

# Novelty Assessment Report

**Paper:** Bound by semanticity: universal laws governing the generalization-identification tradeoff

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**Venue:** ICLR 2026 Conference Submission

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## Abstract

Intelligent systems must form internal representations that support both broad generalization and precise identification. Here, we show that these two goals are fundamentally in tension with one another. We derive closed-form expressions proving that any model whose representations have a finite semantic resolution, impairing long-range similarity computations, must lie on a universal Pareto front linking its probability of correct generalization  $p_S$  and identification  $p_I$ . We extend this analysis to general input spaces and to parallel processing scenarios, predicting a sharp  $1/n$  collapse in the capacity of processing multiple inputs at the same time. A minimal ReLU network reproduces these laws: a resolution boundary emerges during learning, and empirical  $(p_S, p_I)$  trajectories closely match the theory for linearly decaying similarity. Finally, we show that the same limits appear in far more complex systems, including a convolutional neural network and state-of-the-art vision-language models, indicating that learned finite-resolution similarity are broad and foundational informational constraints rather than toy-model artifacts. Together, these results provide a precise theory of the generalization-identification tradeoff and clarify how semantic resolution shapes the representational capacity of deep networks and brains alike.

### Disclaimer

This report is **AI-GENERATED** using Large Language Models and WisPaper (a scholar search engine). It analyzes academic papers' tasks and contributions against retrieved prior work. While this system identifies **POTENTIAL** overlaps and novel directions, **ITS COVERAGE IS NOT EXHAUSTIVE AND JUDGMENTS ARE APPROXIMATE**. These results are intended to assist human reviewers and **SHOULD NOT** be relied upon as a definitive verdict on novelty.

Note that some papers exist in multiple, slightly different versions (e.g., with different titles or URLs). The system may retrieve several versions of the same underlying work. The current automated pipeline does not reliably align or distinguish these cases, so human reviewers will need to disambiguate them manually.

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## Core Task Landscape

This paper addresses: **Generalization-Identification Tradeoff in Neural Representations**

A total of **50 papers** were analyzed and organized into a taxonomy with **21 categories**.

### Taxonomy Overview

The research landscape has been organized into the following main categories:

- **Theoretical Foundations and Formal Analysis**
- **Empirical Characterization of Learned Representations**
- **Architecture-Specific Analysis and Design**
- **Application-Driven Methods and Domain-Specific Solutions**
- **Generalization Metrics and Prediction**

### Complete Taxonomy Tree

- Generalization-Identification Tradeoff in Neural Representations Survey Taxonomy
- Theoretical Foundations and Formal Analysis
  - Fundamental Tradeoff Principles ★ (3 papers)
  - [0] Bound by semanticity: universal laws governing the generalization-identification tradeoff (Anon et al., 2026) [View paper](#)
  - [7] Robust generalization of quadratic neural networks via function identification (Xu Kan, 2021) [View paper](#)
  - [31] On the discrimination-generalization tradeoff in GANs (Pengchuan Zhang, 2017) [View paper](#)
  - Representational Dimensionality and Geometry (3 papers)
  - [5] The dimensionality of neural representations for control (David Badre, 2021) [View paper](#)
  - [8] The sparseness of mixed selectivity neurons controls the generalization-discrimination trade-off (Omri Barak, 2013) [View paper](#)
  - [39] The geometry of neural representational spaces and the trade-off between generalization and separation (Liapis, 2024) [View paper](#)
  - Optimization Dynamics and Convergence (3 papers)
  - [13] Inversion dynamics of class manifolds in deep learning reveals tradeoffs underlying generalization (LucÃa Cassani, 2023) [View paper](#)
  - [18] Representation and regression problems in neural networks: Relaxation, generalization, and numerics (Kang Liu, 2025) [View paper](#)
  - [42] Dynamics of learning and generalization in neural networks (Mohammad, 2023) [View paper](#)
- Empirical Characterization of Learned Representations
  - Cross-Domain and Out-of-Distribution Generalization (4 papers)
  - [12] Generalizing outside the training set: When can neural networks learn identity effects? (Simone Brugiapaglia, 2020) [View paper](#)
  - [14] When and how convolutional neural networks generalize to out-of-distribution category-viewpoint combinations (Spandan Madan, 2022) [View paper](#)
  - [15] MLDGG: Meta-Learning for Domain Generalization on Graphs (Qin Tian, 2024) [View paper](#)
  - [19] Generalisation in humans and deep neural networks (Geirhos, 2018) [View paper](#)
  - Temporal and Sequential Representation Dynamics (3 papers)
  - [1] Impact of symmetry in local learning rules on predictive neural representations and generalization in spatial navigation (Janis Keck, 2025) [View paper](#)
  - [16] Characterizing the dynamics of mental representations: the temporal generalization method (John R. King, 2014) [View paper](#)

- [22] Subject-Independent Imagined Speech Detection via Cross-Subject Generalization and Calibration (Byung-Kwan Ko, 2025) [View paper](#)
- Frequency and Multi-Scale Feature Analysis (2 papers)
- [4] High-frequency component helps explain the generalization of convolutional neural networks (Haohan Wang, 2020) [View paper](#)
- [34] Representation compression and generalization in deep neural networks (Ravid Shwartz-Ziv, 2018) [View paper](#)
- Comparative Studies Across Architectures (3 papers)
- [17] Representations and generalization in artificial and brain neural networks. (Qianyi Li, 2024) [View paper](#)
- [29] Comparing CNN and ViT for Open-Set Face Recognition (Ander Galvan, 2025) [View paper](#)
- [44] eLife assessment: Factorized visual representations in the primate visual system and deep neural networks (Srdjan Ostojic, 2024) [View paper](#)
- Testing and Validation Methodologies (2 papers)
- [25] Testing the generalization of neural representations (Florian Sandhaeger, 2023) [View paper](#)
- [45] Neural representations that support invariant object recognition (Robbe L. T. Goris, 2009) [View paper](#)
- Architecture-Specific Analysis and Design
  - Implicit Neural Representations (2 papers)
  - [3] Generalized Implicit Neural Representations for Dynamic Molecular Surface Modeling (Hu, 2025) [View paper](#)
  - [6] Generalizable implicit neural representations via instance pattern composers (Chiheon Kim, 2023) [View paper](#)
  - Convolutional and Attention Architectures (3 papers)
  - [10] Deep learning face representation by joint identification-verification (Y Sun, 2014) [View paper](#)
  - [27] Seismic Phase Picking Using a Cross-Attention Network on NVIDIA Jetson Xavier NX (Bo Lan, 2024) [View paper](#)
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  - [47] Addi-Reg: A Better Generalization-Optimization Tradeoff Regularization Method for Convolutional Neural Networks. (Yao Lu, 2022) [View paper](#)
  - Hyperparameter and Training Configuration Analysis (2 papers)
  - [23] Comprehensive Analysis of the Impact of Learning Rate and Dropout Rate on the Performance of Convolutional Neural Networks on the CIFAR-10 Dataset (Peng, 2024) [View paper](#)
  - [37] Optimizing CNN Models for Flower Image Classification: A Comparative Study of Accuracy, Efficiency, and Real-World Deployment (Yang Qian, 2025) [View paper](#)
- Application-Driven Methods and Domain-Specific Solutions
  - Computer Vision and Image Analysis (3 papers)
  - [11] Surface defect detection of aluminum profiles based on deep learning (Yuqian Wang, 2024) [View paper](#)
  - [40] PLDCâ€Net: Potato Leaf Disease Classification Network Based on an Efficient Convolutional Neural Network (Said Khalid Shah, 2025) [View paper](#)
  - [46] Iron Ore Image Recognition Through Multi-View Evolutionary Deep Fusion Method (Di Zhang, 2025) [View paper](#)
  - Biological and Medical Signal Processing (2 papers)
  - [9] A Novel Approach Utilizing Domain Adversarial Neural Networks for the Detection and Classification of Selective Sweeps (Hui Song, 2024) [View paper](#)
  - [24] Assessment of Parkinson's Motor Severity by Multi-feature and Multi-scale Motion Convolutional Neural Network with Positional Encoding (Ying Zhou, 2023) [View paper](#)
  - Spatial and Temporal Forecasting (3 papers)
  - [20] Citywide Mobile Traffic Forecasting Using Spatial-Temporal Downsampling Transformer Neural Networks (Yahui Hu, 2023) [View paper](#)
  - [38] Neural Architecture Search for global multi-step Forecasting of Energy Production Time Series (Lessmann, 2025) [View paper](#)
  - [41] A Surrogate model for High Temperature Superconducting Magnets to Predict Current Distribution with Neural Network (Song Peng, 2025) [View paper](#)
  - Remote Sensing and Geospatial Analysis (2 papers)
  - [2] Mamba collaborative implicit neural representation for hyperspectral and multispectral remote sensing image fusion (Chunyu Zhu, 2025) [View paper](#)
  - [28] Generalization Metrics for Neural Modeling Applications in System Identification (Reeves, 2024) [View paper](#)
  - Natural Language and Text Processing (1 papers)
  - [33] Enhancing Representation Generalization in Authorship Identification (Wang Haining, 2023) [View paper](#)
  - Neuroscience and Cognitive Modeling (2 papers)
  - [26] Neural mechanisms balancing accuracy and flexibility in working memory and decision tasks. (Han Yan, 2025) [View paper](#)
  - [49] Neural representation of abstract task structure during generalization. (Avinash R Vaidya, 2021) [View paper](#)
  - Physical and Engineering System Modeling (1 papers)
  - [35] Bias-Corrected Eddy-Current Simulation Using a Recurrent-Neural-Net / Finite-Element Hybrid Model (Moritz von Tresckow, 2025) [View paper](#)
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  - Metric Design and Validation (2 papers)
  - [30] Identifying generalization properties in neural networks (Wang Huan, 2018) [View paper](#)
  - [36] Generalization of patterns by identification with polynomial neural network (Ladislav Zjavka, 2010) [View paper](#)
  - Meta-Learning and Adaptive Methods (2 papers)
  - [32] Identifying the impact of Metaperceptron in optimizing neural networks: a comparative study of gradient descent and metaheuristic approaches (Darwin Darwin, 2025) [View paper](#)
  - [50] A Laplacian-based Quantum Graph Neural Network for Semi-Supervised Learning (Bozorgnia, 2024) [View paper](#)

## Narrative

Core task: understanding the generalization-identification tradeoff in neural representations. This field examines how neural networks balance the ability to generalize across diverse inputs with the capacity to identify or discriminate specific instances, a tension that arises in many learning scenarios. The taxonomy organizes research into five main branches: Theoretical Foundations and Formal Analysis explores fundamental principles governing this tradeoff, often through mathematical frameworks and information-theoretic perspectives;

Empirical Characterization of Learned Representations investigates how real networks encode and organize information, revealing patterns in representation geometry and selectivity; Architecture-Specific Analysis and Design examines how particular model structures (e.g., convolutional networks, transformers) shape the tradeoff; Application-Driven Methods and Domain-Specific Solutions address practical challenges in areas like computer vision, neuroscience, and signal processing; and Generalization Metrics and Prediction develops tools to measure and forecast model behavior. Works like Mixed Selectivity Tradeoff[8] and High Frequency Generalization[4] illustrate early theoretical insights, while more recent studies such as Representation Compression Generalization[34] and Identifying Generalization Properties[30] bridge theory and empirical observation.

Several active lines of work highlight contrasting emphases and open questions. One thread focuses on the role of representation geometry and dimensionality in enabling flexible computation, as seen in Dimensionality Neural Control[5] and Representational Spaces Geometry[39], which explore how neural codes support both task-specific discrimination and cross-context transfer. Another examines domain-specific instantiations of the tradeoff, from visual recognition (Category Viewpoint Generalization[14]) to neuroscience-inspired models (Working Memory Flexibility[26]). The original paper, Semanticity Generalization Tradeoff[0], sits within the Theoretical Foundations branch alongside works like Quadratic Function Identification[7] and Discrimination Generalization GANs[31]. While Quadratic Function Identification[7] emphasizes formal identifiability constraints and Discrimination Generalization GANs[31] probes adversarial training dynamics, Semanticity Generalization Tradeoff[0] appears to articulate a broader principle linking semantic structure to generalization capacity, offering a conceptual lens that complements these more specialized analyses.

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## Related Works in Same Category

The following **2 sibling papers** share the same taxonomy leaf node with the original paper:

### 1. Robust generalization of quadratic neural networks via function identification

**Authors:** Xu Kan, Bastani, Hamsa, Osbert | **Year/Venue:** 2021 | **URL:** [View paper](#)

#### Abstract

A key challenge facing deep learning is that neural networks are often not robust to shifts in the underlying data distribution. We study this problem from the perspective of the statistical concept of parameter identification. Generalization bounds from learning theory often assume that the test distribution is close to the training distribution. In contrast, if we can identify the "true" parameters, then the model generalizes to arbitrary distribution shifts. However, neural networks typically...

#### Relationship Analysis

Both papers belong to the Fundamental Tradeoff Principles category, establishing mathematical laws governing representational capacity. They overlap in addressing the tension between generalization and identification in neural representations, with both deriving formal bounds on this tradeoff. However, the original paper focuses on semantic resolution constraints and derives universal Pareto frontiers for similarity-based tasks across arbitrary input spaces, while the candidate paper approaches the problem through parameter/function identification theory, proving that quadratic neural networks can achieve robust generalization to distribution shifts despite over-parameterization.

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### 2. On the discrimination-generalization tradeoff in GANs

**Authors:** Pengchuan Zhang, Qiang Liu, Dengyong Zhou, Tao Xu, Xiaodong He | **Year/Venue:** 2017 | **URL:** [View paper](#)

#### Abstract

Generative adversarial training can be generally understood as minimizing certain moment matching loss defined by a set of discriminator functions, typically neural networks. The discriminator set should be large enough to be able to uniquely identify the true distribution (discriminative), and also be small enough to go beyond memorizing samples (generalizable). In this paper, we show that a discriminator set is guaranteed to be discriminative whenever its linear span is dense in the set of bou...

#### Relationship Analysis

Both papers belong to the Fundamental Tradeoff Principles category, establishing mathematical laws governing tradeoffs in neural representations. They overlap in formalizing fundamental tensions between competing objectives: the original paper derives universal Pareto frontiers linking generalization and identification capacities through semantic resolution constraints, while the candidate paper establishes a discrimination-generalization tradeoff in GANs through integral probability metrics and Rademacher complexity. The key difference is that the original paper focuses on finite semantic resolution as a universal constraint across architectures (including vision-language models), whereas the candidate paper specifically analyzes GAN discriminator-generator dynamics and their generalization properties under different evaluation metrics.

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## Contributions Analysis

**Overall novelty summary.** The paper derives closed-form expressions for a fundamental Pareto front linking generalization probability and identification probability under finite semantic resolution constraints. It sits within the 'Fundamental Tradeoff Principles' leaf of the taxonomy, which contains only three papers total. This is a sparse research direction within the broader 'Theoretical Foundations and Formal Analysis' branch, suggesting the work addresses a relatively underexplored theoretical question. The sibling papers focus on quadratic function identifiability and adversarial training dynamics, indicating that formal tradeoff principles remain an active but not yet crowded area of inquiry.

The taxonomy tree reveals that neighboring leaves examine representational dimensionality, optimization dynamics, and empirical characterization of learned representations. The paper's theoretical focus on semantic resolution and Pareto frontiers distinguishes it from these adjacent directions, which emphasize geometric properties or training trajectories. The 'Empirical Characterization' branch contains substantially more papers across multiple subtopics, highlighting that while empirical studies of generalization are abundant, formal mathematical frameworks governing tradeoffs remain less developed. The paper's extension to vision-language models bridges this theoretical work with the empirical domain.

Among twelve candidates examined through limited semantic search, none clearly refute the three main contributions. The first contribution (closed-form Pareto expressions) examined two candidates with no refutations; the second (1/n collapse prediction) examined ten candidates with no refutations; the third (exact Pareto quantification framework) examined zero candidates. This suggests that within the top-K semantic neighborhood, the specific mathematical formulations and predictions appear novel. However, the limited search scope means more distant or differently framed prior work may exist outside this candidate set, particularly in information theory or neuroscience literatures not captured by the semantic search.

Based on the available signals, the work appears to occupy a relatively sparse theoretical niche, with formal tradeoff principles less saturated than empirical representation studies. The absence of refutations among twelve examined candidates, combined with the small sibling set in the taxonomy leaf, suggests the specific mathematical framework is not directly anticipated by closely related work. However, the analysis covers only top-K semantic matches and does not exhaustively survey adjacent fields like rate-distortion theory or cognitive neuroscience, where related principles might exist under different terminology.

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This paper presents **3 main contributions**, each analyzed against relevant prior work:

## **Contribution 1: Closed-form expressions for generalization-identification Pareto front under finite semantic resolution**

**Description:** The authors provide exact mathematical formulas (Theorems 1-3) that characterize the fundamental tradeoff between a model's ability to generalize (similarity judgments) and identify (distinguish) stimuli when representations have limited resolution. These expressions reveal a universal constraint independent of specific model architectures.

This contribution was assessed against **2 related papers** from the literature. Papers with potential prior art are analyzed in detail with textual evidence; others receive brief assessments.

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### **1. Adaptive Track Association Method Based on Automatic Feature Extraction**

URL: [View paper](#)

#### **Brief Assessment**

Adaptive Track Association[62] addresses radar-ADS-B track association using trajectory similarity measures (LCSS) and SVM classification. This is a domain-specific engineering application unrelated to the theoretical analysis of generalization-identification tradeoffs in representational systems with finite semantic resolution.

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### **2. Versatile User Identification in Extended Reality using Pretrained Similarity-Learning**

URL: [View paper](#)

#### **Brief Assessment**

Extended Reality Identification[61] focuses on user identification in XR systems using motion data and similarity learning for practical deployment. It does not address theoretical bounds on generalization-identification tradeoffs or provide mathematical expressions characterizing fundamental constraints in representational systems.

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## **Contribution 2: Theory predicting 1/n collapse in multi-item processing capacity**

**Description:** The authors extend their theoretical framework to scenarios with multiple simultaneous inputs, deriving formulas showing that identification performance degrades proportionally to 1/n as the number of items n increases, providing a principled explanation for capacity limits in multi-object reasoning.

This contribution was assessed against **10 related papers** from the literature. Papers with potential prior art are analyzed in detail with textual evidence; others receive brief assessments.

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### **1. Globally optimal object pose estimation in point clouds with mixed-integer programming**

URL: [View paper](#)

#### **Brief Assessment**

Optimal Pose Estimation[56] addresses object pose estimation in point clouds using mixed-integer programming. This is a computer vision problem unrelated to cognitive capacity limits or multi-item parallel processing in neural networks or human cognition.

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### **2. A Novel Feature Fusion Framework for Industrial Automation Single-Multiple Object Detection**

URL: [View paper](#)

#### **Brief Assessment**

Feature Fusion Detection[52] addresses feature confusion in multi-object TCM image detection through architectural improvements (feature fusion, receptive field control), not theoretical analysis of capacity limits or 1/n performance degradation laws in multi-item processing.

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### **3. Scalable and High-Performance Large-Scale Dynamic Graph Storage and Processing System**

URL: [View paper](#)

#### **Brief Assessment**

Dynamic Graph Storage[55] focuses on persistent memory-based graph storage systems and their performance optimization. It does not address cognitive capacity limits, multi-item parallel processing, or theoretical frameworks for performance degradation in reasoning tasks.

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### **4. A Cost-Effective Cooperative Exploration and Inspection Strategy for Heterogeneous Aerial System**

URL: [View paper](#)

#### **Brief Assessment**

Cooperative Aerial Inspection[59] addresses heterogeneous drone coordination for building inspection tasks, not cognitive capacity limits or multi-item parallel processing in neural networks or intelligent systems.

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### **5. A Piezo-based Microgripper with Hybrid Grasping Modes for Versatile Micro-object Handling Tasks**

URL: [View paper](#)

#### **Brief Assessment**

Piezo Microgripper Hybrid[60] focuses on mechanical engineering design of a physical grasping device with multiple operational modes, not cognitive processing capacity or multi-item information processing theory.

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### **6. Deriving the number of salience maps an observer has from the number and quality of concurrent centroid judgments**

URL: [View paper](#)

#### **Brief Assessment**

Salience Maps Observer[57] investigates capacity limits in visual centroid judgments across multiple feature maps (colors), focusing on how many salience maps observers possess. This is fundamentally different from the ORIGINAL paper's theoretical framework deriving 1/n performance degradation laws for general multi-item processing in neural networks based on semantic resolution constraints.

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### **7. Evidence for second-order singleton suppression based on probabilistic expectations.**

URL: [View paper](#)

#### **Brief Assessment**

Singleton Suppression Expectations[58] investigates attentional capture by color singleton distractors in visual search tasks, focusing on probabilistic expectations and suppression mechanisms. This work does not address multi-item processing capacity limits or derive theoretical formulas for performance degradation as a function of the number of simultaneous inputs.

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## 8. Cognitive control beyond single-item tasks: Insights from pupillometry, gaze, and behavioral measures.

URL: [View paper](#)

### Brief Assessment

Cognitive Control Pupillometry[53] examines cognitive control in multi-item tasks using pupillometry and eye-tracking measures, focusing on within-task performance decline in Stroop tasks. This work does not address theoretical frameworks for capacity limits or derive mathematical formulas predicting 1/n performance degradation in multi-item processing.

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## 9. HAGN: A hierarchical attentive graph network with dynamic reward fusion for scalable recommendation

URL: [View paper](#)

### Brief Assessment

Hierarchical Attentive Recommendation[51] focuses on recommendation systems using graph networks with reward fusion. The candidate does not address theoretical frameworks for multi-item processing capacity limits or cognitive performance degradation.

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## 10. Neural mechanisms of dual-task interference and cognitive capacity limitation in the prefrontal cortex

URL: [View paper](#)

### Brief Assessment

Dual Task Interference[54] focuses on neural mechanisms of dual-task interference in prefrontal cortex, not theoretical frameworks for multi-item processing capacity degradation. The candidate's context fragments are too sparse to establish any connection to the original paper's mathematical theory of 1/n performance collapse.

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## Contribution 3: Framework quantifying exact Pareto front between identification and similarity performances

**Description:** The authors introduce a formal framework with closed-form solutions that precisely characterizes the unavoidable tension between representational distinctness and similarity under finite resolution constraints, applicable across different stimulus spaces and probability distributions.

This contribution was assessed against **0 related papers** from the literature. Papers with potential prior art are analyzed in detail with textual evidence; others receive brief assessments.

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## Appendix: Text Similarity Detection

No high-similarity text segments were detected across any compared papers.

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## References

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- [2] Mamba collaborative implicit neural representation for hyperspectral and multispectral remote sensing image fusion [View paper](#)
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