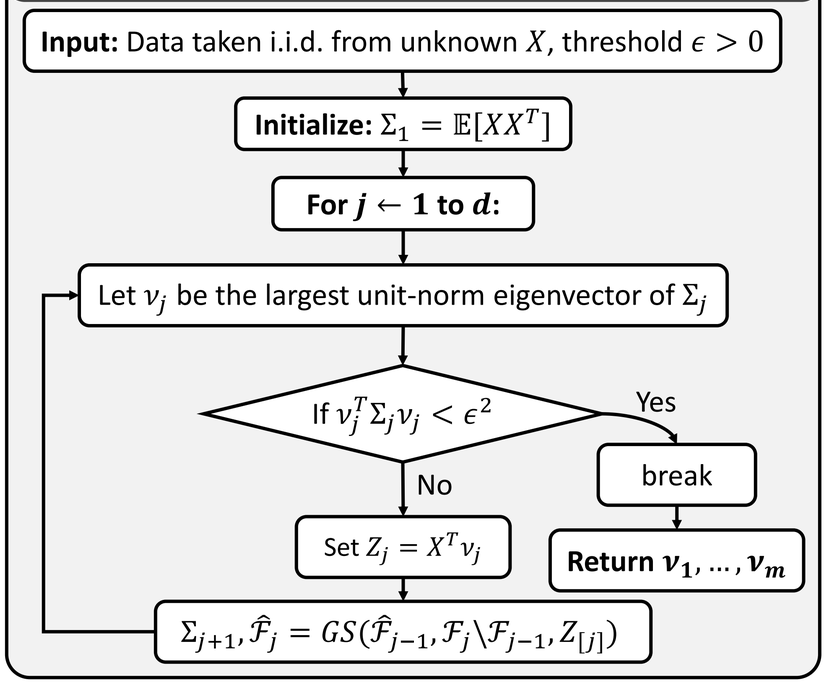
Class Activation Maps (CAMs) are widely used for visual explanations, but existing methods produce single, consolidated heatmaps that create explanatory tunnel vision, failing to capture the multi-faceted reasoning behind model predictions in complex scenes. To address this limitation, we propose **Gram-Schmidt Feature Reduction Class Activation Map (GFR-CAM)**, a novel gradient-free framework that introduces hierarchical feature decomposition to provide a more comprehensive and interpretable understanding of model behavior. GFR-CAM employs Gram-Schmidt orthogonalization to systematically extract a sequence of orthogonal, information-rich components from convolutional or transformer feature maps.



Gram-Schmidt Orthogonalization over Function Spaces



Gram-Schmidt Feature Reduction Class Activation Mapping (GFR-CAM)



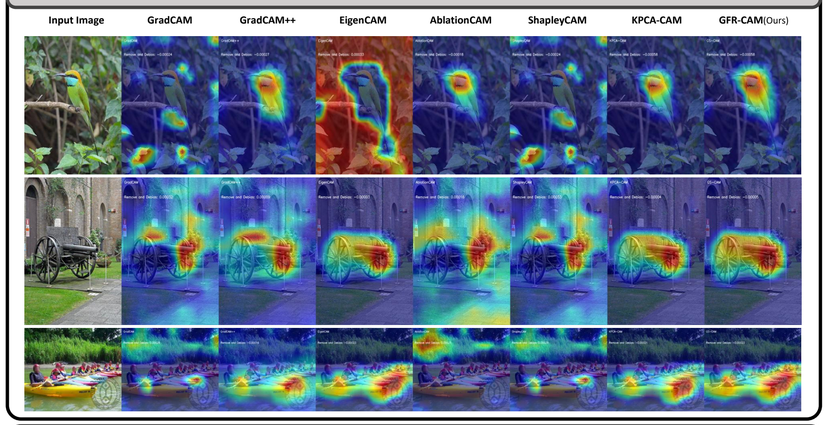
Quantitative comparison of CAM methods on ResNet-50

Method	AD ↓	Coh ↑	Com ↑	ADCC ↑	IC ↑	ADD ↑
GradCAM	12.73	88.12	40.13	67.22	41.97	44.19
GradCAM++[5]	13.79	96.49	**48.22**	71.23	42.85	37.02
HiResCAM	14.35	61.74	20.49	5.07	40.52	43.71
ShapleyCAM-E	12.28	**98.43**	41.27	82.59	39.33	36.23
KPCA CAM	13.98	90.21	35.67	16.23	40.01	41.11
ShapleyCAM	11.75	89.36	39.58	**83.74**	38.29	43.57
GFRCAM (Ours)	**11.17**	91.74	30.91	20.27	**43.31**	**45.57**

Quantitative comparison of CAM methods on Swin Transformer

Method	AD ↓	Coh ↑	Com ↑	ADCC ↑	IC ↑	ADD ↑
GradCAM	57.76	41.38	23.77	6.16	5.45	23.17
GradCAM++	68.15	49.67	25.03	3.65	12.42	24.85
XGradCAM[12]	83.73	50.48	31.63	4.06	21.71	19.58
LayerCAM[16]	71.28	58.94	28.26	5.17	–	–
HiResCAM	82.54	51.48	17.25	6.19	**25.12**	21.45
ShapleyCAM	67.22	**64.93**	30.20	**7.49**	17.42	27.18
GFRCAM (Ours)	**72.39**	62.17	**32.81**	6.53	13.82	**27.43**

Qualitative Evaluation of Visual Explanations



Beyond the First Component: The Explanatory Power of GFR-CAM