When Integral Meets Decomposition: A Signal-Level Self-Supervised Feature Decompose Paradigm for Multi-Modal Image Fusion

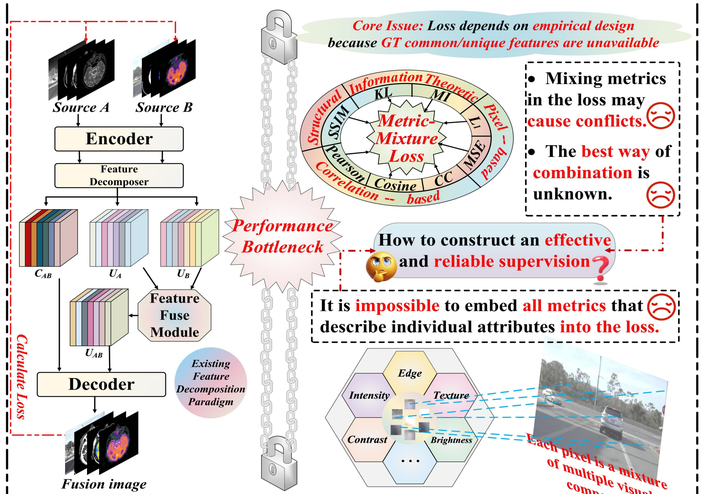
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NEURAL INFORMATION PROCESSING SYSTEMS

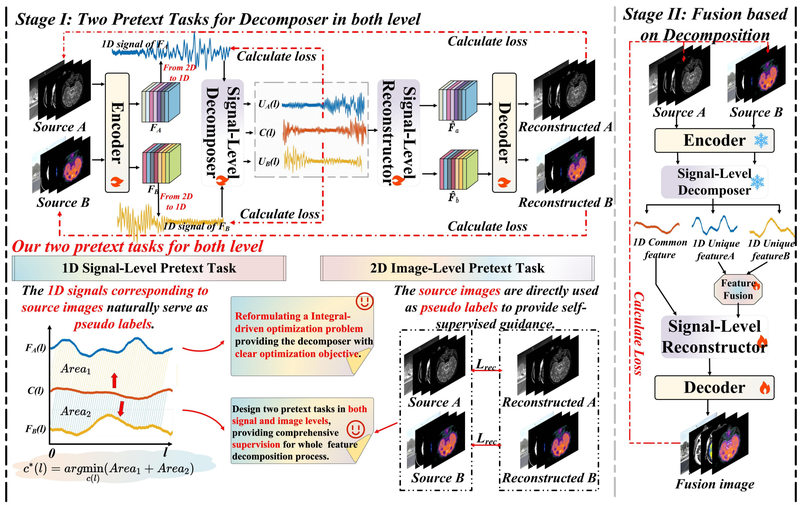
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Motivation



A) Illustration of Problem Analysis and Performance Bottleneck in Currently Feature Decomposition Paradigm

Method

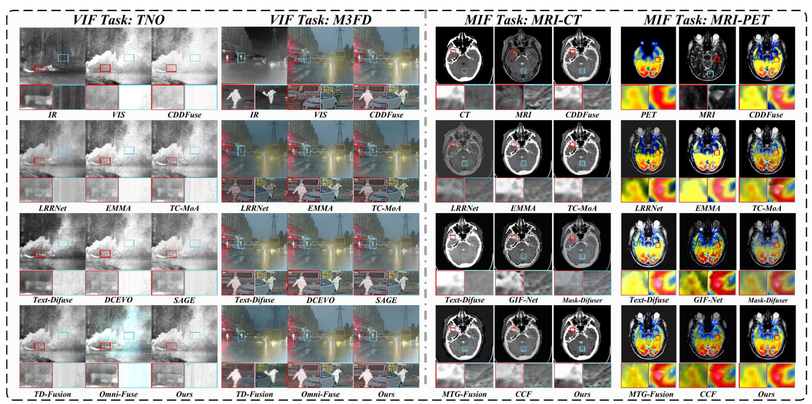


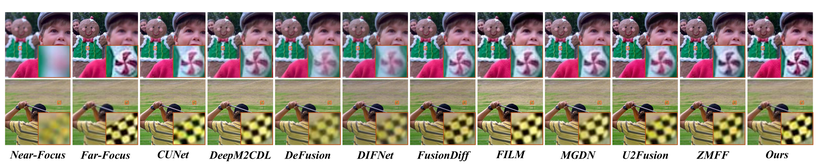
B) Illustration of Proposed 1D Signal-Level Feature Decomposition Paradigm

Contributions

- ***A novel self-supervised feature decomposition paradigm at 1D signal-level** to enable accurate feature decomposition.*
- ***Reformulate the feature decomposition problem** from an image-level supervision problem with unclear objectives into a signal-level integral optimization problem with an explicit mathematical objective.*
- ***Complementary dual pretext tasks at both levels.** The signal-level task offers strong mathematical constraints for decomposition, while the image-level task ensures reliable spatial structures.*

Qualiative Comparisons



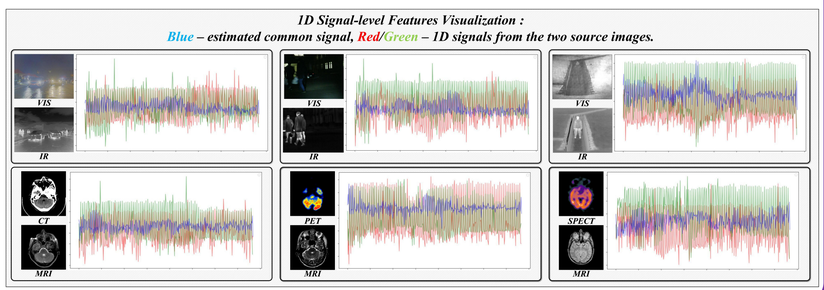


Quantitative Comparisons

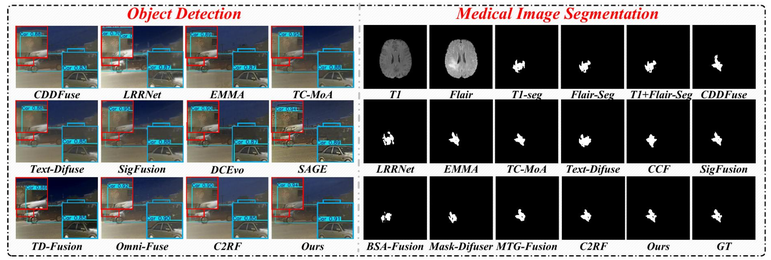
VIF Task	M3FD							MSRS							TNO						
Methods	Pub/Year	$Q_{SF}\uparrow$	$Q_{SCD}\uparrow$	$Q_Y\uparrow$	$Q_{CB}\uparrow$	$MI\uparrow$	$VIF_\omega\uparrow$	$Q_S\uparrow$	$Q_{SF}\uparrow$	$Q_{SCD}\uparrow$	$Q_Y\uparrow$	$Q_{CB}\uparrow$	$MI\uparrow$	$VIF_\omega\uparrow$	$Q_S\uparrow$	$Q_{SF}\uparrow$	$Q_{SCD}\uparrow$	$Q_Y\uparrow$	$Q_{CB}\uparrow$	$MI\uparrow$	$VIF_\omega\uparrow$	$Q_S\uparrow$
CDDFuse	CVPR 23	0.5741	0.8123	0.4554	0.4746	3.8730	0.4410	0.8698	0.7356	0.8229	0.5399	0.5669	4.9889	0.5106	0.8267	0.4654	0.8090	0.3789	0.4504	3.0691	0.4428	0.7874
LRRNet	TPAMI 23	0.6353	0.8073	0.3709	0.4346	2.8124	0.3550	0.7209	0.6608	0.8082	0.3372	0.3928	2.8662	0.2933	0.5067	0.3686	0.8062	0.2303	0.4831	2.3868	0.3685	0.7011
EMMA	CVPR 24	0.5564	0.8118	0.4602	0.4775	3.7712	0.4690	0.7979	0.6413	0.8161	0.4961	0.5432	4.1637	0.5230	0.7840	0.4356	0.8081	0.3550	0.5112	2.9089	**0.4847**	0.8072
TC-MoA	CVPR 24	0.5011	0.8096	0.5133	0.4934	3.3330	0.4603	0.8538	0.7446	0.8119	0.4833	0.5558	3.4925	0.4924	0.8825	0.4068	0.8071	0.4020	0.5124	2.5747	0.4312	0.8664
Text-DiFuse	NeurIPS 24	0.4262	0.8057	0.4323	0.3398	2.0535	0.1574	0.2566	0.7252	0.8032	0.5378	0.3660	1.3095	0.1570	0.2122	0.2977	0.8047	0.1167	0.4296	1.8773	0.2638	0.4410
DCEvo	CVPR 25	0.6085	0.8135	0.4692	0.4801	4.0074	0.4485	0.8987	0.6246	0.8170	0.4967	0.5627	4.0493	0.5107	0.8650	**0.5739**	0.8125	0.4280	0.5089	3.6054	0.4605	**0.9060**
SAGE	CVPR 25	0.4566	0.8080	0.4338	0.4647	2.8508	0.4257	0.8324	0.5153	0.8101	0.4348	0.4775	2.9895	0.3455	0.7732	0.3731	0.8060	0.3323	0.4715	2.2033	0.3963	0.7855
TD-Fusion	CVPR 25	0.4494	0.8081	0.4987	**0.5108**	3.0290	0.4629	0.8519	0.7462	0.8082	0.4170	0.5268	2.8434	0.4407	0.7922	0.3640	0.8062	0.3512	0.5288	2.4507	0.4317	0.8183
Omni-Fuse	TPAMI 25	0.4882	0.8092	0.4770	0.4776	3.2075	0.4432	0.8543	0.7208	0.8077	0.5174	0.4211	2.6643	0.4121	0.7609	0.4374	0.8071	0.1908	0.4374	2.2871	0.3933	0.6406
C2RF	IJCV 25	0.4082	0.8075	0.4989	0.3882	2.4979	0.2241	0.4293	0.6928	0.8039	0.4922	0.4246	1.7292	0.1589	0.3892	0.3535	0.8059	0.1847	0.4362	2.0637	0.2975	0.6155
SigFusion	AAAI 26	**0.7123**	0.8186	0.4665	0.4796	**4.5751**	0.4478	**0.9239**	0.8034	0.8256	**0.5492**	0.5643	4.9123	0.4432	0.8772	0.5296	0.8114	0.3936	0.5064	3.2423	0.4455	0.8911
Ours	-	0.6608	**0.8209**	**0.5735**	0.4998	4.1050	**0.4694**	0.8988	**0.8405**	**0.8290**	0.5483	**0.5798**	**5.4547**	**0.5253**	**0.8936**	0.5711	**0.8128**	**0.4318**	**0.5356**	**3.8015**	0.4768	0.8450

MIF Task	MRI-CT							MRI-PET							MRI-SPECT						
Methods	Pub/Year	$Q_{SF}\uparrow$	$Q_{SCD}\uparrow$	$Q_Y\uparrow$	$Q_{CB}\uparrow$	$MI\uparrow$	$VIF_\omega\uparrow$	$Q_S\uparrow$	$Q_{SF}\uparrow$	$Q_{SCD}\uparrow$	$Q_Y\uparrow$	$Q_{CB}\uparrow$	$MI\uparrow$	$VIF_\omega\uparrow$	$Q_S\uparrow$	$Q_{SF}\uparrow$	$Q_{SCD}\uparrow$	$Q_Y\uparrow$	$Q_{CB}\uparrow$	$MI\uparrow$	$VIF_\omega\uparrow$	$Q_S\uparrow$
CDDFuse	CVPR 23	0.8403	0.8098	0.4122	0.6911	3.7522	0.3735	0.9047	0.7856	0.8064	0.4448	**0.7213**	2.7359	0.3872	**0.9125**	0.8778	0.8068	0.6289	**0.7305**	2.7296	0.4480	0.9118
LRRNet	TPAMI 23	0.6273	0.8066	0.2073	0.2205	2.7570	0.2295	0.3285	0.6427	0.8051	0.3809	0.2129	**3.6627**	0.2807	0.3122	0.7355	0.8056	0.3580	0.1839	**3.8263**	0.2607	0.2763
EMMA	CVPR 24	0.7032	0.8078	0.3160	0.5627	3.2790	0.3575	0.7590	0.6648	0.8055	0.3177	0.5606	2.4481	0.3577	0.7433	0.7086	0.8057	0.3368	0.4834	2.3611	0.3660	0.6633
TC-MoA	CVPR 24	0.7279	0.8080	0.3686	0.5838	3.3169	0.3751	0.7782	0.6758	0.8055	0.4692	0.6129	2.4498	0.3900	0.8394	0.7397	0.8059	0.5564	0.5426	2.3331	0.4422	0.7659
Text-DiFuse	NeurIPS 24	0.6456	0.8075	0.2643	0.3239	3.1594	0.3150	0.3891	0.5235	0.8051	0.3118	0.2606	2.3310	0.2973	0.2630	0.5638	0.8053	0.3649	0.1976	2.2253	0.3261	0.2550
CCF	NeurIPS 24	0.7361	0.8079	0.2825	0.3479	3.2844	0.2968	0.4329	0.6439	0.8050	0.2733	0.2637	2.4926	0.2854	0.3114	0.7520	0.8058	0.3911	0.2372	2.9410	0.3356	0.3177
BSAFusion	AAAI 25	0.6929	0.8079	0.3229	0.3905	3.2802	0.3435	0.4578	0.7470	0.8068	0.4788	0.3446	2.8615	0.4197	0.4200	0.8150	0.8072	0.6393	0.3106	2.7563	**0.4550**	0.3766
Mask-Difuser	TPAMI 25	0.7171	0.8081	0.3595	0.3443	3.2990	0.3088	0.4206	0.6911	0.8062	0.4399	0.3035	2.7060	0.3676	0.3590	0.7334	0.8062	0.5022	0.2620	2.5270	0.3672	0.3300
MTG-fusion	IJCV 25	0.6610	0.8076	0.3896	0.3466	3.1782	0.2873	0.4343	0.5958	0.8053	0.3977	0.2651	2.3778	0.3043	0.3453	0.6129	0.8053	0.3987	0.2673	2.3096	0.2844	0.3084
C2RF	IJCV 25	0.6374	0.8072	0.1306	0.3464	2.9530	0.2188	0.3220	0.5827	0.8050	0.2842	0.3543	2.1825	0.2205	0.2686	0.6760	0.8055	0.5087	0.3513	2.2566	0.3184	0.2887
SigFusion	AAAI 26	0.8176	0.8086	**0.6689**	0.3560	3.4913	0.3819	0.9063	0.8762	0.8074	0.4965	0.7157	3.0495	**0.4610**	0.4273	0.8310	**0.8083**	0.5162	0.6621	2.8941	0.4418	0.8798
Ours	-	**0.9369**	**0.8108**	0.4034	**0.7008**	**4.0184**	**0.4034**	**0.9439**	**0.8843**	**0.8074**	**0.4967**	0.4740	3.0547	0.4577	0.5808	**0.9778**	**0.8083**	0.5507	0.6697	3.0655	0.4520	**0.9149**

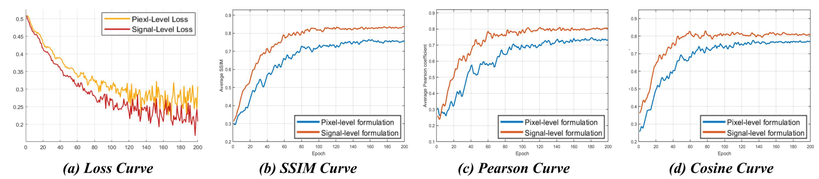
Signal Visualizations



Downstream Tasks



Training Curve



(a) Loss Curve *(b) SSIM Curve* *(c) Pearson Curve* *(d) Cosine Curve*

- ***Our signal-level objective converges faster and achieves a lower final loss, while maintaining higher and more stable similarity between the learned common features and source signals.***