Explainable Image-Centric Forgery Detection: A Survey

Anonymous authors
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Abstract

The rapid growth of AI-driven image manipulation technologies poses critical challenges for verifying content authenticity. While many forgery detection systems achieve high accuracy, their black-box nature limits deployment in high-stakes domains that demand transparency and explainability. This survey presents the first comprehensive review of explainable image-centric forgery detection, introducing a novel taxonomy structured around three dimensions: Forgery Localization (FL), which pinpoints manipulated regions; Forgery Attribution (FA), which identifies manipulation sources; and Forgery Judgment Basis (FJB), which clarifies decision reasoning. We systematically analyze 48 state-of-the-art methods across single-modal and multi-modal settings, examining architectural innovations and interpretability mechanisms. Four feature-driven strategies (RGB, frequency-domain, noise-texture, and representation learning) are reviewed in detail, highlighting their complementary strengths. Benchmark datasets and evaluation protocols are also compared, and open challenges are identified, including the need for standardized explanation formats, uncertainty quantification, and broader dataset coverage. By establishing this taxonomy and synthesizing recent progress, this survey lays a foundation for developing transparent and trustworthy forgery detection systems, supporting real-world applications in forensic analysis, news verification, and regulatory compliance.

1 Introduction

The rapid advancement of sophisticated image manipulation technologies has fundamentally reshaped the digital media landscape, posing unprecedented challenges to content authenticity and trust. From traditional editing techniques such as splicing and copy-move to modern AI-driven generative models including Generative Adversarial Networks (GANs) and Diffusion Models (DMs), the ability to create highly realistic forged content has become easily accessible to both experts and ordinary users. This evolution introduces concerning societal risks, as manipulated images are increasingly employed in misinformation campaigns, identity theft, fraud, and various forms of digital deception, with potential implications for journalism, legal proceedings, and public trust.

These escalating risks highlight the urgent need for more robust detection systems capable of addressing the growing sophistication of image forgeries. Recent progress in generative AI has significantly lowered the technical barrier to producing photorealistic synthetic content. Large-scale diffusion models such as Stable Diffusion (Rombach et al., 2022a), DALL · E (Ramesh et al., 2021), and Midjourney (Midjourney, Inc., 2022) are capable of generating images that are almost indistinguishable from real photographs, making traditional detection techniques increasingly inadequate. Meanwhile, the emergence of multimodal manipulation, which simultaneously alters visual, textual, and audio content, has further complicated detection. In such cases, inconsistencies can be strategically distributed across modalities to evade analysis. As shown in Figure 1, the field of forgery detection has witnessed remarkable growth in recent years, with numerous methods proposed at top-tier venues. Early works focused primarily on binary classification systems that distinguish real from fake, while subsequent studies before 2024 concentrated on explanation through visual localization. Since 2024, the field has witnessed a shift toward deeper explainability, addressing tasks such as model attribution and manipulation analysis. Representative approaches such as TruFor (Guillaro et al., 2023), HAMMER (Shao et al., 2024), FakeShield (Xu et al., 2024), ForgerySleuth (Sun et al., 2024),

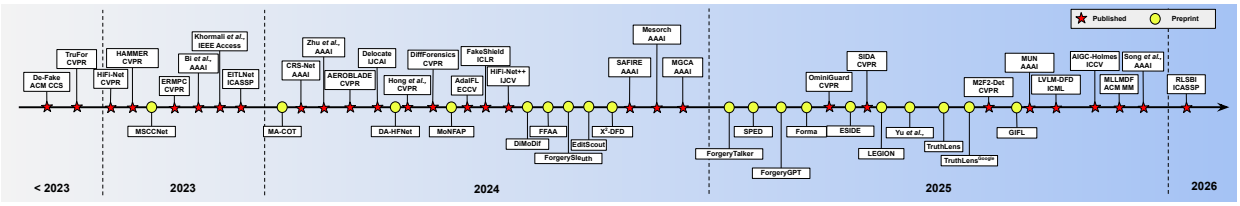


Figure 1: A roadmap of explainable image-centric forgery detection methods.

Table 1: Comparison of existing related surveys on image and multimodal forgery detection in terms of architecture analysis, explainability, data modality, and scope. (**FL**: Forgery Localization; **FA**: Forgery Attribution; **FJB**: Forgery Judgement Basis.)

Survey	Year	Architecture Analysis	Explainability			Data Modality		Scope
			FL	FA	FJB	Single Modality	Multi Modality	
Alam et al., (Alam et al., 2021)	2021	✓	✗	✗	✗	Image, Text, Video, Audio	-	Social Media Fake Image Detection
Lin et al., (Lin et al., 2024)	2024	✗	✗	✗	✗	Images, Text, Video, Audio	Image-Text	AIGC Generated Detection
Pei et al., (Pei et al., 2024)	2024	✗	✗	✗	✗	Image, Text, Audio	Image-Text, Image-Audio	Facial Deepfake Detection
Yu et al., (Yu et al., 2024a)	2024	✗	✗	✗	✗	Image, Text, Video, Audio	Image-Text	AIGC Generated Detection
Xu et al., (Xu et al., 2025)	2025	✓	✗	✗	✗	Image	Image-Text	Diffusion Generated Detection
Zou et al., (Zou et al., 2025)	2025	✗	✓	✗	✗	Image, Text, Video, Audio	Image-Text, Image-Audio	AIGC Generated Detection
Ours	2026	✓	✓	✓	✓	Image, Video	Image-Text, Image-Audio	Image-Centric Explainable Forgery Detection

and TruthLens (Kundu et al., 2025b) illustrate this progression toward more mature and interpretable detection solutions.

Despite these advances, most existing forgery detection systems still operate as black-box models, providing little transparency into their decision-making processes. Although they may achieve high accuracy in controlled environments, their lack of explainability severely limits deployment in high-risk applications. In domains such as forensic analysis, news verification, regulatory compliance, and content moderation, understanding the reasoning behind detection outcomes is essential for building trust and accountability. This limitation becomes especially critical when the system produces erroneous predictions or when results require human verification. As detection systems are increasingly integrated into real-world applications, transparency, auditability, and human explainability are becoming essential requirements. Unlike conventional classifiers that provide only a binary label, explainable detection systems must deliver insights along three key dimensions: forgery localization (FL), which identifies the precise regions of manipulation; forgery attribution (FA), which determines the manipulation method, source, or origin; and forgery judgment basis (FJB), which clarifies the rationale behind the system's decision. Such multidimensional explainability not only enhances user trust and system reliability but also enables forensic analysts, journalists, and moderators to make well-informed decisions based on verifiable evidence.

Several surveys (Alam et al., 2021; Lin et al., 2024; Pei et al., 2024; Yu et al., 2024a; Xu et al., 2025) have reviewed image forgery detection and related areas, making significant contributions to understanding detection methodologies and architectural innovations. Table 1 shows that these surveys have effectively addressed technical performance, generalization capabilities, and specific application domains. However, the rapidly evolving landscape of AI-generated content and increasing deployment requirements in high-stakes applications have created new demands for systematic explainability analysis that extend beyond the scope of previous reviews. While *Zou et al.* (Zou et al., 2025) acknowledges the importance of explainability in AI-generated media detection, their work primarily focuses on detection techniques rather than establishing systematic taxonomies for multidimensional explainability analysis. As detection systems are increasingly deployed in critical applications requiring transparency and accountability, there emerges a clear opportunity for developing structured approaches to explainable detection that can address the fundamental questions of where, how, and why manipulations occur. More importantly, the scope of existing surveys is often constrained to specific application scenarios such as social media misinformation detection or facial deepfake detection, or to particular generative techniques such as Artificial Intelligence Generated Content (AIGC) or diffusion models. A comprehensive taxonomy centered on interpretability, particularly one that spans multimodal detection capabilities, is still lacking.

To address this gap, this survey provides the first comprehensive review of explainable image-centric forgery detection. We introduce a taxonomy structured around three core explainable tasks: forgery localization (FL), forgery attribution (FA), and forgery judgment basis (FJB). This taxonomy goes beyond technical categorization by offering a structured understanding of how different approaches address spatial localization, source attribution, and decision reasoning. Building on this framework, we systematically analyze about 40 state-of-the-art methods across unimodal and multimodal paradigms, examining architectural innovations, feature extraction strategies, and mechanisms for interpretability. Furthermore, we review four major feature-driven detection strategies, each offering distinct advantages in different manipulation scenarios: RGB features preserve spatial and color information and are effective for detecting boundary inconsistencies and occlusion mismatches; frequency-domain features capture periodic structures and spectral anomalies that are difficult to detect in the spatial domain; noise-texture features leverage high-pass filtering to capture statistical patterns of the imaging process, making them highly sensitive to subtle manipulations; and representation learning features automatically learn high-level semantic abstractions through deep networks, which are particularly important for multimodal detection. The main contributions of this survey can be summarized as follows:

- We propose a comprehensive taxonomy of forgery detection methods centered on three explainability dimensions: forgery localization (FL), forgery attribution (FA), and forgery judgment basis (FJB).
- We systematically analyze four feature-driven detection strategies, namely RGB features, frequency-domain features, noise-texture features, and representation learning features, and discuss their strengths across different manipulation scenarios.
- We provide an extensive review of unimodal and multimodal detection architectures, highlighting their design principles, explainability mechanisms, and implementation strategies.
- We offer a holistic overview of benchmark datasets and evaluation protocols that have been specifically developed for explainable detection tasks.
- We identify key challenges and outline promising directions for future research, aiming to guide the development of transparent, accountable, and trustworthy forgery detection systems.

In the context of the ongoing arms race between generative and detection technologies, this survey aims to equip researchers, practitioners, and policymakers with a structured understanding of the current capabilities and limitations of explainable forgery detection. By establishing a clear taxonomy, highlighting technical innovations, and identifying future opportunities, we seek to accelerate progress toward detection systems that achieve not only high accuracy but also the transparency and explainability required for responsible deployment in trust-critical applications.

2 Related Work

The field of image forgery detection has experienced significant growth over the past decade, with multiple survey articles systematically examining this rapidly expanding research domain from various perspectives. *Alam et al.* (Alam et al., 2021) presented pioneering work focused on multimodal disinformation detection, with particular emphasis on content authenticity verification in social media environments. As shown in Table 1, their survey covered multiple modalities, including images, text, video, and audio, while providing architectural analysis primarily focused on social media fake image detection scenarios. Their research revealed correlations between factuality and harmfulness, finding that these correlations vary across different linguistic contexts, specifically, 56% of false Arabic content was also harmful, compared to 24% for English content. This work emphasized the critical role of multimodal content in disinformation propagation, demonstrating that images and videos are more easily consumed, attract greater attention, are perceived as more credible, and spread further than plain text. *Lin et al.* (Lin et al., 2024) provided a comprehensive analysis of multimedia content detection generated by Large AI Models (LAIMs), introducing an innovative taxonomy categorized by media modality. Their survey covered text, images, videos, and audio generated by diffusion models and large language models, analyzing the field from two perspectives: "pure detection"

(enhancing detection performance) and "beyond detection" (adding attributes like generalizability, robustness, and interpretability). Their work encompassed images, text, video, audio, and image-text multimodal processing, establishing an important theoretical framework for the AIGC detection domain, though with limited development in specific interpretability dimensions. *Pei et al.* (Pei et al., 2024) presented a specialized analysis of deepfake generation and detection, comprehensively covering tasks including face swapping, face reenactment, talking face generation, and facial attribute editing. Their survey provided a detailed technical analysis of diffusion-based methods, covering image, text, and audio processing while supporting image-text and image-audio multimodal detection, though primarily limited to facial-related deepfake detection scenarios. *Yu et al.* (Yu et al., 2024a) focused on the theoretical foundations and detection methods of Fake Artificial Intelligence Generated Content (FAIGC), proposing an innovative taxonomy encompassing three dimensions: FAIGC intent, modality generation technologies, and creation methods. This work systematically analyzed FAIGC detection techniques across images, text, video, and audio, supporting image-text multimodal processing and contributing valuable insights to FAIGC detection theory construction. *Xu et al.* (Xu et al., 2025) specialized in generalizable diffusion-generated image detection, demonstrating outstanding performance in architectural analysis and deeply exploring technical details and methodological innovations in diffusion model detection. Their survey covered image and image-text multimodal processing, providing important references for this cutting-edge technical domain, though with relatively limited interpretability analysis. *Zou et al.* (Zou et al., 2025) provided a comprehensive perspective on the evolution from non-multimodal large language models to multimodal large language models, covering images, text, video, audio, and image-text and image-audio multimodal processing. This work offered valuable analysis in forgery localization, recognizing the importance of explainability in AI-generated media detection, though primarily focusing on detection techniques rather than systematic explainability analysis frameworks.

Although existing surveys have made valuable contributions within their specialized domains, these works lack systematic dimensional categorization from an explainability perspective. Most existing surveys focus on specific application scenarios or particular generative technologies, without providing a unified framework that comprehensively addresses the fundamental questions of `"where"`, `"how"`, and `"why"` in forgery detection. To address this critical need, this survey provides the first systematic analysis of image-centric forgery detection from an explainability perspective. We construct a taxonomy centered on three core explainable tasks: Forgery Localization (FL), Forgery Attribution (FA), and Forgery Judgment Basis (FJB), establishing a structured framework for understanding how different approaches handle spatial localization, source attribution, and decision reasoning. Compared to existing work, our survey is the first to provide comprehensive coverage from an explainability-centered perspective across the three dimensions of FL, FA, and FJB, while supporting both unimodal detection of images and videos, and multimodal detection capabilities for image-text and image-audio content.

3 Background

This section provides essential background on the evolution of content forgery techniques and the fundamental principles of forgery detection. We examine the progression from traditional manipulation methods to modern AI-driven approaches, and establish the mathematical foundations for detection systems. As generative models produce increasingly realistic synthetic content that challenges conventional detection methods, understanding both forgery mechanisms and detection formulations becomes crucial for developing more interpretable and explainable frameworks.

3.1 Image Forgery Techniques

3.1.1 Traditional Image Forgery Methods.

Before the rise of deep learning, traditional image forgeries relied on classical image processing and low-level signal manipulation. Despite their simplicity, these methods were capable of producing visually convincing results within the technological constraints of the time. The primary traditional image-centric forgery techniques can be broadly categorized into several types.

- Splicing (Ng & Chang, 2004) involves combining regions from different source images to manipulate the semantic content of the final image. This technique is frequently used in fabricated news or altered historical photographs (Verdoliva, 2020).
- Copy-Move (Fridrich et al., 2003) refers to duplicating a region within the same image, often to obscure certain elements or artificially increase visual complexity.
- Removal (Criminisi et al., 2004) entails deleting specific regions from an image, followed by inpainting or texture synthesis to plausibly fill the resulting gaps.
- Retouching (Chen et al., 2018) and Repainting (Criminisi et al., 2004) involve manually or semi-automatically redrawing selected areas, typically for restoration or object modification.

To enhance realism and reduce detection, traditional forgeries often incorporate auxiliary operations such as geometric transformations, including rotation, scaling, and perspective correction for spatial consistency; color and lighting adjustments for tonal uniformity; edge blending and gradient-domain fusion for seamless integration; and noise injection or compression simulation to mask traces of manipulation. These supporting techniques are typically layered on top of core forgery strategies to improve plausibility.

Despite these enhancements, such methods face notable limitations. They remain confined to the visual modality and often leave detectable artifacts in the frequency spectrum or compression residuals. Their dependence on manual intervention constrains scalability and automation. Most critically, they struggle to produce truly photorealistic results or operate at the scale required for mass content generation. These shortcomings, coupled with the rapid advances in deep learning, have propelled AI-driven forgery techniques to become the prevailing standard in digital content manipulation (Masood et al., 2023; Verdoliva, 2020).

3.1.2 AI-Driven Image Forgery Methods.

The emergence of generative AI has greatly increased the complexity and subtlety of digital forgeries. Compared to traditional forgery techniques, AI-driven methods (Ramesh et al., 2022; Razzhigaev et al., 2023; CompVis, 2023) enable high-quality content generation with greater scalability and lower technical barriers. As deep learning advances, these forgery methods have achieved remarkable realism and precise control, posing significant challenges for detection systems.

VAE-based Image Forgery Methods. Early generative models, such as Variational Autoencoders (VAEs) (Kingma et al., 2013), established the foundation for AI-driven forgery by learning latent representations for image synthesis and editing. For example, β-VAEs (Higgins et al., 2017) enable detailed manipulation of facial attributes like age or gender, which can be used to obscure identity or create fraudulent documents and profiles. Vector Quantized Variational Autoencoders (VQ-VAEs) (Van Den Oord et al., 2017) generate high-quality facial reconstructions through discrete latent representations, making them effective tools for creating convincing face swaps and identity manipulations. Tools such as DeepFakes (dee, 2019) and FaceSwap (Kowalski, 2016) have lowered the technical threshold, enabling broader misuse.

GAN-based Image Forgery Methods. Generative Adversarial Networks (GANs) (Goodfellow et al., 2020) represent a major milestone in synthetic content creation, greatly enhancing the realism of generated images and enabling sophisticated forgery techniques. Early advances like ProGAN (Karras et al., 2017) and BigGAN (Brock et al., 2018) established high-resolution synthesis capabilities that could produce convincing fake images across diverse categories. StyleGANs (Karras et al., 2019) generate fully synthetic, photorealistic images with unprecedented quality, creating entirely fabricated faces, objects, and scenes that are virtually indistinguishable from authentic content. Domain translation methods such as CycleGAN (Zhu et al., 2017) and StarGAN (Choi et al., 2018) enable sophisticated image manipulation by altering visual characteristics, including lighting, weather conditions, and artistic styles, to create misleading or deceptive content.

DM-based Image Forgery Methods. Diffusion models (DM) are currently at the forefront of generative forgery technologies, enabling the creation of highly realistic and structurally controllable synthetic content. Early breakthroughs such as DALL · E (Ramesh et al., 2022), Imagen (Saharia et al., 2022), and the

open-source Stable Diffusion (CompVis, 2023) demonstrated the capability of text-to-image generation to produce fabricated scenes and fake historical imagery directly from textual prompts. These models have significantly lowered the barrier for large-scale image forgery and accelerated the proliferation of synthetic content. In addition to general purpose synthesis, diffusion-based methods (Ruiz et al., 2023; Rombach et al., 2022b; Song et al., 2020b) have evolved to support more targeted and controlled generation. Personalization techniques like DreamBooth (Ruiz et al., 2023) allow model fine-tuning with a handful of images, enabling the creation of highly specific forgeries involving particular individuals or branded objects. Beyond generation from scratch, modern diffusion-based inpainting techniques (Lugmayr et al., 2022; Zeng et al., 2021; Rombach et al., 2022b; CompVis, 2023) integrated into tools such as Adobe Firefly and RunwayML support seamless addition, removal, or alteration of image elements while maintaining visual realism. These tools blur the boundaries between original and manipulated content, making it increasingly difficult to distinguish authentic images from forged ones.

In a nutshell, these advancements not only enhance the visual fidelity of synthetic content but also introduce new challenges for forgery detection, especially when modifications are subtle, identity-targeted, or semantically aligned with the input prompt. The sophisticated control mechanisms in diffusion models enable highly localized edits that maintain global consistency, making traditional artifact-based detection methods less effective. Furthermore, the ability to generate contextually coherent content creates forgeries that are increasingly difficult to distinguish from authentic material through visual inspection alone.

3.1.3 Multi-Modal Image Forgery Methods.

While single-modal AI forgeries continue to advance rapidly, most real-world content combines multiple modalities such as text, images, and audio. Discrepancies between these modalities can reveal forgeries, but aligning them effectively increases the credibility of fake content. This challenge has led to the rise of multi-modal forgery techniques, which manipulate several modalities simultaneously to produce more convincing and difficult-to-detect disinformation.

Image-Text Forgery. In image-text forgery, diffusion models (CompVis, 2023; Ramesh et al., 2022; Rombach et al., 2022b) are commonly used to generate fabricated visuals aligned with false textual narratives, while large language models (LLMs), such as LaMa (Suvorov et al., 2022), ChatGPT (Achiam et al., 2023), Gemini (Team et al., 2023), and Vicuna (Zheng et al., 2023), are employed to produce corresponding textual descriptions. For example, an attacker may simulate a traffic accident by generating coherent images and accompanying reports, thereby increasing the perceived authenticity. Incorporating multiple image perspectives further enhances the illusion of independent corroboration.

Video-Audio Forgery. In video-audio forgery, techniques such as Wav2Lip (Prajwal et al., 2020) synchronize synthetic audio with authentic footage, producing highly believable fake speeches that preserve lip movements as well as subtle facial expressions and gestures. Real-time manipulation tools like Face2Face (Thies et al., 2016) enable alteration of facial expressions during live video calls, allowing impersonation of individuals such as CEOs or officials for fraudulent purposes.

Compared to single-modal forgeries, multi-modal methods provide several advantages. They create the impression of corroboration across modalities, which raises perceived authenticity. They also better avoid detection since inconsistencies may be hidden in the less examined modality. Moreover, multi-modal content tends to attract greater social media engagement, enabling faster spread. Lastly, the coherent presentation across modalities reduces cognitive load for users, making it easier for false information to be accepted and shared.

3.2 Formulation of Real-versus-Fake Image Forgery Detection

The rapid growth of digital media and forgery techniques has made it harder to verify image content authenticity. With easy access to advanced editing tools and realistic AI-generated media, it is often difficult to tell real images from fake ones, especially in cases of disinformation, identity theft, or evidence manipulation. These risks highlight the urgent need for automated, robust detection systems that can keep up with evolving forgeries.

Real-versus-fake classification forms the foundation of conventional forgery detection, aiming to determine whether a given image is authentic or has been synthetically altered. This task is typically framed as a binary classification problem. Let the training dataset be defined as $\mathcal{D} = \{(\mathbf{x}_n, y_n)\}_{n=1}^{N}$, where $\mathbf{x}_n \in \mathcal{X}$ denotes the input sample (*e.g.,* image, video), N is the number of training samples, and $y_n \in \{0, 1\}$ is the authenticity label, with 0 indicating real and 1 indicating fake content, we denote the sets of real and fake samples as $\mathcal{R}$ and $\mathcal{F}$, respectively. A model $f_\theta : \mathcal{X} \to \{0, 1\}$, parameterized by θ, processes the input samples. The objective is to minimize the loss $\mathcal{L}$:

$$\theta^* = \arg\min_{\theta} \frac{1}{N} \sum_{n=1}^{N} \mathcal{L}\big(f_\theta(\mathbf{x}_n),\ y_n\big) \tag{1}$$

As discussed earlier, forged content was mainly created using traditional methods (*e.g.,* splicing, copy-move, *etc.*) or early AI-driven techniques (*e.g.,* VAEs and GANs). The rise of diffusion models, such as Stable Diffusion (CompVis, 2023) and Imagen (Saharia et al., 2022), has greatly improved the realism and variety of synthetic images, making them a key source of modern forgeries. To cope with this evolving challenge of detecting highly realistic diffusion-generated content that exhibits minimal traditional artifacts, some works have developed detection methods that exploit the unique properties of the diffusion process. For example, DIRE (Wang et al., 2023) and SeDID (Ma et al., 2023a) utilize discrepancies between forward and reverse generation steps to reveal subtle artifacts, while LatentTracer (Wang et al., 2024) operates in the latent space to trace generation trajectories, enabling effective detection even when the specific generative model is partially known. These approaches can be generally formulated as $f_\theta = ||x_0 - \hat{x}_\theta(x_t, t)||$, with t representing the timestep in the diffusion process and $\hat{x}_\theta$ denoting the denoising network. Although diffusion models currently dominate, generative techniques continue to evolve, and future forgeries may stem from more diverse or hybrid generators. This presents the additional challenge of developing detection methods that can generalize across unknown and emerging generative architectures. Consequently, some researchers have explored model-agnostic detection strategies. ESSP (Chen et al., 2024a) boosts generalization to unseen generators by exploiting camera-specific noise retained in "simple patches", formulated as $f_\theta = \theta(\text{SRM}(x))$, where SRM (Steganalysis Rich Model) (Fridrich & Kodovsky, 2012) uses high-pass filters to extract high-frequency noise patterns, which generative models tend to overlook in favor of textured regions. Meanwhile, UniFD (Ojha et al., 2023) introduces a training-free method that detects forgeries via nearest-neighbor search, expressed as $f_\theta = d(\theta(x), \mathcal{R}) - d(\theta(x), \mathcal{F})$, where $\theta(x)$ represents CLIP feature extraction and $d(\cdot, \cdot)$ measures distances to the reference sets $\mathcal{R}$ and $\mathcal{F}$, offering high adaptability without model-specific assumptions. Furthermore, several approaches leverage cross-modal cues, particularly the semantic alignment between textual descriptions and images. Such methods are especially effective for detecting content generated by text-to-image models or forged image–text pairs. For example, FatFormer (Liu et al., 2024b) explicitly integrates text–image alignment and incorporates text-guided semantic features, which can be formulated as $f_\theta = \cos\big(f_\theta^I(x^I),\ f_\theta^T(x^T)\big)$, where $f_\theta^I(\cdot)$ and $f_\theta^T(\cdot)$ denote modality-specific encoders that project images and text into a shared embedding space. By exploiting cross-modal consistency, FatFormer achieves improved detection performance and is well aligned with the growing trend of text-driven generation.

While the aforementioned detection methods have achieved considerable progress in terms of accuracy and robustness, they predominantly operate as black-box systems with limited explainability capabilities. Overall, these approaches span diverse methodologies and application domains. Some specialize in identifying diffusion-based forgeries, others aim for general-purpose AI image detection, while certain methods are tailored for specific scenarios such as facial forgeries or text-to-image content. These methods have demonstrated notable advances in performance and efficiency. However, most remain limited to binary classification, outputting only a `"real"` or `"fake"` label without providing insights into the reasoning behind their decisions. This black-box nature limits their applicability in high-stakes domains such as forensic analysis, news verification, and content moderation, where explainability and traceability are crucial. To bridge this gap, this survey focus on the emerging field of explainable forgery detection, systematically reviewing its key explainable tasks. As illustrated in Figure 2, explainable detection typically comprises three core components:

- Forgery Localization: Identifying the specific manipulated regions within an image, either as pixel-level masks or textual descriptions.

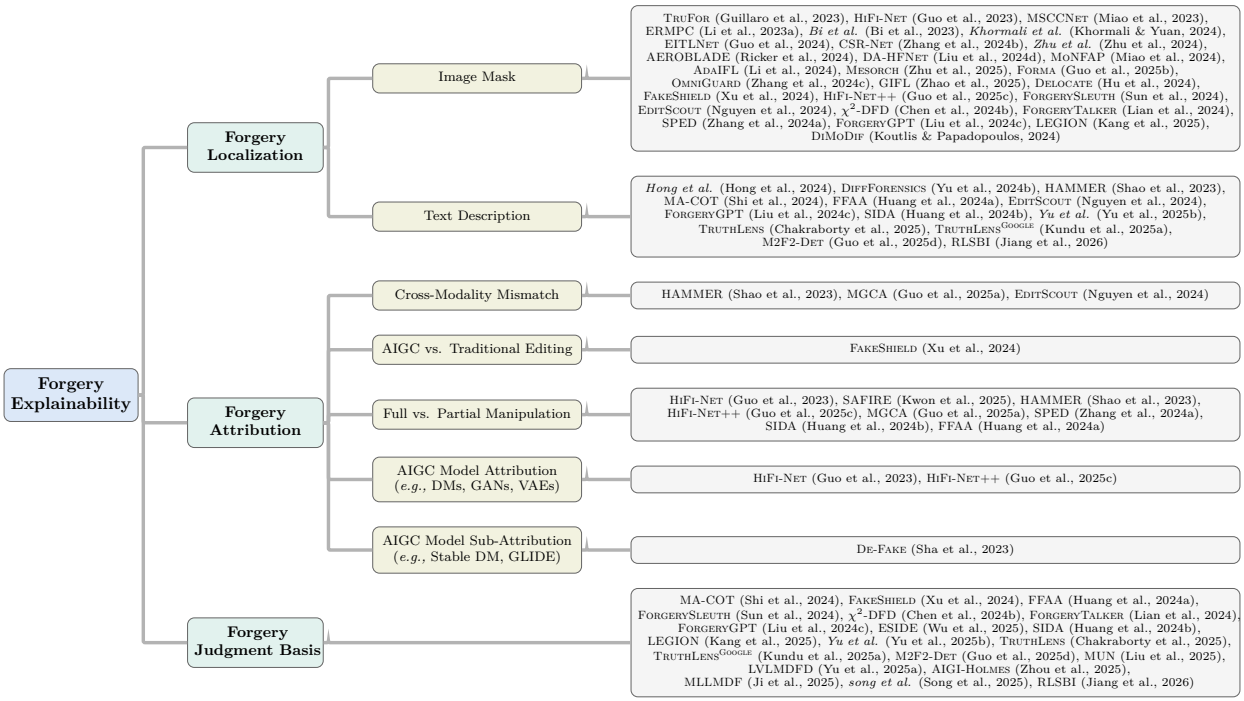


Figure 2: A hierarchical taxonomy of forgery explainability techniques. **Cross-Modality Mismatch:** Assessment of semantic consistency across different modalities (*e.g.,* image-text and image-audio alignment). **AIGC vs. Traditional Editing:** Attribution based on the source of manipulation (*e.g.,* AI-generated content versus traditional editing approaches such as Photoshop). **Full vs. Partial Manipulation:** Characterization of the extent of content manipulation (*e.g.,* fully manipulated images, partial modifications, face swaps, or object-level edits). **AIGC Model Attribution:** Attribution to broad categories of generative model families (*e.g.,* GANs, diffusion models, or VAE-based architectures). **AIGC Model Sub-Attribution:** Fine-grained attribution to specific generative models within a given category (*e.g.,* Stable Diffusion (CompVis, 2023), GLIDE (Nichol et al., 2021), *etc.*).

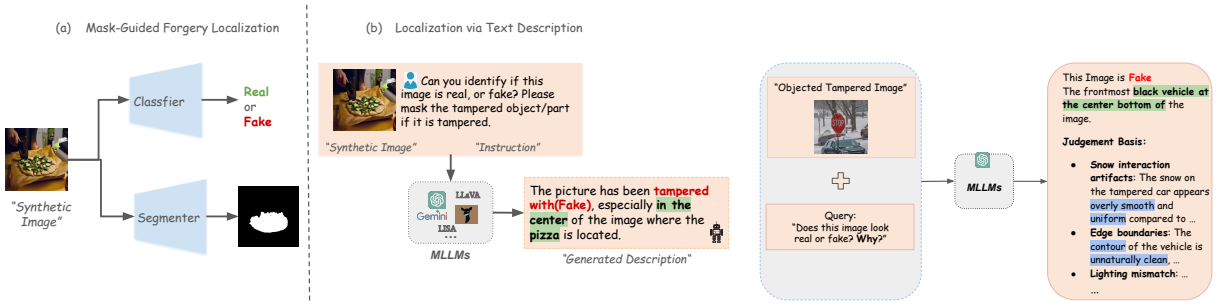
- Forgery Attribution: Determining the type or source of manipulation, organized hierarchically from coarse to fine levels, ranging from broad categories such as cross-modality mismatch to specific model-level attribution.

- Forgery Judgment Basis: Explaining why an image is classified as fake by providing transparent and verifiable supporting evidence.

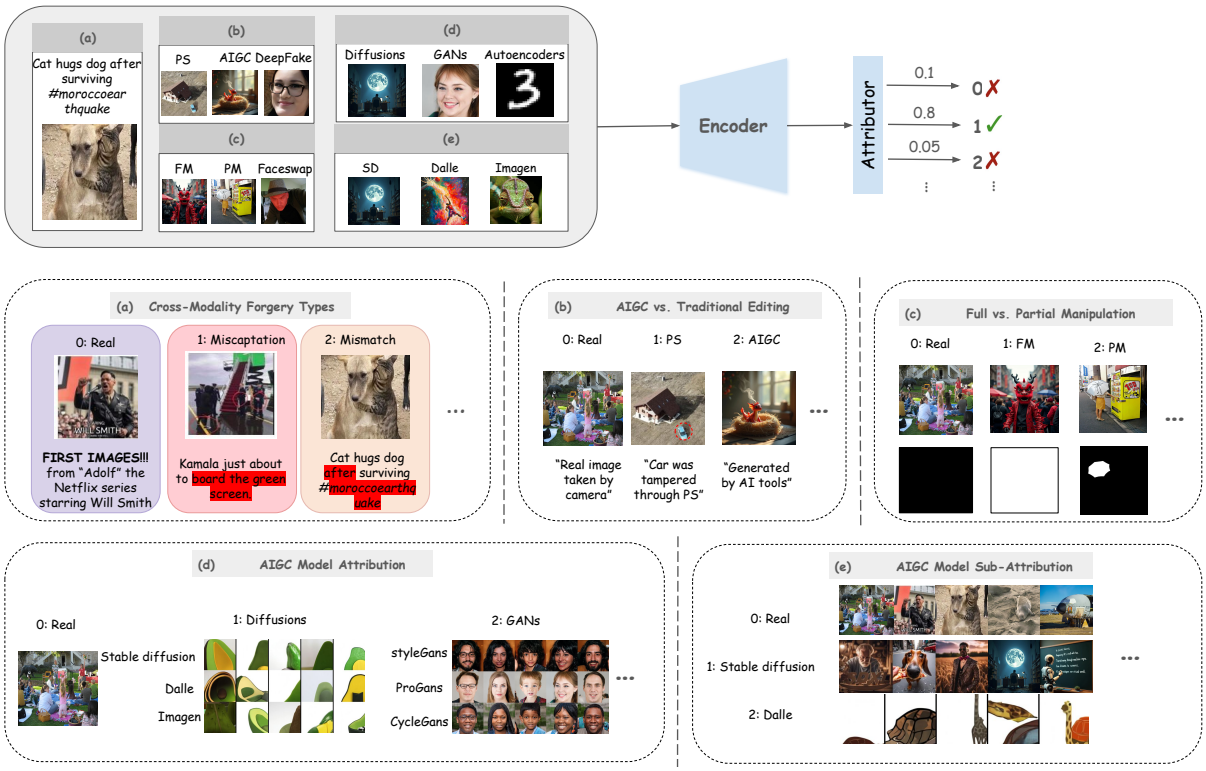
This taxonomy provides a structured foundation for advancing interpretable forgery detection and facilitates the development of methods that go beyond binary decisions.

4 Explainable Forgery Detection

While concurrent work (Zou et al., 2025) briefly touches on explainability in AI-generated content detection, our work specifically focuses on the emerging paradigm of explainable forgery detection. We systematically examine explainability requirements and establish a comprehensive taxonomy of explainable tasks. This section presents a structured framework that goes beyond binary classification to provide interpretable analysis through three core dimensions: Forgery Localization(Section 4.1), which identifies manipulated regions within content; Forgery Attribution(Section 4.2), which determines the source and method of manipulation; and Forgery Judgment Basis(Section 4.3), which provides reasoning for detection decisions.



(a) Forgery Localization. (b) Forgery Judgment Basis.



(c) Forgery Attribution.

Figure 3: Illustration of three key explainability tasks in forgery detection: (a) Localization, (b) Judgment Basis, and (c) Attribution. (a) Shows mask-guided and text-based localization approaches for identifying tampered regions. (b) Demonstrates structured reasoning with specific evidence for detection decisions. (c) Presents hierarchical attribution from cross-modal mismatch to fine-grained model identification.

4.1 Forgery Localization

Forgery Localization (FL) aims to identify manipulated regions within an image by providing spatial localization, typically in the form of segmentation masks or natural language descriptions. Unlike traditional binary classification methods that only output `"real"` or `"fake"`, FL addresses the crucial question of where the manipulation occurs. As illustrated in Figure 3a, FL generates image masks that highlight the tampered areas, while these masks demonstrate localization through textual descriptions specifying the affected regions and manipulation characteristics. This capability substantially enhances the interpretability of detection results, fosters user trust and confidence, and provides valuable visual and semantic evidence for forensic analysis and content verification in high-stakes real-world scenarios.

Formally, given an input X (either a single image $I \in \mathbb{R}^{H \times W \times C}$ or a video sequence), visual localization methods produce outputs such as:

- Pixel-wise probability map: $P \in [0,1]^{H \times W}$, where $P(i,j)$ indicates the probability that pixel (i,j) has been manipulated.
- Instance masks: $M = \{M_1, \ldots, M_k\}$, where each $M_i \in \{0,1\}^{H \times W}$ corresponds to a binary mask of an individual tampered region, enabling fine-grained segmentation akin to instance segmentation techniques (*e.g.,* SAM (Kirillov et al., 2023b)).
- Bounding boxes: $B = \{B_1, \ldots, B_k\}$, where each $B_i = [x_i^{\text{center}}, y_i^{\text{center}}, w_i, h_i]$ represents a rectangular region around suspected manipulations. Here, $(x_i^{\text{center}}, y_i^{\text{center}})$ denotes the center coordinates and w_i, h_i denote the width and height, respectively.
- Frame-level binary maps: $F \in \{0,1\}^{T \times D}$, where T denotes the number of video frames and D represents the number of modalities (*e.g.,* visual and audio). Each entry $F_{t,d} = 1$ indicates that frame t contains manipulated content in modality $d \in \{v, a\}$, enabling coarse-grained temporal localization across different media streams. For example, $F_{1,v} = 1$ and $F_{1,a} = 0$ means that the 1st frame is visually manipulated but has authentic audio.

In addition, textual localization, particularly in multimodal settings, generates natural language descriptions T that explicitly specify manipulated regions, *e.g.,* "The mouth region in the face is fake". We can thus define a localization model Λ_ϕ as a mapping $\Lambda_\phi : X \mapsto \mathcal{O}$, where the output space $\mathcal{O}$ includes one or more forms:

$$\mathcal{O} \subseteq \{P, M, B, F, T\} \tag{2}$$

Here, T represents textual output describing manipulated areas within the input. Such flexible and multi-form outputs allow localization models to suit a wide range of forgery detection scenarios, enhancing transparency and interpretability. Most forgery localization methods can be categorized into five main approaches:

- Pixel-level mask methods offer the most precise spatial localization, especially in boundary identification. These methods typically predict pixel-wise tampering probability maps by fusing image representations with tampering features. For instance, TruFor (Guillaro et al., 2023) and MUN (Liu et al., 2025) integrate noise pattern analysis to generate probabilistic masks, HiFi-Net (Guo et al., 2023) leverages multi-scale feature fusion to output binary masks, MSCCNet (Miao et al., 2023) captures frequency-domain traces through a multi-spectral class center module, and AEROBLADE (Ricker et al., 2024) achieves fine-grained localization via reconstruction error from an autoencoder.
- Instance-level localization methods further incorporate semantic understanding. *Khormali et al.* (Khormali & Yuan, 2024) model facial images as graphs and combine features extracted by a Vision Transformer with a graph convolutional network and transformer-based discriminator to produce a relevancy map, allowing not only spatial localization but also identification of the manipulated facial components.
- Bounding box-based methods provide coarse localization using rectangular regions. For example, HAMMER (Shao et al., 2023) fuses image features from a Vision Transformer and text features from BERT through cross-modal attention to predict bounding boxes that enclose manipulated regions, offering more intuitive visual feedback.
- Frame-level localization extends explainability along the temporal dimension. DiMoDif (Koutlis & Papadopoulos, 2024) extracts features from visual and audio speech recognition and employs a transformer encoder to process cross-modal discrepancies. It combines classification and regression heads to identify manipulated segments in the video timeline.
- Text-based explanation methods generate natural language descriptions through fine-tuned large language models. Methods such as ForgerySleuth (Sun et al., 2024), FakeShield (Xu et al., 2024), ForgeryGPT (Liu et al., 2024c), and RLSBI (Jiang et al., 2026) adopt various strategies, including integrating the LLaVA (Liu et al., 2023) framework to generate text that explains the manipulation's

location, type, and rationale, or using LoRA-tuned language models to generate analytical descriptions which are then linked to pixel-level masks via the SAM (Kirillov et al., 2023a) model, providing textual support for visual explanations.

These five categories reflect the current technical landscape of explainable forgery localization. Through diverse feature extraction and fusion strategies, they collectively enable multi-level explainable outputs ranging from fine-grained spatial localization to high-level semantic localization, supporting comprehensive understanding in forgery detection.

4.2 Forgery Attribution

While forgery localization focuses on *where* manipulations occur within an image, Forgery Attribution (FA) addresses a complementary question: *how* the manipulation was performed. Rather than identifying spatial regions of tampering, FA aims to explain the semantic nature and technical origin of the manipulation. To support this goal, we categorize attribution into five progressively fine-grained levels, each capturing a specific perspective on the manipulation process, as shown in Figure 3c. At the coarsest level, Cross-Modality Mismatch assesses whether information conveyed across different modalities, such as image-text or image-audio pairs, is semantically consistent. This capability is particularly important in multimodal disinformation scenarios, where content coherence is intentionally disrupted. The second level, AIGC *vs.* Traditional Editing, distinguishes between manipulations generated by AI models (such as diffusion models or GANs) and those produced using conventional editing tools (such as splicing or inpainting via Photoshop). This classification provides insight into the generation pipeline and the associated risk profile. The third level, Full vs. Partial Manipulation, characterizes the manipulation scope by determining whether the entire image is synthetic or only specific regions have been modified, such as in localized face swaps or object removal. This distinction helps assess the semantic severity and visual impact of the forgery. Moving further, AIGC Model Attribution identifies the category of generative model responsible for the manipulation, for example GANs, VAEs, or diffusion models. This level supports model family traceability and enables the detection of model-specific artifacts. Finally, AIGC Model Sub-Attribution further refines the analysis by pinpointing the exact generative model instance used, such as Stable Diffusion or GLIDE. This fine-grained attribution is valuable for forensic accountability, provenance tracking, and validation of anti-forgery measures such as watermarks.

Building on this intuition, forgery attribution can be formally modeled as a multi-class classification problem that goes beyond binary judgments. Specifically, we define a set of content categories $\mathcal{C} = \{c_0, c_1, \ldots, c_n\}$, where c_0 represents `real` content, and $\{c_1, \ldots, c_n\}$ correspond to different manipulation types, including synthetic generations and manual tampering. A model $f_\psi : \mathcal{X} \to \mathcal{C}$ is trained to predict the manipulation category of each input sample:

$$\psi^* = \arg\min_{\psi} \frac{1}{N} \sum_{n=1}^{N} \mathcal{L}_{\text{ce}}\big(f_\psi(x_n),\ c_n\big) \tag{3}$$

where $\mathcal{L}_{\text{ce}}$ denotes the standard cross-entropy loss. This formulation provides a unified way to accommodate coarse and fine-grained attribution schemes under a common framework.

Based on the above multi-class formulation, existing methods define different label spaces $\mathcal{C}$ to model various aspects of manipulation, thereby enabling more structured and explainable forgery attribution. For cross-modality mismatch, MGCA (Guo et al., 2025a) extracts semantic elements from image-text pairs, such as entities and temporal cues, and aligns them to detect inconsistencies. HAMMER (Shao et al., 2023) constructs real and tampered multimodal pairs and applies contrastive learning to capture semantic shifts induced by manipulation. These models allow outputs that indicate not only whether manipulation occurred, but also where semantic conflicts arise across modalities. To distinguish AIGC from traditional editing, Fakeshield (Xu et al., 2024) treats manipulation sources such as AIGC, DeepFake, and Photoshop as classification targets. It generates manipulation-type prompts using a domain tag predictor and feeds them into a multimodal model to assist in identifying the editing mechanism. When modeling full versus partial manipulation, Hifi-Net++ (Guo et al., 2025c) and Hammer (Shao et al., 2023) first assess image authenticity, then localize tampered regions to estimate manipulation extent. Safire (Kwon et al.,

2025) uses the Segment Anything Model to propose candidate regions and assesses source consistency, while MGCA (Guo et al., 2025a) segments manipulated areas using class-guided features. SIDA (Huang et al., 2024b) and FFAA (Huang et al., 2024a) generate both manipulation masks and descriptive text to support spatial attribution, and SPED (Zhang et al., 2024a) detects frequent forgery artifacts to assist in partial manipulation recognition. To identify the type of generative model involved, Hifi-Net (Guo et al., 2023) and Hifi-Net++ (Guo et al., 2025c) classify images based on features left by different model categories such as GANs or diffusion models. Hifi-Net++ (Guo et al., 2025c) introduces a hierarchical structure to first detect AIGC-generated content and then determine its model family, enabling more accurate and explainable predictions. For finer-grained model sub-attribution, De-Fake (Sha et al., 2023) maps fake images to specific generators like Stable Diffusion or Glide (Nichol et al., 2021). It designs both image-only and image-plus-prompt classifiers to capture subtle model-specific signals and improve instance-level discrimination. By treating manipulation types, regions, and source models as structured outputs, forgery attribution enhances the link between model representations and forgery semantics. This supports improved interpretability through attention maps, concept-level reasoning, and traceable model behavior.

4.3 Forgery Judgment Basis

Unlike Forgery Localization (FL), which focuses on identifying *where* manipulations occur, and Forgery Attribution (FA), which explains *how* and *by what means* forgeries are created, Forgery Judgment Basis (FJB) addresses the fundamental question of *why* a detection model determines an image to be fake. In other words, it focuses on what visual evidence the model relies on to support its decision. FJB requires detection systems to output not only classification results but also explicit, human-interpretable reasoning based on observable artifacts in the image. As illustrated in Figure 3b, when presented with a suspected tampered image, an FJB-enabled system provides structured justifications across multiple semantic dimensions. The system identifies the manipulated object or region, such as "the frontmost black vehicle at the bottom center of the image", and presents detailed reasoning elements such as snow interaction inconsistencies, where "the snow on the tampered car appears overly smooth and uniform compared to the surrounding terrain", unnatural edge boundaries, where "the contour of the vehicle is excessively clean and lacks natural blending", and scene-level lighting mismatches. These explanations should be both readable and verifiable, helping users understand which regions the model distrusts and what evidence leads to that assessment. The motivation for FJB lies in a key limitation of current detection systems. Although many models can achieve high classification accuracy, they typically do not reveal the internal reasoning behind their predictions. This lack of transparency becomes a significant barrier in high-stakes applications such as forensic analysis, regulatory inspection, and journalistic verification, where explanations must be evidence-based and traceable. By linking detection results to specific, interpretable image cues, FJB improves the transparency, debuggability, and accountability of image forgery detection models.

To formalize this process, we define FJB as the task of extracting interpretable reasoning factors that substantiate a model's authenticity judgment. These factors may include texture inconsistencies, edge artifacts, lighting or shading anomalies, semantic contradictions, or temporal mismatches across modalities (*e.g.*, audio-visual misalignment). Given an input sample X and its classification result $f(X;\theta)$, the explanation module g aims to generate a set of explicit reasoning elements that support the decision:

$$g(f(X;\theta), X;\omega) = R \tag{4}$$

where $R = \{r_1, r_2, \ldots, r_k\}$ represents the set of judgment elements supporting the decision, and ω denotes the parameters of the explanation module. In practice, this task is often approached through fine-tuning large-scale models to produce textual justifications or by training on datasets with annotated rationale. Outputs may include attention maps, saliency-based attributions, or natural language explanations, all of which provide insight into the model's internal decision-making process.

Building on the formulation above, existing FJB methods typically generate natural language explanations to reveal *why* a model considers an image to be manipulated. One group of approaches employs prompt-based strategies to explicitly guide LLMs toward structured justifications. For example, ForgerySleuth (Sun et al., 2024) decomposes the reasoning process into sub-tasks such as identifying manipulated objects, explaining specific evidence, and articulating conclusions, using separate prompts to generate answers for

each stage. ForgeryGPT (Liu et al., 2024c) adopts a unified question-answering format to elicit complete textual rationales in a single step. Other methods enhance controllability by conditioning the generation on auxiliary semantic cues. FakeShield (Xu et al., 2024) first predicts the manipulation type (*e.g.,* AIGC or Photoshop), then uses the predicted label as a domain-specific prompt to generate type-aware explanations. χ^2-DFD (Chen et al., 2024b) performs statistical comparisons between real and fake images and converts the results into textual templates for explanation. Some models further align textual output with internal model representations. *Yu et al.* (Yu et al., 2025b) extract manipulation-aware visual features and feed them into the language model as conditioning inputs, improving alignment between explanation content and model attention. ForgeryTalker (Lian et al., 2024) detects manipulated regions and encodes them as region-specific keywords, which are used to prompt a language model to generate localized textual explanations for why those regions appear fake. SIDA (Huang et al., 2024b) and FFAA (Huang et al., 2024a) incorporate dual learning mechanisms to enforce consistency between generated explanations and model-predicted manipulation masks, improving spatial grounding of the output. Similarly, LEGION (Kang et al., 2025) and M2F2-Det (Guo et al., 2025d) integrate explanation generation into multimodal understanding modules, jointly predicting salient regions and corresponding textual evidence. Building on these multimodal paradigms, recent methods leverage large-scale vision-language models: LVLMDFD (Yu et al., 2025a) fine-tunes MLLMs with forgery-specific prompts, AIGI-Holmes (Zhou et al., 2025) employs preference optimization for human-aligned explanations, MLLMDF (Ji et al., 2025) adopts training-free prompting strategies, *Song et al.* (Song et al., 2025) design multi-paradigm reasoning frameworks, and RLSBI (Jiang et al., 2026) applies specialized prompt engineering for deepfake scenarios.

Other approaches adopt a more structured strategy by constructing explanation templates or tag-based descriptions. MA-COT (Shi et al., 2024) performs multi-attribute analysis across various forgery cues (*e.g.*, lighting, texture, boundary), then aggregates the results and reformulates them into coherent textual rationales. ESIDE (Wu et al., 2025) and TruthLens (Chakraborty et al., 2025) identify salient visual regions or concept-level forgery artifacts and express them as concise textual descriptions using predefined patterns. Although these methods vary in design, they share a common objective which is to generate human-readable and verifiable explanations that connect model predictions with interpretable reasoning.

5 Forgery Detection Strategies

This section provides a concise review of technical advances in explainable forgery detection, focusing on feature-driven strategies and architectural paradigms across singel-modal and multi-modal settings. Our discussion is organized into four key dimensions: feature extraction strategies, single-modal detection architectures, multi-modal detection frameworks, and evaluation protocols. As illustrated in Figure 4, existing approaches predominantly leverage four types of features: RGB, frequency, noiseprint, and representation. These feature paradigms span from low-level pixel statistics to high-level semantic abstractions, offering complementary advantages for detecting various manipulation cues and forming the basis for explainability. singel-modal methods typically exploit low-level artifacts such as edge inconsistencies or spectral anomalies within a single modality. In contrast, multi-modal methods emphasize modeling semantic alignment across modalities such as image-text or audio-visual pairs. These methods predominantly rely on representation features to capture cross-modal inconsistencies. This preference stems from the intrinsic challenge of multi-modal forgery detection, where manipulations often introduce semantic mismatches rather than pixel-level artifacts, necessitating a unified embedding space for meaningful comparison and reasoning. Moreover, Table 2 summarizes representative methods across both paradigms, detailing their targeted manipulation types, architectural designs, feature-driven type, interpretability outputs, and code availability.

5.1 RGB Features

RGB features serve as the most direct and widely used input modality in visual forgery detection. They retain complete pixel-level spatial and color information of the image without requiring additional transformations or preprocessing. As illustrated in Figure 4, RGB features represent one of the primary shallow-level cues in feature-driven detection. They are extracted directly from raw image channels and preserve essential spatial and color structures for low-level visual analysis, including boundary inconsistencies, occlusion mismatches,

Table 2: Overview of architecture and feature strategies for forgery detection methods.

Method	Target Synthetic Images†	Strategies‡	Output§	Backbones			Feature-Driven Detection	Tasks		Code Availability
				Vision	Non-Vision	Multi-Modality		Real vs. Fake	Exp.¶	
Single-Modality										
Image										
TruFor (Guillaro et al., 2023)	T: SP, CM	SSL, SL	M	DnCNN, SegFormer	-	-	Noiseprint, RGB	✓	FL	✓
HiFi-Net (Guo et al., 2023)	T: SP G: DMs	SL	C, M	ResNet50	-	-	RGB, Freq.	✓	FL, FA	✓
MSCCNet (Miao et al., 2023)	G: GANs, DMs	SL	C, M	ResNet50	-	-	Freq.	✓	FL	✓
ERMPC (Li et al., 2023a)	T: SP, CM, RM	SL	M	ResNet50	-	-	Noiseprint, RGB	✗	FL	✗
Bi et al., (Bi et al., 2023)	T: SP, CM, RM	SSL	M	CNN-based	-	-	Noiseprint	✗	FL	✗
Khormali et al., (Khormali & Yuan, 2024)	T: Low Resolution, Color Mismatch, Inaccurate Fake Masks G: DeepFakes, Face2Face, FaceSwap, NeuralTextures	SSL	C, M	ViT, Graph CNN	-	-	Rep.	✓	FL	✗
EITLNet (Guo et al., 2024)	T: SP, CM, RM	SL	M	SegFormer	-	-	Noiseprint, RGB	✗	FL	✓
CSR-Net (Zhang et al., 2024b)	T: SP, CM, RM	SL	M	ResNet50	-	-	Rep.	✗	FL	✗
Zhu et al., (Zhu et al., 2024)	T: SP, CM, RM	SL	C, M	ResNet50 ConvGeM	-	-	Noiseprint, RGB	✓	FL	✗
AEROBLADE (Ricker et al., 2024)	G: LDMs	TF	C	-	-	-	-	✓	FL	✓
DA-HFNet (Liu et al., 2024d)	G: Img/Text-Guided GANs, DMs	SL	C, M	HRNet	-	-	Noiseprint, RGB, Freq.	✓	FL	✗
Hong et al., (Hong et al., 2024)	T: Low Resolution, Color Mismatch, Inaccurate Fake Masks G: DeepFakes, Face2Face, FaceSwap, NeuralTextures	SL	T	ResNet34, ResNet50, SwinT	-	-	Rep.	✓	FL	✗
DiffForensics (Yu et al., 2024b)	T: SP, CM, RM G: AI-Editing	SSL, SL	T	SegFormer, DDPM	-	-	Rep., Freq.	✓	FL	✗
MoNFAP (Miao et al., 2024)	G: GANs, FaceSwap, FsGAN, DeepFaceLab	SL	M	ConvNeXtV2-atto+ ResNet50	-	-	RGB, Freq.	✓	FL	✓
AdaIFL (Li et al., 2024)	T: SP, CM, RM	SL	M	ViT	-	-	Rep., RGB	✗	FL	✓
SAFIRE (Kwon et al., 2025)	T: CM, SP G: DMs, SAM	SL	C, T	SAM	-	-	Rep.	✗	FA	✓
Mesorch (Zhu et al., 2025)	T: SP, CM, RM	SL	M	{ResNet50, ConvNeXT-Tiny} + {MAE, PvT0-B3, SegFormer-B3, SwinT-Base}	-	-	Rep., RGB, Freq.	✗	FL	✓
Forma (Guo et al., 2025b)	T: SP, CM, RM	SL	M	VMamba-tiny	-	-	Freq.	✗	FL	✓
OmniGuard (Zhang et al., 2024c)	G: VAEs, SDs	SL	M	VAE, ViT-B	-	-	Rep.	✗	FL	✗
GIFL (Zhao et al., 2025)	T: SP, CM, RM G: Deepfillv2, CTSDG, CR-Fill, LaMa, LDM, SSDE, DDNM, Repaint	SL	M	ViT-L/14	-	-	Rep.	✗	FL	✗
MUN (Liu et al., 2025)	T: SP, CM, RM G: DMs, GANs, AEs,Deepfakes	SL	C, M	ConvNeXt V2	-	-	Noiseprint, RGB	✓	FL	✓
Video										
Delocate (Hu et al., 2024)	T: Low Resolution, Color Mismatch, Inaccurate Fake Mask G: AEs, GANs, DeepFakes	SL	M	ViT, ResNet-18	-	-	Rep.	✓	FL	✗
Multi-Modality										
Image-Text										
De-Fake (Sha et al., 2023)	G: SDs	SL	C	ViT-B/32	Transformer	MLP	Rep.	✓	FA	✓
HAMMER (Shao et al., 2023)	T: Misinformation	SL	C, T	ViT-B/16	BERT-base	Attention + MLP	Rep.	✓	FL, FA	✓
MA-COT (Shi et al., 2024)	G: Face2Face, FaceSwap, NeuralTextures DeepFakes, GANs, DMs	TF	T	-	-	GPT-4v, Gemini	-	✓	FL, FJB, FA	✓
FakeShield (Xu et al., 2024)	T: PS G: DMs, Deepfakes	SL	C, M, T	ViT-L/14, SAM	-	LLaVa	Rep.	✓	FL, FJB, FA	✓
HiFi-Net++ (Guo et al., 2025c)	G: DMs, GANs, Faceshifter	SL	C, M	FPN, ResNet50	Transformer	-	Rep., RGB, Freq.	✓	FL, FA	✓
FFAA (Huang et al., 2024a)	G: DeepFakes, Face2Face, FaceSwap, GANs, DMs	SL	T	ViT-L/14	T5-Encoder	LLaVA-v1.6-7B	Rep.	✓	FL, FJB, FA	✓
ForgerySleuth (Sun et al., 2024)	T: SP, CM, RM, PS	SL	M, T	ViT-H	-	LLaVa-v1-7B	Rep.	✓	FL, FJB	✓
EditScout (Nguyen et al., 2024)	G: DMs	SL	M, T	SAM	-	LLaVA	Rep.	✗	FL	✗
χ^2-DFD (Chen et al., 2024b)	G: DeepFakes, Face2Face, FaceSwap, NeuralTextures	SL	C, M, T	-	GPT-4o	LLaVA-7B	Rep.	✓	FL, FJB, FA	✗
MGCA (Guo et al., 2025a)	T: Misinformation	SL	C	ViT-B/16	Vicuna, BERT	LLaVA-1.5	Rep.	✓	FA	✓
ForgeryTalker (Lian et al., 2024)	G: GANs, DMs-Inpainting	SL	M, T	ViT, CoordConv Block with MHA	FlanT5/Vicuna	Q-Fromer	Rep.	✗	FL, FJB	✗
SPED (Zhang et al., 2024a)	T: Warped Photo Attacks, Cut Photo Attacks, Replay/Video Attacks	TF	C, M	Unspecified*	Unspecified*	-	-	✓	FL	✗
ForgeryGPT (Liu et al., 2024c)	T: SP, CM, RM G: Repaint-Inpaint(SAM, DMs)	SL	C, M, T	ViT-B/16	Vicuna-7B	-	Rep.	✓	FL, FJB, FA	✗
ESIDE (Wu et al., 2025)	G: DMs	SL	C, T	DDIM, ViT-L/14	GPT-4o	-	Rep., Freq.	✓	FL, FJB	✓
SIDA (Huang et al., 2024b)	G: DMs	SL	C, M, T	-	-	Lang-SAM, LISA	Rep.	✓	FL, FJB, FA	✓
LEGION (Kang et al., 2025)	G: DMs	SL	C, M, T	ViT-H/14 , SAM	-	GLaMM	Rep.	✓	FL, FJB	✓
Yu et al., (Yu et al., 2025b)	G: DeepFakes, Face2Face, FaceSwap, NeuralTextures	SL	C, T	ImageBind-Huge	ImageBind-Huge	Vicuna-7B	Rep.	✓	FL, FJB	✗
TruthLens (Chakraborty et al., 2025)	G: GANs, DMs	TF	T	-	-	LLaVA, BLIP-2, GPT-4	-	✓	FL, FJB, FA	✗
TruthLens^{Google} (Kundu et al., 2025a)	G: DeepFakes, Face2Face, FaceSwap, NeuralTextures, DMs	SL	T	SigLIP-So400m/14, DINOv2	Gemma2-3B	PaliGemma2	Rep.	✓	FL, FJB, FA	✗
M2F2-Det (Guo et al., 2025d)	G: DeepFakes, Face2Face, FaceSwap, NeuralTextures	SL	C, T	ViT-L/14 , EfficientNet-B4	Transformer	Vicuna-7B	Rep.	✓	FL, FJB	✓
LVLMDFD (Yu et al., 2025a)	G: DeepFakes	SL	C, T	-	-	LLaVA, MiniGPT-4, BLIP-2	Rep.	✓	FJB	✓
AIGI-Holmes (Zhou et al., 2025)	G: DMs, GANs, DeepFakes	SL	C, T	ViT-L/14	-	LLaVA	Rep.	✓	FJB	✓
MLLMDF (Ji et al., 2025)	G: DMs, GANs, AEs	TF	C, T	-	-	GPT-4o, LLaVA	-	✓	JB	✓
Song et al, (Song et al., 2025)	G: DMs, GANs, VAEs	SL	C, T	-	-	GPT-4o, GPT-4o-mini, Llama-3.2, LLaVA	Rep.	✓	JB	✓
RLSBI (Jiang et al., 2026)	G: DeepFakes	SL	C, T	-	-	LLaVA-1.5	Rep.	✓	FL, FJB	✓
Image-Audio										
DiMoDif (Koutlis & Papadopoulos, 2024)	G: GANs, Faceswap, TTS, Wav2Lip, ChatGPT	SL	M	VSR	ASR	Transformer	Rep.	✓	FL	✓

†: T: Traditional editing methods, *e.g.*: Splicing(SP), Copy and Move(CM), Removal(RM); G: GAN- and Diffusion-based synthetic images.
‡: SL = Supervised Learning, SSL = Self-Supervised Learning, TF = Training Free.
§: M = Mask, C = Class, T = Text.
¶: RF = Real vs Fake, FL = Localization, FJB = Forgery Judgement Basis, FA = Attribution.
*: Backbone mentioned but not disclosed.

- References of mentioned synthetic-image generators in Table 2: DeepFakes (dee, 2019), Face2Face (Thies et al., 2016), FaceSwap (Kowalski, 2016), NeuralTextures (Thies et al., 2019), Stable Diffusion / LDMs (CompVis, 2023; Razzhigaev et al., 2023; Ramesh et al., 2022; Schuhmann et al., 2022), SAM (Kirillov et al., 2023a), FsGAN (Nirkin et al., 2022), DeepFaceLab (Perov et al., 2020), Deepfillv2 (Yu et al., 2019), CTSDG (Guo et al., 2021), CR-Fill (Zeng et al., 2021), LaMa (Suvorov et al., 2022), LDM (Rombach et al., 2022b), SSDE (Song et al., 2020b), DDNM (Wang et al., 2022b), Repaint (Lugmayr et al., 2022).
- References of mentioned backbones in Table 2: *Vision Backbones*: DnCNN (Zhang et al., 2017), SegFormer (Xie et al., 2021), ResNet50 / ResNet34 (He et al., 2016), CNN-based (Bi et al., 2023), ViT variants (B/16, B/32, L/14, H/14) (Dosovitskiy et al., 2020), GraphCNN (Kipf & Welling, 2016), SwinT / SwinT-Base (Liu et al., 2021), DDPM (Ho et al., 2020a), DDIM (Song et al., 2020a), ConvNeXtV2 (Woo et al., 2023), ConvGeM (Dong et al., 2022), HRNet (Sun et al., 2019), ConvNeXT-Tiny (Ma et al., 2023b), MAE (He et al., 2022), PvT0-B3 (Wang et al., 2022a), SegFormer-B3 (Xie et al., 2021), VMamba-tiny (Liu et al., 2024e), FPN (Lin et al., 2017), EfficientNet-B4 (Tan & Le, 2019), ImageBind-Huge (Su et al., 2023), SAM (Kirillov et al., 2023a), CoordConv / MHA block (Liu et al., 2018), VSR (Ma et al., 2022). *Non-Vision Backbones*: Transformer (Vaswani et al., 2017b), BERT-base (Devlin et al., 2019), T5-Encoder (Raffel et al., 2020), GPT-4o (Achiam et al., 2023), ImageBind-Huge (Su et al., 2023), FlanT5 / Vicuna (InstructBLIP) (Dai et al., 2023), Gemma2-3B (Team et al., 2024), ASR (Ma et al., 2022) *Multi-Modality Modules*: GPT-4 / GPT-4v / GPT-4o (Achiam et al., 2023), Gemini (Team et al., 2023), LLaVA (Liu et al., 2023), LLaVA-v1.6 (Liu et al., 2024a), BLIP-2 (Li et al., 2023b), Q-Former (Dai et al., 2023), Vicuna-7B (Zheng et al., 2023), PaliGemma2 (Steiner et al., 2024), Lang-SAM (Team, 2024), LISA (Lai et al., 2024), GLaMM (Rasheed et al., 2024), SigLIP-So400m/14 (Alabdulmohsin et al., 2023), DINOv2 (Oquab et al., 2023), LLAMA-3.2 (Grattafiori et al., 2024)

and unnatural blending. Local visual anomalies introduced through region replacement or content splicing can often be identified using shallow convolutional networks applied directly to RGB inputs. The main advantage of RGB-based approaches lies in their computational efficiency and strong visual interpretability, since detected anomalies can be directly observed and verified within the original image. However, when manipulation signals are subtle, such as compression artifacts or fine-grained noise inconsistencies, RGB features may prove insufficient because raw pixel intensities lack the ability to capture higher-order statistical variations or frequency-domain irregularities.

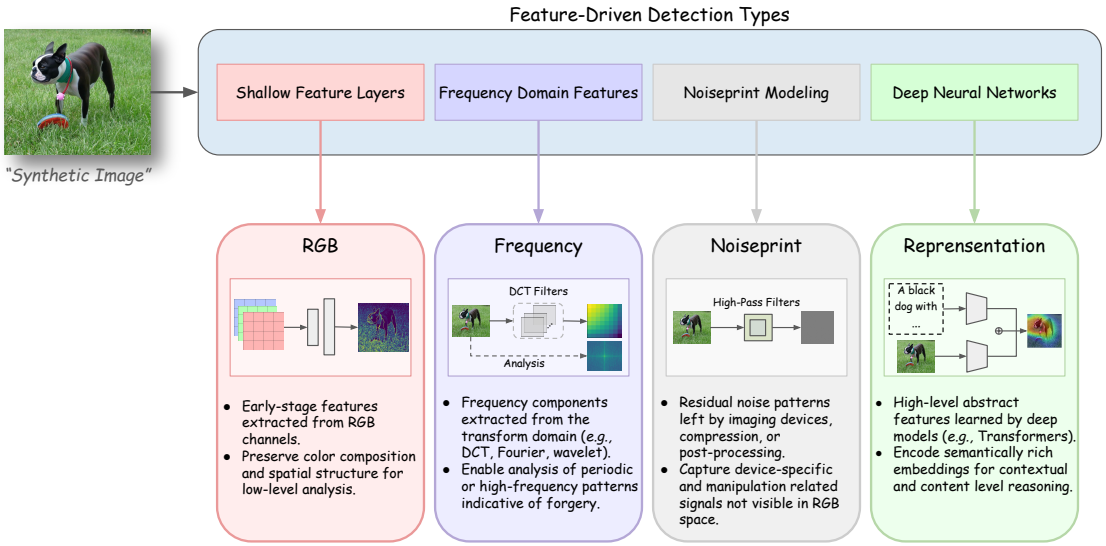


Figure 4: Feature-Driven types in forgery detection. Four primary feature extraction approaches: **RGB Features** preserve spatial and color information for boundary analysis, **Frequency Features** capture spectral anomalies through transform domain analysis (DCT, Fourier, wavelet), **Noiseprint Features** extract residual patterns via high-pass filtering to reveal device-specific traces, and **Representation Features** employ deep networks to learn semantic abstractions for multimodal reasoning.

As summarized in Table 2, RGB-driven methods have adopted diverse architectural designs and enhancement strategies in unimodal detection settings. MoNFAP (Miao et al., 2024) employs a hybrid backbone combining ConvNeXtV2-atto+ (Woo et al., 2023) and ResNet50 (He et al., 2016), integrating a noise-aware module to enhance multi-scale RGB features that highlight forgery-sensitive regions. DA-HFNet (Liu et al., 2024d) builds on HRNet (Sun et al., 2019) and incorporates channel and spatial attention mechanisms to emphasize discriminative RGB cues, particularly useful for detecting fine-grained local inconsistencies while preserving high-resolution spatial information. HiFi-Net (Guo et al., 2023) is based on a multi-branch ResNet50 (He et al., 2016) architecture, jointly processing RGB and frequency-domain features through hierarchical fusion, thus capturing both fine-scale manipulation traces and global consistency patterns. Some models treat RGB as an auxiliary modality. For example, AdaIFL (Li et al., 2024) leverages a ViT-based architecture that fuses RGB with high-level representation features to improve generalization across manipulation types. Mesorch (Zhu et al., 2025) combines ResNet50 with multiple Transformer variants (e.g., MAE (He et al., 2022), PvT (Wang et al., 2022a), SegFormer (Xie et al., 2021), SwinT (Liu et al., 2021)) to enhance RGB feature expressiveness through ensemble learning. EITLNet (Guo et al., 2024), although built on SegFormer and primarily driven by noiseprint signals, incorporates RGB inputs to support spatial localization and reasoning. Similarly, ERMPC (Li et al., 2023a) adopts a parallel dual-stream design using ResNet50 to process both RGB and noiseprint features, demonstrating how multi-branch architectures can exploit RGB information even under compression artifacts. MUN (Liu et al., 2025) further advances dual-stream RGB-noise fusion by employing parallel ConvNeXt V2 (Woo et al., 2023) backbones and introducing a Multi-scale Max-pooling Query (MMQ) module that enables cross-domain feature correlation, allowing RGB features to guide the extraction of manipulation-relevant noise patterns. This architectural diversity reflects the adaptability of RGB features across detection scenarios and technical pipelines.

5.2 Frequency Features

Frequency features convert images from the spatial domain into the frequency domain by applying transformations such as the Fast Fourier Transform (FFT) or Discrete Cosine Transform (DCT). This transformation enables the detection of periodic structures and spectral inconsistencies that are often imperceptible in the RGB space. Previous research has demonstrated that manipulations such as splicing, copy-move, inpainting,

and AI-generated synthesis frequently disturb the natural frequency distributions found in authentic images. As a result, frequency-based analysis is particularly effective in identifying artifacts introduced by JPEG compression, resampling operations, and the characteristic spectral signatures produced by generative models. These signals are often subtle and not easily captured by RGB-based methods, which primarily rely on spatial information. The principal advantage of frequency features lies in their ability to detect statistical anomalies and periodic patterns that remain invisible in the spatial domain, making them especially useful for the detection of high-quality or visually coherent forgeries. However, frequency features are also sensitive to preprocessing operations such as filtering and scaling.

To fully leverage spectral information for forgery detection, recent methods have proposed a variety of architectural designs that integrate frequency-domain features. DA-HFNet (Liu et al., 2024d) incorporates a dedicated frequency extraction branch within an HRNet (Sun et al., 2019) backbone, enabling the model to preserve high-resolution spectral details while detecting inconsistencies across different generative sources. This design facilitates the fusion of frequency and spatial features, improving the model's ability to identify subtle manipulations. Mesorch (Zhu et al., 2025) adopts a dual-path ensemble architecture that combines a ResNet50-based CNN stream with multiple Transformer variants including MAE, PvT, SegFormer, and SwinT. This setup decouples the processing of high- and low-frequency components, allowing the CNN branch to focus on local spectral anomalies while the Transformer branch models global semantic relationships, achieving robust detection across manipulation types. HiFi-Net (Guo et al., 2023) and its extension HiFi-Net++ (Guo et al., 2025c) are both built upon ResNet50 and Feature Pyramid Network (FPN) backbones. These models apply Laplacian of Gaussian (LoG) filters to the intermediate CNN feature maps, explicitly extracting frequency-sensitive patterns. By employing multi-scale branches, they enhance the model's ability to perform fine-grained classification and precise localization of manipulation artifacts. HiFi-Net++ (Guo et al., 2025c) further extends this framework to the multimodal setting by incorporating Transformer-based modules that process textual information, illustrating the compatibility of frequency features with cross-modal forgery analysis. MSCCNet (Miao et al., 2023), another frequency-driven approach based on ResNet50, introduces a multi-spectral class center module that utilizes DCT to decompose semantic features into distinct frequency bands. This architecture is specifically designed to extract class-specific high-frequency cues associated with different forgery types, and is trained using a supervised strategy tailored to enhance the discriminative power of frequency features. ESIDE (Wu et al., 2025) leverages frequency-domain discrepancies between real and synthetic images by perturbing inputs across diffusion timesteps, revealing distinctive high-frequency patterns in the Fourier spectrum for detection without requiring task-specific annotations. In summary, frequency features provide a complementary perspective to spatial-domain analysis and have been successfully integrated into a range of architectures. Their capacity to capture imperceptible manipulation signals makes them a powerful tool in both supervised and unsupervised detection pipelines, particularly when paired with multi-branch or attention-based designs that accommodate the complexity of spectral patterns.

5.3 Noiseprint Features

Noiseprint features represent a distinct class of forensic cues that capture content-independent statistical patterns arising from underlying imaging processes, including sensor response, compression encoding, and image reconstruction. Unlike RGB features that emphasize spatial structure and color composition, noiseprint features are extracted through high-pass filtering or residual modeling, with the goal of isolating high-frequency signal components. These features are particularly effective at revealing subtle perturbations introduced by manipulations, such as edge smoothing, compression artifacts, and inpainting operations, which are often imperceptible in other feature domains. In addition to general residual signals, a related form known as cam-based noise is also relevant in forgery detection. This category includes sensor-specific traces such as photo-response non-uniformity (PRNU), lens distortions, thermal noise, and artifacts introduced by the image signal processing pipeline. These characteristics are inherently embedded in images captured by real cameras. In contrast, AI-generated content typically lacks such acquisition-specific patterns, making the presence or absence of cam-based noise a useful indicator of authenticity. Together, these signal-level residuals provide complementary robustness for detecting subtle manipulations, particularly in high-quality or heavily compressed forgeries where pixel-level or semantic features may be insufficient.

Several models have been proposed to effectively extract and use noiseprint features. TruFor (Guillaro et al., 2023) combines a lightweight DnCNN backbone with a SegFormer architecture. It uses a pretrained residual extractor to generate noise maps that suppress image content while preserving manipulation cues, and applies dual attention modules to improve focus on suspicious regions. A self-supervised training strategy enables the model to work without dense annotations. ERMPC (Li et al., 2023a) adopts a two-stream ResNet50 design to process RGB and noise residuals in parallel, using patch-level supervision and multi-scale fusion to improve detection under compression. Similarly, MUN (Liu et al., 2025) employs dual ConvNeXt V2 encoders for parallel RGB and Noiseprint++ extraction, with cross-domain feature correlation enabling more effective noise pattern discovery. EITLNet (Guo et al., 2024) extends SegFormer by integrating handcrafted noise maps and semantic features using a cross-scale attention mechanism, enhancing its ability to capture diverse forgery patterns. *Bi et al.* propose a self-supervised method that learns to detect forgery boundaries by modeling JPEG compression differences, reducing reliance on detailed annotations. DA-HFNet (Liu et al., 2024d) includes a dedicated noise branch alongside RGB and frequency branches in an HRNet framework, using spatial attention to guide the model toward manipulation-sensitive regions. *Zhu et al.* (Zhu et al., 2024) further introduce a noise-guided attention mechanism that applies pseudo-perturbations to residual signals, helping the model focus on vulnerable areas. Overall, noiseprint-based methods are particularly useful in identifying tampering traces that are not easily captured by other features. Their ability to expose low-level inconsistencies makes them a valuable component of explainable forgery detection systems.

5.4 Representation Features

Representation features denote high-level semantic abstractions acquired automatically through deep neural networks, with Transformer-based architectures playing a central role. Unlike handcrafted low-level features such as RGB, frequency, or noiseprint signals, these features are learned end-to-end and encode complex patterns encompassing object semantics, spatial dependencies, and cross-modal associations. Such features enhance model generalization across varied manipulation types while supporting interpretability through semantic masks and textual justifications. In multi-modal forgery detection, representation learning is particularly critical, as it enables effective alignment across heterogeneous modalities—including visual, textual, and auditory signals. Recent methods commonly integrate large-scale pre-trained models such as ViT, CLIP, and LLaVA to construct a unified embedding space that jointly encodes multi-modal inputs, thereby improving both generalization and explainability.

In single-modal forgery detection, diverse network architectures are tailored to extract discriminative representations from specific data types. CSR-Net (Zhang et al., 2024b) introduces a multi-scale semantic extraction module supervised by spline regression loss for refined mask prediction. GIFL (Zhao et al., 2025) enhances a ViT-L/14 encoder with deep residual blocks to improve tampering sensitivity. Delocate (Hu et al., 2024) adopts a dual-branch framework combining frame-level ViT and ResNet-18 to capture spatiotemporal cues in videos. AdaIFL (Li et al., 2024) proposes an adaptive cross-scale reconstruction module fusing RGB and ViT features for improved domain generalization. Mesorch (Zhu et al., 2025) leverages CNN backbones and diverse Transformer decoders (e.g., MAE, SwinT) to disentangle frequency streams and jointly model local and global contexts. *Khormali et al.* (Khormali & Yuan, 2024) employ masked image modeling and graph convolutions in a self-supervised setup to extract structured facial representations. OmniGuard (Zhang et al., 2024c) uses a VAE to generate forgery prior maps, which are fused with ViT outputs to refine attention on suspicious areas. SAFIRE (Kwon et al., 2025) integrates SAM-based segmentation with ViT to produce attention-guided features. *Hong et al.* (Hong et al., 2024) apply contrastive learning to refine ViT-based localization, while DiffForensics (Yu et al., 2024b) injects diffusion priors into ViT encoders to generate more discriminative features.

Building upon these single-modal advances, multi-modal models further extend representation learning by establishing shared embedding spaces across modalities. De-Fake (Sha et al., 2023) introduces a visual-textual consistency mechanism using ViT-B/32 and MLP encoders. HAMMER (Shao et al., 2023) fuses ViT-B/16 and BERT embeddings via hierarchical attention. MGCA (Guo et al., 2025a) designs multi-granularity alignment blocks between ViT and Vicuna features. FFAA (Huang et al., 2024a) aligns ViT-L/14 and T5 features through LLaVA-v1.6-7B. ForgeryGPT (Liu et al., 2024c) and ForgeryTalker (Lian et al., 2024) combine ViT and Vicuna with Q-Former modules for joint classification and explanation. M2F2-Det (Guo

et al., 2025d) proposes a lightweight fusion of EfficientNet-B4, ViT-L/14, and Vicuna. FakeShield (Xu et al., 2024) and LEGION (Kang et al., 2025) stack ViT, SAM, and language models (e.g., LLaVA, GLaMM) for vision-language fusion. SIDA (Huang et al., 2024b) uses Lang-SAM and LISA for language-conditioned masking. ForgerySleuth (Sun et al., 2024) aligns ViT-H masks with LLaVA-generated captions through a consistency loss. TruthLens^{Google} (Kundu et al., 2025a) jointly trains SigLIP-So400m/14 and DINOv2 with Gemma2 and PaliGemma2 for vision-language space unification. HiFi-Net++ (Guo et al., 2025c) integrates frequency pyramids with language embeddings. ESIDE (Wu et al., 2025) perturbs DDIM latents to produce frequency-aware masks, fused with GPT-4o features. EditScout (Nguyen et al., 2024) promotes cross-modal consistency between diffusion-edited images and text. *Yu et al.* (Yu et al., 2025b) and DiMoDif (Koutlis & Papadopoulos, 2024) project audio and visual features into shared spaces using ImageBind-Huge or Transformer-based ASR/VSR fusion to capture modality inconsistencies. Recent MLLM-based methods further advance explainable detection by leveraging large-scale vision-language models. LVLMDFD (Yu et al., 2025a) fine-tunes pre-trained MLLMs to generate textual explanations for deepfake detection. AIGI-Holmes (Zhou et al., 2025) augments LLaVA's encoder with a noiseprint-based visual expert and employs direct preference optimization to align model outputs with human judgment. *Song et al.* (Song et al., 2025) introduce a multi-paradigm prompting strategy across various MLLMs to enhance reasoning consistency. RLSBI (Jiang et al., 2026) adapts LLaVA-1.5 (Liu et al., 2023) for deepfake detection through specialized prompt engineering and semantic-guided localization. Collectively, these methods underscore the pivotal role of representation learning in advancing both single- and multi-modal forgery detection paradigms.

6 Benchmark Datasets and Evaluations

This section examines representative benchmark datasets and evaluation protocols supporting various forgery detection tasks. Commonly used datasets are first categorized by modality and construction strategy in Table 3. The discussion then turns to evaluation metrics for classification, localization, and judgment basis tasks, emphasizing their importance in assessing model performance across different explainability dimensions.

6.1 Datasets

Benchmark datasets are essential to forgery detection, enabling not only standard binary classification but also advanced tasks such as localization, attribution, and explanation. Most existing datasets are constructed using generative models such as GANs or diffusion-based methods to synthesize controlled forgeries that follow consistent patterns (Rössler et al., 2019; Dolhansky et al., 2020; Li et al., 2020). A smaller subset of benchmarks is curated from social media platforms or user-submitted content, where manipulations often appear as mismatched image and text pairs or unstructured edits (Miao et al., 2024; Wu et al., 2025). These real-world forgeries are generally more diverse and less predictable, presenting a higher degree of challenge due to their contextual variability and the lack of standardized annotation.

To reflect the distinctions in modality and supervision level, we divide the datasets into two categories: public source datasets and curated datasets introduced in recent methods. Among the 40 methods we surveyed, 22 introduced their own curated datasets. To better understand how these datasets were constructed, we also tracked their source datasets—*i.e.,* the underlying datasets used to generate forgeries. Importantly, the "`Tasks`" column in Table 3 aggregates all downstream tasks supported by each curated dataset across the methods that used them, which implies the detection capabilities those datasets are designed to evaluate. Based on modality, the datasets broadly fall into two groups: single-modal vision datasets and multi-modal vision-text datasets, each supporting different aspects of interpretable detection.

6.2 Single-Modal Vision Datasets

Image-Modal Datasets. Single-modality visual datasets have underpinned the rapid progress of image and video forgery detection. These datasets typically consist of real and forged visual content and are primarily designed for facial forgery detection, object-level splicing, or frame-wise tampering. Early datasets such as FF++ (Rössler et al., 2019) and Celeb-DF (V2) (Li et al., 2020) provided large-scale facial manipulations and played a foundational role in training supervised detectors. Most image-based datasets

Table 3: Overview of **public** and **curated** datasets commonly used in forgery detection.

Dataset	Modality	Tasks†	Fake		Real		Annotator Availability		Remark
			# w/ Type	Source	# w/ Type	Source			
Public Source Dataset									
FF++ (Rössler et al., 2019)	Image	FL, FJB, FA	1.8M Facial Frames	DeepFakes, Face2Face, FaceSwap, NeuralTextures	509K Facial Frames	YouTube	-	✓	Real (from 1K videos) and fake facial images (from 4K videos) paired with pixel-level forgery masks.
WildDeepfake (Zi et al., 2020)	Image	FL	3.5K Facial Sequences	Internet	3.8K Facial Sequences	Internet	Human	✓	1M face images from 7K face sequences extracted from 707 internet videos.
Celeb-DF (V2) (Li et al., 2020)	Image	FL	21M Facial Frames	Faceswap	2M Facial Frames	Youtube	-	✓	590 real and 5,639 fake videos of celebrities generated by DeepFake synthesis pipeline.
CASIAv2 (Dong et al., 2013a)	Image	FL	5K Images	Splicing, Copy-Move, Removal	7K Images	-	-	✓	Images with mask pairs.
ALASKA (Ruiz et al., 2021)	Image	FL	2M Images	Generated with J-UNIWARD	2M Images	ALASKA#2, BOSS, Dresden, RAISE, StegoApp, Wesaturate	-	✓	Real and Fake (quality factor 75) created from RAW public datasets using J-UNIWARD.
Fantasitic-Reality (Kniaz et al., 2019a)	Image	FL	16K Images	Splicing with Generative Retoucher	16k Images	-	Human	✓	Real and spliced images with pixel-level tamper masks, instance masks, and 10-class semantic labels including person, car, bus, etc.
Protocol-CAT (Ma et al., 2024)	Image	FL	-	CASIA (Dong et al., 2013a), Coverage, Columbia, NIST16, IMD2020, NC2016, NC2017, Defacto	-	CASIA v2.0, Coverage, Columbia, NIST16, IMD2020, NC2016, NC2017, Defacto	-	✓	This provided through a codebase referenced IMDL-BenCo.
Synthesized Dataset (Liu et al., 2025)	Image	FL	156K Images	NIST16, CASIA, IMD2020, CocoGlide, Wild, CASIA, ADE20K	-	-	-	✓	There are 156006 synthesized images(140432 for training, 7787 for validation, and 7787 for testing).
WildFake (Hong & Zhang, 2024)	Image	FJB	2M Images	GANs, DMs, AEs	1M Images	LAION-5B, Wukong, COCO, ImageNet, FFHQ, CelebA-HQ, AFHQ, LSUN	-	✓	WildFake contains 3.69M images (1M real, 2M fake)
DF40 (Yan et al., 2024b)	Image	FJB	1M Images	PixArt-α, Face-swapping, Face-reenactment, Entire Face Synthesis, Face Editing	-	-	-	✓	Large-scale deepfake benchmark with 40 manipulation methods.
DeepfakeBench (Yan et al., 2023)	Video	FL, FJB	133k Videos	FF++, CelebDF-v1, CelebDF-v2, DFD, DFDC, UADFV, FaceShifter, DeeperForensics-1.0	78K Videos	FF++, CelebDF-v1, CelebDF-v2, DFD, DFDC, UADFV, FaceShifter, DeeperForensics-1.0	-	✓	DeepfakeBench provides preprocessed facial deepfake datasets from multiple public sources, including cropped faces, masks, and landmarks, enabling direct image- and video-level evaluation.
DeeperForensics-1.0 (Jiang et al., 2020)	Video	FL	5M Facial Frames	Faceswap (Tampered via DF-VAE)	12.6M Frames	From 100 Paid Actors	Human	✓	Frames from 60K facial videos with diverse perturbations.
DFDC (Dolhansky et al., 2020)	Video	FL	100K Video Clips	AEs, GANs, TTS Audio Swap	28K Video Clips	3,426 Paid Actors	-	✓	Videos with face/audio swaps, from 3,426 paid actors in diverse lighting and scene conditions.
DD-VQA (Zhang et al., 2024d)	Image-Text	FL, FJB	3K Facial Images	FF++	1k Videos	FF++	Human	✓	Facial images and 14K Q-A pairs.
MagicBrush (Zhang et al., 2023)	Image-Text	FL	10K Images	DALL · E 2	5K real source images	MSCOCO	Human	✓	Real and Fake with multi-turn instruction-guided edits, covering object addition, removal, attribute change, etc.
AutoSplice (Jia et al., 2023)	Image-Text	FL	3.5K Images	Visual News with DALL · E 2	2K Images	Visual News	Human	✓	Fake and Real images, each with pixel-level forgery mask, based on news photos and text edits from real media.
DVF (Song et al., 2024)	Image-Text	FL, FJB	4K Videos	TikTok, OpenSora, VideoCrafter1	2.7K Videos	Internvid-10M, YouTube-8M	-	✓	AI-generated videos and real-world videos covering diverse semantics and video qualities.
FakeAVCeleb (Khalid et al., 2021)	Video-Text	FL	19.5K Videos	Faceswap on VoxCeleb2	500 Videos	VoxCeleb2	-	✓	Videos with all 4 combinations of real/fake video and audio (ARVR, AFVR, ARVF, AFVF) with lip-sync alignment, diverse ethnicity, and gender.
LAV-DF (Cai et al., 2022)	Video-Text	FL	99K Videos	VoxCeleb2	36K Videos	VoxCeleb2	-	✓	Videos from 153 identities; includes real and multimodally manipulated clips (audio-only, video-only, both), with frame-level sentiment and timing labels.
AVDeepfake1M (Cai et al., 2024)	Video-Text	FL	860K Videos	ChatGPT	286K Videos	VoxCeleb2	-	✓	Videos from 2K subjects, with insert/delete/replace edits across audio, video, or both; includes 1.8K hours of high-quality AV data.
Curated Dataset									
OFV2 (Miao et al., 2024)	Image	FL	70K Facial Images	OpenForensics (Tampered via GANs)	-	Open Images (Kuznetsova et al., 2020)	-	✗	A multi-face forgery image dataset with forged images and pixel-level forgery masks.
Miao et al., (Miao et al., 2024)	Image	FL	20K Facial Videos	FFIW (Multiface manipulations only)	-	FFIW	-	✗	Multi-face forgery video frames(Faceswap,Fsgan,Deepfacelab) with masks.
Miao et al., (Miao et al., 2023)	Image	FL	273K Facial Frames	P-FF++ (Rossler et al., 2019), Dolos (Tántaru et al., 2024) (DMs, GANs, LaMa)	188K Frames	P-FF++ (Rossler et al., 2019), Dolos (Tántaru et al., 2024)	-	✓	Real-Fake facial image pairs with masks.
DA-HFNet (Liu et al., 2024d)	Image	FL	21K Images	GANs, DMs, Inpaint Anything, StyleCLIP	20K Images	COCO2017 (Lin et al., 2014), ImageNet (Deng et al., 2009)	-	✗	Combining full and partial image forgeries generated by GAN and Diffusion models guided by text or image inputs.
HiFi-IFDL (Guo et al., 2025c)	Image	FA, FL	1.3M Images	LSUN, CelebAHQ, FFHQ, AFHQ, Youtube (Tampered via GANs, DMs, Faceshifter)	-	-	-	✓	Fake images are paired with high-resolution binary forgery masks.
SafireMSExpert (Kwon et al., 2025)	Image	FA, FL	238 Images	DPReview, COCO2017	-	-	Human	✗	A high-quality, manually constructed image forgery dataset with multi-source edits and pixel-level masks designed by human experts.
SafireAuto (Kwon et al., 2025)	Image	FA, FL	123K Images	DPReview, COCO2017 (Tampered via Copy-Move, Splicing, Removal, Generative Reconstruction)	30K Images	DPReview, COCO2017	-	✗	A large-scale automatically generated dataset using SAM-based masks over real images from COCO and DPReview, with 4 editing types and paired masks.
X-FAS (Zhang et al., 2024a)	Image	FA, FL	56 Spoof Images	CASIA-FASD	-	-	Human	✗	56 CASIA-FASD spoof images annotated by experts with four semantic-level spoofing evidences for evaluating explainable face anti-spoofing methods.
GENHARD (Wu et al., 2025)	Image	FA	108K Images	GenImage (Zhu et al., 2023)	112K Images	GenImage (Zhu et al., 2023)	-	✗	A curated set of "hard" real and fake images from GenImage, chosen based on consistent misclassification.
ForgeryADE (Zhao et al., 2025)	Image	FA, FL	177K Images	ADE 20 (Zhou et al., 2017)	22K Images	ADE20K	-	✗	A dataset containing manipulated images and authentic images, with diverse occlusion masks and 8 modern forgery methods.
Manual-Fake (Miao et al., 2024)	Video	FL	1K Videos	YouTube, TikTok, Bilibili	1K Videos	Internet	-	✗	A multi-face forgery video dataset for evaluation on real-world deepfakes, with pixel-level annotations
Sha et al., (Sha et al., 2023)	Image-Text	FA	40K Images	DMs	40K Images	MSCOCO (Lin et al., 2014), Flickr30k (Young et al., 2014)		✗	Images generated from textual prompts using DMs.
DGM^4 (Shao et al., 2023)	Image-Text	FA, FL	152K Image-Text Pairs	CelebA-HQ, VisualNews (Liu et al., 2020)	77K Image-Text Pairs	VisualNews	-	✓	Image-text news-style pairs with manipulated pairs covering face and text edits, annotated for multimodal detection and grounding.
MMTD-Set (Xu et al., 2024)	Image-Text	FA, FL, FJB	51k Images	Fantastic Reality (Kniaz et al., 2019b), CASIAv2 (Dong et al., 2013b), FaceAPP (Stehouwer et al., 2019), AIGC-Editing (Lugmayr et al., 2022)	54k Images	Fantastic Reality (Kniaz et al., 2019b), CASIAv2 (Dong et al., 2013b), FFHQ (Karras et al., 2019), COCO (Lin et al., 2014)	GPT-4o	✓	General image and tampered masks, with instruction.
FFA-VQA (Huang et al., 2024a)	Image-Text	FA, FL, FJB	67K Frames	FF++, Celeb-DF-v2, DFFD, GanDiffFace	27K Frames	FF++ (Rössler et al., 2019), Celeb-DF-v2 (Li et al., 2020), DFFD (Stehouwer et al., 2019)	GPT-4o, Human	✓	Face images with identity swap, attribute manipulation, or entire face synthesis, each paired with GPT-generated VQA analysis.
ForgeryAnalysis (Sun et al., 2024)	Image-Text	FL, FJB	50K Image -Text Pairs	MIML (Qu et al., 2024), CASIA2 (Dong et al., 2013b), DEFACTO (Mahfoudi et al., 2019), AutoSplice (Jia et al., 2023)	-	-	Human	✓	50k manipulated image-mask-analysis text pairs.
AMG (Guo et al., 2025a)	Image-Text	FA	2K Posts	Instagram, Facebook, Twitter	3K Posts	Fact-checking sites, Reuters (Reuters, 2023), NewsNation (NewsNation, 2023)	Human	✓	Social media posts from 2016–2024, annotated with fine-grained attribution reasons for misinformation.
MMTT (Lian et al., 2024)	Image-Text	FA, FL, FJB	128K Facial Images	CelebAMaskHQ (Zhu et al., 2022), FFHQ (Karras et al., 2019) (Tampered via GANs (Goodfellow et al., 2014), Transformers (Vaswani et al., 2017a) , DMs (Ho et al., 2020b))	100K Facial Images	CelebAMask-HQ, FFHQ	Human	✗	Each of the face images is paired with a high resolution binary forgery mask and a detailed human written caption describing manipulated regions and their artifacts.
Liu et al., (Liu et al., 2024c)	Image-Text	FA, FL, FJB	768K Image-Caption Pairs	MSCOCO (Lin et al., 2014) (Tampered via Splicing, Copy-Move, Removal)	-	-	GPT-4	✗	A multi-granularity dataset containing image-caption pairs generated using traditional manipulate techniques.
GENEXPLAIN (Wu et al., 2025)	Image-Text	FA, FJB	54K Images	GenImage (Zhu et al., 2023)	-	-	GPT-4o	✗	A high-resolution Image-Text dataset with 14 flaw categories, GPT-4o-generated and refined explanations for each fake image.
SID-Set (Huang et al., 2024b)	Image-Text	FA, FL, FJB	200K Images	FLUX (Flux Model Team, 2024), Kandinsky3.0 (Arkhipkin et al., 2023), SDXL (Podell et al., 2023), AbsoluteReality (Absolutereality Model Team, 2024), LD (CompVis, 2023)	100K Images	OpenImages V7 (Google Research, 2022)	GPT-4o, Human	✓	A dataset for deepfake detection on social media, includes segmentation masks and 3K textual explanations.
SynthScars (Kang et al., 2025)	Image-Text	FA, FL, FJB	12K Images	RichHF-18K (Liang et al., 2024), Chameleon (Yan et al., 2024a), FFAA (Huang et al., 2024a)	-	-	Human	✓	A dataset containing images with irregular polygon masks, detailed explanations, and classification into 3 artifact types: physics, distortion, and structure.
Holmes-Set (Zhou et al., 2025)	Image-Text	FJB	65K Images-Text Pairs	GANDetection (Wang et al., 2020), GenImage (Zhu et al., 2023)	-	-	Human	✓	Holmes-SFTSet/DPOSet: Explanation-rich SFT and human-preference datasets enabling aligned explainable AIGI detection.

†: **FL**: Forgery Localization, **FA**: Forgery Attribution, **FJB**: Forgery Judgment Basis.

only contain visual samples with binary or pixel-level labels, thus they are predominantly used for forgery

localization. Several datasets focus specifically on facial manipulations, such as FF++ (Rössler et al., 2019), WildDeepfake (Zi et al., 2020), and Celeb-DF (V2) (Li et al., 2020), where synthetic faces are generated using DeepFakes, Face2Face, FaceSwap, or NeuralTextures applied to real face data. In addition, hybrid datasets that combine facial and natural images, including CASIAv2 (Dong et al., 2013a), ALASKA (Ruiz et al., 2021), GENHARD (Wu et al., 2025), WildFake (Hong & Zhang, 2024), and others (Kniaz et al., 2019b; Ma et al., 2024; Liu et al., 2024d; Guo et al., 2025c; Kwon et al., 2025; Zhang et al., 2024a; Zhao et al., 2025; Yan et al., 2024b) are constructed to support evaluation across more diverse manipulation scenarios.

These datasets are typically constructed from diverse sources and include various forgery methods, ranging from traditional splicing and removal to advanced model-based generation (*e.g.,* text-to-image editing, repainting, inpainting via diffusion models). While most of these datasets are limited to image–mask pairs and thus suitable for localization tasks, it is worth noting that some works (Yu et al., 2025b; Khormali & Yuan, 2024; Hong et al., 2024; Hu et al., 2024) extend the use of source datasets like FF++ (Rössler et al., 2019) to also support attribution and explanation tasks via additional annotations or processing.

Video-Modal Datasets. In contrast to image forgeries, relatively few works in our survey focus on video-level forgery detection. Among them, DeeperForensics-1.0, DFDC, DeepfakeBench and Manual-Fake (Jiang et al., 2020; Dolhansky et al., 2020; Yan et al., 2023; Miao et al., 2024) represent three distinct strategies for constructing annotated video datasets, each supporting forgery localization, robustness evaluation, or generalization studies. DeeperForensics-1.0 is built from 100 paid actors and generates over 5 million forged frames using DF-VAE (Jiang et al., 2020), with simulated perturbations to assess robustness to degradations (Jiang et al., 2020). DFDC remains the largest competition-scale benchmark for deepfake detection, featuring over 3,000 participants and a wide variety of manipulation types (GAN, AutoEncoder, audio swap), making it ideal for large-scale multimodal forgery analysis (Dolhansky et al., 2020). In contrast, Manual-Fake is derived from social platforms (YouTube, TikTok, Bilibili), capturing naturally occurring manipulations with pixel-level annotations (Miao et al., 2024). Although smaller in scale, it provides high authenticity and multi-face occlusion scenarios, posing unique challenges. Compared to image datasets, these video benchmarks offer greater complexity in temporal modeling, scene variation, and multimodal integration, making them especially valuable for advancing explainable video forgery detection.

6.3 Vision–Text Multimodal Datasets

Image–Text Multimodality. In image–text datasets for forgery detection, the text component can take multiple forms depending on the dataset's design. One common format is a descriptive caption summarizing the visual content, typically describing the scene or objects within the image. Such captions provide semantic context and are used to assess cross-modal consistency. For example, they help ensure alignment between the image and its textual description, or improve model performance through cross-domain feature fusion and alignment (Sha et al., 2023). Another format involves explanatory annotations that specify manipulation-related information, such as the type of operation (*e.g.,* splicing, copy-move, or AI generation), the exact tampered regions, or the reasoning beyond the real/fake classification (Shao et al., 2023; Guo et al., 2025a). These annotations provide explicit forensic cues and help models learn to associate anomalies in the image with specific features or regions, thereby enhancing interpretability. Some datasets, such as DD-VQA and FFA-VQA, adopt a question–answer format, where each image is paired with targeted questions about its authenticity or content. The corresponding answers include both the classification result and a supporting explanation. This QA format encourages stepwise reasoning and typically requires the model to express its decision-making process in natural language. Lastly, many datasets generate explanation texts during the tampering process, either through manual annotation or by using prompt-based methods with large language models (Achiam et al., 2023; Liu et al., 2023; Zhou et al., 2025). These various text forms reflect different supervisory signals and learning objectives: caption-based datasets emphasize cross-modal consistency between images and descriptions; explanatory annotations support visual attribution; and QA-style supervision promotes interactive and interpretable reasoning. Training strategies should therefore be selected in accordance with the target task and the characteristics of the dataset.

Video–Text Multimodality. Several recent benchmarks have been introduced to support multimodal forgery detection involving both video and text or audio. These datasets consist of paired video and audio content, where either modality may be real or manipulated. FakeAVCeleb (Khalid et al., 2021) contains

19.5K video samples generated by applying FaceSwap to VoxCeleb2 (Chung et al., 2018). The dataset includes four combinations of authenticity across the audio and video streams: real video with real audio (ARVR), real video with fake audio (ARVF), fake video with real audio (AFVR), and fake video with fake audio (AFVF). All samples are lip-synced and include a diverse range of demographic attributes such as ethnicity and gender. LAV-DF (Cai et al., 2022) comprises 99K videos across 153 unique identities, constructed from VoxCeleb2 clips. It contains real as well as manipulated samples, with forgery applied to the audio only, video only, or both. Each clip is annotated with frame-level sentiment labels and temporal alignment information. AVDeepfake1M (Cai et al., 2024) consists of 860K synthetic video clips created using ChatGPT for dialogue generation and VoxCeleb2 as the visual source. The manipulations include insertion, deletion, and replacement in the audio, video, or both. The dataset comprises approximately 1.8K hours of video and audio content and features 2K distinct speaker identities.

6.4 Evaluation Metrics

We categorize evaluation metrics in forgery detection into three main groups: classification-oriented, localization-oriented, and explanation-oriented. Classification and localization are well-defined tasks with widely adopted quantitative metrics. In comparison, texual explanation is an open-ended objective that often requires more flexible and interpretive forms of evaluation, particularly in scenarios involving Multimodal Large Language Models (MLLMs). This section provides a brief overview of classification and localization metrics, with particular emphasis on explanation quality evaluation.

Classification-oriented Metrics. Classification tasks commonly adopt a series of standard metrics, including Accuracy, AUC, Equal Error Rate (EER), F1 Score, and Average Precision (AP/mAP). Accuracy reflects the proportion of correctly classified instances and is widely used in balanced datasets. AUC measures the discriminative ability of a model across varying thresholds and is particularly robust under class-imbalanced conditions. EER identifies the threshold at which false acceptance and false rejection rates are equal, which is especially relevant in authentication and identity verification scenarios. The F1 Score combines precision and recall into a single metric and applies to both image-level classification and pixel-level forgery detection. AP evaluates the precision-recall trade-off for individual classes, while mAP generalizes this evaluation across multiple classes or samples, making it well-suited for video forgery detection and temporal segment localization.

Localization-oriented Metrics. In localization tasks, evaluation metrics aim to assess the spatial or temporal precision of identifying manipulated regions. These metrics can be categorized as follows:

- Image-level Metrics. Common metrics include:
  - Intersection over Union (IoU): Measures the overlap between predicted and ground truth masks; widely used as a core indicator of localization accuracy.
  - Pixel-wise F1 Score: Captures both precision and recall at the pixel level; suitable for binarized probability maps.
  - Pixel-wise Binary Classification Accuracy (PBCA): Computes overall pixel-wise accuracy, though it may be biased by the dominant non-manipulated class.
  - Dice Score: Evaluates region-level overlap; often used both as an evaluation metric and a loss function in training.
- Text-level Metrics. Token-wise F1 Score is used to evaluate whether the model accurately identifies manipulated segments within a text sequence.
- Video-level Metrics. Metrics such as those used in DiMoDif (Koutlis & Papadopoulos, 2024) include:
  - AP@p: Measures average precision under an IoU threshold p (*e.g.,* $0.5, 0.75, 0.95$).
  - AR@n: Computes average recall given up to n candidate proposals; reflects the model's ability to retrieve manipulated segments over time.
- Multi-source Clustering Metrics. Some models such as SAFIRE (Kwon et al., 2025) use:

- Adjusted Rand Index (ARI): Evaluates consistency between predicted and ground truth manipulation clusters. ARI is defined as:

$$\text{ARI} = \frac{\text{RI} - \mathbb{E}[\text{RI}]}{\max(\text{RI}) - \mathbb{E}[\text{RI}]} \tag{5}$$

  where RI denotes the raw Rand Index. ARI corrects for chance and provides a normalized measure of agreement, making it suitable for segmentation consistency evaluation.

Texual Explanation-oriented Metrics. Assessing the quality of generated textual explanations in forgery detection involves a wide array of evaluation strategies, each emphasizing different aspects of language quality, semantic fidelity, or task utility. We summarize these methods into 5 categories:

- Text Similarity Metrics. These metrics measure surface-level lexical and syntactic similarity between generated explanations and reference texts.
  - N-gram Overlap (*e.g.,* BLEU-3/4) (Chakraborty et al., 2025; Guo et al., 2025d; Lian et al., 2024): BLEU evaluates the precision of contiguous word sequences (n-grams). BLEU-4 captures four-word phrase-level coherence. Higher scores indicate greater overlap in wording and phrasing.
  - Sequence Matching (*e.g.,* ROUGE-L) (Liu et al., 2024c; Kang et al., 2025): ROUGE-L computes the longest common subsequence between candidate and reference texts, capturing structural similarity.
  - Comprehensive Metrics (*e.g.,* CIDEr, METEOR) (Kundu et al., 2025a; Guo et al., 2025d): CIDEr incorporates TF-IDF weights to emphasize important words, while METEOR integrates synonym and stem matching. These metrics provide more nuanced assessments than n-gram precision alone, especially in multimodal settings.
- Semantic Consistency Metrics. These metrics assess deeper meaning alignment beyond lexical overlap.
  - Cosine Semantic Similarity (CSS) (Xu et al., 2024; Kang et al., 2025): Explanations are embedded using pretrained models (*e.g.,* MiniLM, BERT), and cosine similarity is computed between vectors. This accounts for paraphrasing and semantic equivalence.
  - Image–Text Consistency: This metric evaluates whether textual explanations align with visual evidence. ESIDE (Wu et al., 2025) employs such evaluation to validate that explanations describe manipulated content in the associated image.
- LLM-based Evaluation Frameworks. Large language models (LLMs) are increasingly adopted to evaluate explanations by simulating human judgment. Typically, the explanation is presented to the model together with contextual inputs such as the manipulated image or a reference response, formulated through a task-specific prompt. The LLM is then prompted to assign structured scores or output binary decisions.
  - Structured Scoring (*e.g.,* ForgeryAnalysis-Eval): ForgerySleuth (Sun et al., 2024) uses GPT-4 to score explanations on a 1–10 scale across three axes: (i) object recognition accuracy, (ii) evidence relevance, and (iii) logical reasoning. This enables structured and reproducible evaluation.
  - Binary LLM-as-a-Judge (Kundu et al., 2025a; Yu et al., 2025b): Models like Gemini or GPT-4 output Yes/No decisions indicating whether the explanation agrees with the ground truth.
- Human Evaluation Protocols. Human raters provide subjective but trusted assessments of explanation quality.
  - Expert/Crowdsourced Ratings: χ^2-DFD (Chen et al., 2024b) collects human feedback on clarity, correctness, and relevance using Likert scales or ranking. These evaluations offer fine-grained judgment often used as ground truth in benchmarks.
  - Task Utility Assessment (Chakraborty et al., 2025; Kwon et al., 2025; Huang et al., 2024a): User studies test whether explanations help improve task performance (*e.g.,* fake image identification), measuring practical effectiveness and interpretability.
- Functional Assessment. These methods indirectly evaluate explanations through their impact on downstream tasks.

- Performance Improvement: Systems like TruthLens (Chakraborty et al., 2025) and SHIELD (Shi et al., 2024) report increased classification accuracy when explanations are incorporated, implying functional value.
- Cross-Modal Consistency: FFAA (Huang et al., 2024a) ensures that visual evidence (*e.g.,* heatmaps) and textual explanations refer to the same manipulated content, validating coherence across modalities.

7 Challenges and Future Directions

With the rapid advancement of AI-generated content technologies in recent years, the interplay between generation and detection has increasingly resembled a two-player game, akin to a cat-and-mouse dynamic (Lin et al., 2024). As generation methods evolve, they continuously expose the limitations of current detection techniques. In response, the field faces a number of open challenges that remain insufficiently addressed. To advance the robustness and transparency of forgery detection, we highlight several promising research directions spanning methodology, dataset curation, and evaluation protocols.

Explainable Detection Outputs. One major challenge in forgery detection lies in the absence of structured and standardized formats for explanation generation. Although some existing models offer limited interpretability, most rely on ad hoc techniques such as free-form textual rationales or saliency maps that highlight suspicious regions. Although these forms provide partial insight, they often fall short of delivering comprehensive and consistent justifications for the decisions of the model. Critically, few systems offer explanations that address all key dimensions of forensic analysis: (1) accurate localization of manipulated regions, (2) source attribution, such as identifying the generative model or the type of manipulation, and (3) explicit judgment basis that outlines the rationale of the decision. The lack of such multi-dimensional outputs significantly limits interpretability and accountability. Establishing these three explanation dimensions as standard outputs could form a foundation for transparent, auditable, and trustworthy detection systems. Notable exceptions like FakeShield (Xu et al., 2024; Huang et al., 2024a) demonstrate the feasibility of this approach by producing tripartite explanations that jointly cover localization, manipulation type, and decision rationale. However, such designs remain rare. Future research should therefore explore methods to guide model outputs toward these richer explanation formats. Promising directions include task-specific instruction tuning and explanation-aware multi-task learning objectives, which explicitly condition model outputs on locality, attribution, and reasoning targets. Additionally, modular architectures that decouple detection from explanation could enable more dedicated interpretability modeling. Finally, incorporating structured output formats inspired by recent advances in vision-language reasoning tasks would promote consistency and human-readability across systems. Advancing these directions would enable the development of explanation-rich detectors that not only identify manipulations but also articulate how and why a given decision is made.

Uncertainty-Aware Detection. Existing methods largely prioritize accuracy, with limited attention to predictive confidence. In high-risk applications such as misinformation detection and legal forensics, the absence of uncertainty estimation can lead to overreliance on unreliable outputs. While a small subset of recent works has begun to explore uncertainty modeling to improve system robustness (Guillaro et al., 2023; Kwon et al., 2025; Huang et al., 2024a; Chakraborty et al., 2025), many of these efforts remain limited in scope. Some methods, such as TruFor (Guillaro et al., 2023) and SAFIRE (Kwon et al., 2025), provide explicit or weakly explicit confidence estimates for localized predictions. However, others rely on implicit indicators of uncertainty. For example, FFAA (Huang et al., 2024a) employs a Multi-answer Intelligent Decision System (MIDS) to evaluate the consistency of responses generated under different hypotheses, using it as a proxy for sample difficulty. TruthLens (Chakraborty et al., 2025) includes textual labels such as *"confidence: high"* in its explanations, but these lack grounding in formal probabilistic estimation. Established techniques such as Bayesian neural networks, deep ensembles, and temperature scaling offer principled foundations for calibrated uncertainty estimation. Future work should investigate how these methods can be effectively integrated into forgery detection pipelines, enabling models to output interpretable and trustworthy confidence measures and improving their reliability in real-world applications.

Data Coverage and Annotation Gaps. Forgery detection remains constrained by the limited scope, diversity, and annotation granularity of current datasets. Although several curated datasets have facilitated

recent progress, many remain confined to narrow domains (*e.g.,* facial imagery, social media content, or synthetic benchmarks). As a result, they often fail to represent emerging manipulation techniques, including both traditional editing methods and content generated by modern generative AI models. Many datasets include visual-text pairs, but only a small subset involve human verification. This lack of verification makes it difficult to assess label reliability, particularly for fine-grained manipulations. Furthermore, most datasets provide only binary authenticity labels (real or fake) and lack detailed annotations such as manipulation type, affected image regions, or source-target attribution. These limitations hinder the development of robust, generalizable, and explainable forgery detection systems. To address these gaps, future datasets should be designed to cover a broader range of manipulation types and encompass more modalities and languages. They should also provide richer annotations such as region-level masks, semantic consistency judgments, manipulation provenance, and human-authored rationales. Such enhancements would better support multi-task learning and facilitate attribution-focused research.

Benchmark for Explainable Forgery Detection. Recent advances in forgery detection have introduced a variety of explanation modalities, including visual heatmaps for manipulation localization, source attribution of the forgery (*e.g.,* identifying the source generative model), and textual rationales that articulate the basis for detection decisions. Despite these developments, the field lacks a unified framework or standardized metrics for assessing the quality, faithfulness, and consistency of such outputs. This gap complicates meaningful comparison between methods and presents a barrier to reproducibility, as current evaluation practices remain largely qualitative and task-specific. This motivates the need for systematic evaluation protocols and benchmark datasets that can support reliable, cross-method assessment of interpretability in both unimodal and multimodal detection scenarios.

Limited Explainability in Video-based Detection. Explainability for video forgery detection remains significantly underdeveloped. While many detectors operate on temporal data to predict real or fake labels, only a few methods explicitly address explainability, and among them, only two provide interpretable forgery localization outputs. Most existing approaches are confined to static frame-level visualizations, offering limited insight into motion inconsistencies or temporally distributed manipulation patterns. Structured outputs such as source attribution or judgment rationales grounded in temporal evidence are even more scarce. This gap is particularly limiting given that many forgeries exploit subtle cross-frame artifacts, which static explanations fail to capture. Future research should explore techniques such as temporal attention visualization, prototype-based motion analysis, and video-language models capable of generating temporally grounded natural language explanations. Defining structured explanation formats for video, encompassing when a manipulation occurs, where it appears, and why it is detected, will be essential for developing interpretable and trustworthy video forgery detection systems.

8 Conclusion

In summary, this survey has synthesized recent progress in explainable image-centric forgery detection and traced the field's evolution from binary classification to multi-dimensional interpretability. We demonstrated the complementary nature of four feature-driven strategies (RGB, frequency, noise-texture, and representation learning) and examined how single-modal and multi-modal methods approach localization, attribution, and reasoning tasks. Despite these advances, significant challenges remain, including the absence of standardized explanation protocols, limited uncertainty quantification, insufficient dataset diversity, and underexplored video-based explainability. Addressing these issues requires principled frameworks, robust benchmarks, and methods capable of handling temporal consistency. Looking forward, we argue that forgery detection systems must achieve not only high accuracy but also transparency and accountability to earn trust in real-world deployments. The proposed taxonomy and identified research directions provide a roadmap for developing reliable and interpretable detection technologies that can serve critical applications in forensic analysis, journalism, and governance.

References

Faceswap: Deepfakes software for all. Available: https://github.com/deepfakes/faceswap, 2019.

Absolutereality Model Team. Absolutereality model repository, 2024. URL https://huggingface.co/jochemstoel/absolutereality-model-repository.

Josh Achiam, Steven Adler, Sandhini Agarwal, Lama Ahmad, Ilge Akkaya, Florencia Leoni Aleman, Diogo Almeida, Janko Altenschmidt, Sam Altman, Shyamal Anadkat, et al. Gpt-4 technical report. *arXiv preprint arXiv:2303.08774*, 2023.

Ibrahim M Alabdulmohsin, Xiaohua Zhai, Alexander Kolesnikov, and Lucas Beyer. Getting vit in shape: Scaling laws for compute-optimal model design. *Advances in Neural Information Processing Systems*, 36: 16406–16425, 2023.

Firoj Alam, Stefano Cresci, Tanmoy Chakraborty, Fabrizio Silvestri, Dimiter Dimitrov, Giovanni Da San Martino, Shaden Shaar, Hamed Firooz, and Preslav Nakov. A survey on multimodal disinformation detection. *arXiv preprint arXiv:2103.12541*, 2021.

Vladimir Arkhipkin, Andrei Filatov, Viacheslav Vasilev, Anastasia Maltseva, Said Azizov, Igor Pavlov, Julia Agafonova, Andrey Kuznetsov, and Denis Dimitrov. Kandinsky 3.0 technical report. *arXiv preprint arXiv:2312.03511*, 2023.

Xiuli Bi, Wuqing Yan, Bo Liu, Bin Xiao, Weisheng Li, and Xinbo Gao. Self-supervised image local forgery detection by jpeg compression trace. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 37, pp. 232–240, 2023.

Andrew Brock, Jeff Donahue, and Karen Simonyan. Large scale gan training for high fidelity natural image synthesis. *arXiv preprint arXiv:1809.11096*, 2018.

Zhixi Cai, Kalin Stefanov, Abhinav Dhall, and Munawar Hayat. Do you really mean that? content driven audio-visual deepfake dataset and multimodal method for temporal forgery localization. In *2022 International Conference on Digital Image Computing: Techniques and Applications (DICTA)*, pp. 1–10. IEEE, 2022.

Zhixi Cai, Shreya Ghosh, Aman Pankaj Adatia, Munawar Hayat, Abhinav Dhall, Tom Gedeon, and Kalin Stefanov. Av-deepfake1m: A large-scale llm-driven audio-visual deepfake dataset. In *Proceedings of the 32nd ACM International Conference on Multimedia*, pp. 7414–7423, 2024.

Ritabrata Chakraborty, Rajatsubhra Chakraborty, Ali Khaleghi Rahimian, and Thomas MacDougall. Truthlens: A training-free paradigm for deepfake detection. *arXiv preprint arXiv:2503.15342*, 2025.

Chen Chen, Qifeng Chen, Jia Xu, and Vladlen Koltun. Learning to see in the dark. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pp. 3291–3300, 2018.

Jiaxuan Chen, Jieteng Yao, and Li Niu. A single simple patch is all you need for ai-generated image detection. *arXiv preprint arXiv:2402.01123*, 2024a.

Yize Chen, Zhiyuan Yan, Siwei Lyu, and Baoyuan Wu. X^2-dfd: A framework for explainable and extendable deepfake detection. *arXiv preprint arXiv:2410.06126*, 2024b.

Yunjey Choi, Minje Choi, Munyoung Kim, Jung-Woo Ha, Sunghun Kim, and Jaegul Choo. Stargan: Unified generative adversarial networks for multi-domain image-to-image translation. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pp. 8789–8797, 2018.

Joon Son Chung, Arsha Nagrani, and Andrew Zisserman. Voxceleb2: Deep speaker recognition. *arXiv preprint arXiv:1806.05622*, 2018.

CompVis. Stable diffusion. https://github.com/CompVis/stable-diffusion, 2023.

Antonio Criminisi, Patrick Pérez, and Kentaro Toyama. Region filling and object removal by exemplar-based image inpainting. *IEEE Transactions on image processing*, 13(9):1200–1212, 2004.

Wenliang Dai, Junnan Li, Dongxu Li, Anthony Meng Huat Tiong, Junqi Zhao, Weisheng Wang, Boyang Li, Pascale Fung, and Steven Hoi. Instructblip: towards general-purpose vision-language models with instruction tuning. In *Proceedings of the 37th International Conference on Neural Information Processing Systems*, NIPS '23, Red Hook, NY, USA, 2023. Curran Associates Inc.

Jia Deng, Wei Dong, Richard Socher, Li-Jia Li, Kai Li, and Li Fei-Fei. Imagenet: A large-scale hierarchical image database. In *2009 IEEE conference on computer vision and pattern recognition*, pp. 248–255. Ieee, 2009.

Jacob Devlin, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova. Bert: Pre-training of deep bidirectional transformers for language understanding. In *Proceedings of the 2019 conference of the North American chapter of the association for computational linguistics: human language technologies, volume 1 (long and short papers)*, pp. 4171–4186, 2019.

Brian Dolhansky, Joanna Bitton, Ben Pflaum, Jikuo Lu, Russ Howes, Menglin Wang, and Cristian Canton Ferrer. The deepfake detection challenge (dfdc) dataset. *arXiv preprint arXiv:2006.07397*, 2020.

Chengbo Dong, Xinru Chen, Ruohan Hu, Juan Cao, and Xirong Li. Mvss-net: Multi-view multi-scale supervised networks for image manipulation detection. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 45(3):3539–3553, 2022.

Jing Dong, Wei Wang, and Tieniu Tan. CASIA image tampering detection evaluation database. In *2013 IEEE China Summit and International Conference on Signal and Information Processing*. IEEE, July 2013a. doi: 10.1109/chinasip.2013.6625374. URL `https://doi.org/10.1109/chinasip.2013.6625374`.

Jing Dong, Wei Wang, and Tieniu Tan. Casia image tampering detection evaluation database. In *2013 IEEE China summit and international conference on signal and information processing*, pp. 422–426. IEEE, 2013b.

Alexey Dosovitskiy, Lucas Beyer, Alexander Kolesnikov, Dirk Weissenborn, Xiaohua Zhai, Thomas Unterthiner, Mostafa Dehghani, Matthias Minderer, Georg Heigold, Sylvain Gelly, et al. An image is worth 16x16 words: Transformers for image recognition at scale. *arXiv preprint arXiv:2010.11929*, 2020.

Flux Model Team. Flux model, 2024. URL `https://huggingface.co/black-forest-labs/FLUX.1-dev`. Text-to-image generation model.

Jessica Fridrich and Jan Kodovsky. Rich models for steganalysis of digital images. *IEEE Transactions on information Forensics and Security*, 7(3):868–882, 2012.

Jessica Fridrich, David Soukal, Jan Lukas, et al. Detection of copy-move forgery in digital images. In *Proceedings of digital forensic research workshop*, volume 3, pp. 652–63. Cleveland, OH, 2003.

Ian Goodfellow, Jean Pouget-Abadie, Mehdi Mirza, Bing Xu, David Warde-Farley, Sherjil Ozair, Aaron Courville, and Yoshua Bengio. Generative adversarial networks. *Communications of the ACM*, 63(11): 139–144, 2020.

Ian J Goodfellow, Jean Pouget-Abadie, Mehdi Mirza, Bing Xu, David Warde-Farley, Sherjil Ozair, Aaron Courville, and Yoshua Bengio. Generative adversarial nets. *Advances in neural information processing systems*, 27, 2014.

Google Research. Open images dataset v7, 2022. URL `https://storage.googleapis.com/openimages/web/index.html`. Large-scale dataset for computer vision with localized narratives.

Aaron Grattafiori, Abhimanyu Dubey, Abhinav Jauhri, Abhinav Pandey, Abhishek Kadian, Ahmad Al-Dahle, Aiesha Letman, Akhil Mathur, Alan Schelten, Alex Vaughan, et al. The llama 3 herd of models. *arXiv preprint arXiv:2407.21783*, 2024.

Fabrizio Guillaro, Davide Cozzolino, Avneesh Sud, Nicholas Dufour, and Luisa Verdoliva. Trufor: Leveraging all-round clues for trustworthy image forgery detection and localization. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 20606–20615, 2023.

Hao Guo, Zihan Ma, Zhi Zeng, Minnan Luo, Weixin Zeng, Jiuyang Tang, and Xiang Zhao. Each fake news is fake in its own way: An attribution multi-granularity benchmark for multimodal fake news detection. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 39, pp. 228–236, 2025a.

Kun Guo, Haochen Zhu, and Gang Cao. Effective image tampering localization via enhanced transformer and co-attention fusion. In *ICASSP 2024-2024 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pp. 4895–4899. IEEE, 2024.

Kun Guo, Gang Cao, Zijie Lou, Xianglin Huang, and Jiaoyun Liu. A lightweight and effective image tampering localization network with vision mamba. *IEEE Signal Processing Letters*, 2025b.

Xiao Guo, Xiaohong Liu, Zhiyuan Ren, Steven Grosz, Iacopo Masi, and Xiaoming Liu. Hierarchical fine-grained image forgery detection and localization. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 3155–3165, 2023.

Xiao Guo, Xiaohong Liu, Iacopo Masi, and Xiaoming Liu. Language-guided hierarchical fine-grained image forgery detection and localization. *International Journal of Computer Vision*, 133(5):2670–2691, 2025c.

Xiao Guo, Xiufeng Song, Yue Zhang, Xiaohong Liu, and Xiaoming Liu. Rethinking vision-language model in face forensics: Multi-modal interpretable forged face detector. *arXiv preprint arXiv:2503.20188*, 2025d.

Xiefan Guo, Hongyu Yang, and Di Huang. Image inpainting via conditional texture and structure dual generation. In *Proceedings of the IEEE/CVF international conference on computer vision*, pp. 14134–14143, 2021.

Kaiming He, Xiangyu Zhang, Shaoqing Ren, and Jian Sun. Deep residual learning for image recognition. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pp. 770–778, 2016.

Kaiming He, Xinlei Chen, Saining Xie, Yanghao Li, Piotr Dollár, and Ross Girshick. Masked autoencoders are scalable vision learners. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 16000–16009, 2022.

Irina Higgins, Loic Matthey, Arka Pal, Christopher Burgess, Xavier Glorot, Matthew Botvinick, Shakir Mohamed, and Alexander Lerchner. beta-vae: Learning basic visual concepts with a constrained variational framework. In *International conference on learning representations*, 2017.

Jonathan Ho, Ajay Jain, and Pieter Abbeel. Denoising diffusion probabilistic models. *Advances in neural information processing systems*, 33:6840–6851, 2020a.

Jonathan Ho, Ajay Jain, and Pieter Abbeel. Denoising diffusion probabilistic models. *Advances in neural information processing systems*, 33:6840–6851, 2020b.

Cheng-Yao Hong, Yen-Chi Hsu, and Tyng-Luh Liu. Contrastive learning for deepfake classification and localization via multi-label ranking. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 17627–17637, 2024.

Yan Hong and Jianfu Zhang. Wildfake: A large-scale challenging dataset for ai-generated images detection. *arXiv preprint arXiv:2402.11843*, 2024.

Juan Hu, Xin Liao, Difei Gao, Satoshi Tsutsui, Qian Wang, Zheng Qin, and Mike Zheng Shou. Delocate: Detection and localization for deepfake videos with randomly-located tampered traces. *arXiv preprint arXiv:2401.13516*, 2024.

Zhengchao Huang, Bin Xia, Zicheng Lin, Zhun Mou, Wenming Yang, and Jiaya Jia. Ffaa: Multi-modal large language model based explainable open-world face forgery analysis assistant. *arXiv preprint arXiv:2408.10072*, 2024a.

Zhenglin Huang, Jinwei Hu, Xiangtai Li, Yiwei He, Xingyu Zhao, Bei Peng, Baoyuan Wu, Xiaowei Huang, and Guangliang Cheng. Sida: Social media image deepfake detection, localization and explanation with large multimodal model. *arXiv preprint arXiv:2412.04292*, 2024b.

Yikun Ji, Yan Hong, Jiahui Zhan, Haoxing Chen, Jun Lan, Huijia Zhu, Weiqiang Wang, Liqing Zhang, and Jianfu Zhang. Towards explainable fake image detection with multi-modal large language models. In *Proceedings of the 33rd ACM International Conference on Multimedia*, pp. 4398–4407, 2025.

Shan Jia, Mingzhen Huang, Zhou Zhou, Yan Ju, Jialing Cai, and Siwei Lyu. Autosplice: A text-prompt manipulated image dataset for media forensics. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 893–903, 2023.

Liming Jiang, Ren Li, Wayne Wu, Chen Qian, and Chen Change Loy. Deeperforensics-1.0: A large-scale dataset for real-world face forgery detection. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 2889–2898, 2020.

Ning Jiang, Dingheng Zeng, Yanhong Liu, Haiyang Yi, Shijie Yu, Minghe Weng, Haifeng Shen, and Ying Li. Explainable deepfake detection with rl enhanced self-blended images. *arXiv preprint arXiv:2601.15624*, 2026.

Hengrui Kang, Siwei Wen, Zichen Wen, Junyan Ye, Weijia Li, Peilin Feng, Baichuan Zhou, Bin Wang, Dahua Lin, Linfeng Zhang, et al. Legion: Learning to ground and explain for synthetic image detection. *arXiv preprint arXiv:2503.15264*, 2025.

Tero Karras, Timo Aila, Samuli Laine, and Jaakko Lehtinen. Progressive growing of gans for improved quality, stability, and variation. *arXiv preprint arXiv:1710.10196*, 2017.

Tero Karras, Samuli Laine, and Timo Aila. A style-based generator architecture for generative adversarial networks. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 4401–4410, 2019.

Hasam Khalid, Shahroz Tariq, Minha Kim, and Simon S Woo. Fakeavceleb: A novel audio-video multimodal deepfake dataset. *arXiv preprint arXiv:2108.05080*, 2021.

Aminollah Khormali and Jiann-Shiun Yuan. Self-supervised graph transformer for deepfake detection. *IEEE Access*, 2024.

Diederik P Kingma, Max Welling, et al. Auto-encoding variational bayes, 2013.

Thomas N Kipf and Max Welling. Semi-supervised classification with graph convolutional networks. *arXiv preprint arXiv:1609.02907*, 2016.

Alexander Kirillov, Eric Mintun, Nikhila Ravi, Hanzi Mao, Chloe Rolland, Laura Gustafson, Tete Xiao, Spencer Whitehead, Alexander C Berg, Wan-Yen Lo, et al. Segment anything. In *Proceedings of the IEEE/CVF international conference on computer vision*, pp. 4015–4026, 2023a.

Alexander Kirillov, Eric Mintun, Nikhila Ravi, Hanzi Mao, Chloe Rolland, Laura Gustafson, Tete Xiao, Spencer Whitehead, Alexander C Berg, Wan-Yen Lo, et al. Segment anything. In *Proceedings of the IEEE/CVF international conference on computer vision*, pp. 4015–4026, 2023b.

Vladimir V Kniaz, Vladimir Knyaz, and Fabio Remondino. The point where reality meets fantasy: Mixed adversarial generators for image splice detection. *Advances in neural information processing systems*, 32, 2019a.

Vladimir V Kniaz, Vladimir Knyaz, and Fabio Remondino. The point where reality meets fantasy: Mixed adversarial generators for image splice detection. *Advances in neural information processing systems*, 32, 2019b.

Christos Koutlis and Symeon Papadopoulos. Dimodif: Discourse modality-information differentiation for audio-visual deepfake detection and localization. *arXiv preprint arXiv:2411.10193*, 2024.

Marek Kowalski. Faceswap. Available: https://github.com/MarekKowalski/FaceSwap/, 2016.

Rohit Kundu, Athula Balachandran, and Amit K Roy-Chowdhury. Truthlens: Explainable deepfake detection for face manipulated and fully synthetic data. *arXiv preprint arXiv:2503.15867*, 2025a.

Rohit Kundu, Shan Jia, Vishal Mohanty, Athula Balachandran, and Amit K Roy-Chowdhury. Truthlens: Explainable deepfake detection for face manipulated and fully synthetic data. *arXiv preprint arXiv:2503.15867*, 2025b.

Alina Kuznetsova, Hassan Rom, Neil Alldrin, Jasper Uijlings, Ivan Krasin, Jordi Pont-Tuset, Shahab Kamali, Stefan Popov, Matteo Malloci, Alexander Kolesnikov, et al. The open images dataset v4: Unified image classification, object detection, and visual relationship detection at scale. *International journal of computer vision*, 128(7):1956–1981, 2020.

Myung-Joon Kwon, Wonjun Lee, Seung-Hun Nam, Minji Son, and Changick Kim. Safire: Segment any forged image region. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 39, pp. 4437–4445, 2025.

Xin Lai, Zhuotao Tian, Yukang Chen, Yanwei Li, Yuhui Yuan, Shu Liu, and Jiaya Jia. Lisa: Reasoning segmentation via large language model. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 9579–9589, 2024.

Dong Li, Jiaying Zhu, Menglu Wang, Jiawei Liu, Xueyang Fu, and Zheng-Jun Zha. Edge-aware regional message passing controller for image forgery localization. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 8222–8232, 2023a.

Junnan Li, Dongxu Li, Silvio Savarese, and Steven Hoi. Blip-2: Bootstrapping language-image pre-training with frozen image encoders and large language models. In *International conference on machine learning*, pp. 19730–19742. PMLR, 2023b.

Yuezun Li, Xin Yang, Pu Sun, Honggang Qi, and Siwei Lyu. Celeb-df: A large-scale challenging dataset for deepfake forensics. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 2020.

Yuxi Li, Fuyuan Cheng, Wangbo Yu, Guangshuo Wang, Guibo Luo, and Yuesheng Zhu. Adaifl: Adaptive image forgery localization via a dynamic and importance-aware transformer network. In *European Conference on Computer Vision*, pp. 477–493. Springer, 2024.

Jingchun Lian, Lingyu Liu, Yaxiong Wang, Yujiao Wu, Li Zhu, and Zhedong Zheng. A large-scale interpretable multi-modality benchmark for facial image forgery localization. *arXiv preprint arXiv:2412.19685*, 2024.

Youwei Liang, Junfeng He, Gang Li, Peizhao Li, Arseniy Klimovskiy, Nicholas Carolan, Jiao Sun, Jordi Pont-Tuset, Sarah Young, Feng Yang, et al. Rich human feedback for text-to-image generation. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 19401–19411, 2024.

Li Lin, Neeraj Gupta, Yue Zhang, Hainan Ren, Chun-Hao Liu, Feng Ding, Xin Wang, Xin Li, Luisa Verdoliva, and Shu Hu. Detecting multimedia generated by large ai models: A survey. *arXiv preprint arXiv:2402.00045*, 2024.

Tsung-Yi Lin, Michael Maire, Serge Belongie, James Hays, Pietro Perona, Deva Ramanan, Piotr Dollár, and C Lawrence Zitnick. Microsoft coco: Common objects in context. In *European conference on computer vision*, pp. 740–755. Springer, 2014.

Tsung-Yi Lin, Piotr Dollár, Ross Girshick, Kaiming He, Bharath Hariharan, and Serge Belongie. Feature pyramid networks for object detection. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pp. 2117–2125, 2017.

Fuxiao Liu, Yinghan Wang, Tianlu Wang, and Vicente Ordonez. Visual news: Benchmark and challenges in news image captioning. *arXiv preprint arXiv:2010.03743*, 2020.

Haotian Liu, Chunyuan Li, Qingyang Wu, and Yong Jae Lee. Visual instruction tuning. *Advances in neural information processing systems*, 36:34892–34916, 2023.

Haotian Liu, Chunyuan Li, Yuheng Li, and Yong Jae Lee. Improved baselines with visual instruction tuning. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 26296–26306, 2024a.

Huan Liu, Zichang Tan, Chuangchuang Tan, Yunchao Wei, Jingdong Wang, and Yao Zhao. Forgery-aware adaptive transformer for generalizable synthetic image detection. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 10770–10780, 2024b.

Jiawei Liu, Fanrui Zhang, Jiaying Zhu, Esther Sun, Qiang Zhang, and Zheng-Jun Zha. Forgerygpt: Multimodal large language model for explainable image forgery detection and localization. *arXiv preprint arXiv:2410.10238*, 2024c.

Rosanne Liu, Joel Lehman, Piero Molino, Felipe Petroski Such, Eric Frank, Alex Sergeev, and Jason Yosinski. An intriguing failing of convolutional neural networks and the coordconv solution. *Advances in neural information processing systems*, 31, 2018.

Yang Liu, Xiaofei Li, Jun Zhang, Shengze Hu, and Jun Lei. Da-hfnet: Progressive fine-grained forgery image detection and localization based on dual attention. In *2024 3rd International Conference on Image Processing and Media Computing (ICIPMC)*, pp. 51–58. IEEE, 2024d.

Yaqi Liu, Shuhuan Chen, Haichao Shi, Xiao-Yu Zhang, Song Xiao, and Qiang Cai. Mun: Image forgery localization based on m^3 encoder and un decoder. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 39, pp. 5685–5693, 2025.

Yue Liu, Yunjie Tian, Yuzhong Zhao, Hongtian Yu, Lingxi Xie, Yaowei Wang, Qixiang Ye, Jianbin Jiao, and Yunfan Liu. Vmamba: Visual state space model. *Advances in neural information processing systems*, 37: 103031–103063, 2024e.

Ze Liu, Yutong Lin, Yue Cao, Han Hu, Yixuan Wei, Zheng Zhang, Stephen Lin, and Baining Guo. Swin transformer: Hierarchical vision transformer using shifted windows. In *Proceedings of the IEEE/CVF international conference on computer vision*, pp. 10012–10022, 2021.

Andreas Lugmayr, Martin Danelljan, Andres Romero, Fisher Yu, Radu Timofte, and Luc Van Gool. Repaint: Inpainting using denoising diffusion probabilistic models. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 11461–11471, 2022.

Pingchuan Ma, Stavros Petridis, and Maja Pantic. Visual speech recognition for multiple languages in the wild. *Nature Machine Intelligence*, 4(11):930–939, 2022.

Ruipeng Ma, Jinhao Duan, Fei Kong, Xiaoshuang Shi, and Kaidi Xu. Exposing the fake: Effective diffusion-generated images detection. *arXiv preprint arXiv:2307.06272*, 2023a.

Xiaochen Ma, Bo Du, Zhuohang Jiang, Ahmed Y Al Hammadi, and Jizhe Zhou. Iml-vit: Benchmarking image manipulation localization by vision transformer. *arXiv preprint arXiv:2307.14863*, 2023b.

Xiaochen Ma, Xuekang Zhu, Lei Su, Bo Du, Zhuohang Jiang, Bingkui Tong, Zeyu Lei, Xinyu Yang, Chi-Man Pun, Jiancheng Lv, et al. Imdl-benco: A comprehensive benchmark and codebase for image manipulation detection & localization. *Advances in Neural Information Processing Systems*, 37:134591–134613, 2024.

Gaël Mahfoudi, Badr Tajini, Florent Retraint, Frederic Morain-Nicolier, Jean Luc Dugelay, and Marc Pic. Defacto: Image and face manipulation dataset. In *2019 27Th european signal processing conference (EUSIPCO)*, pp. 1–5. IEEE, 2019.

Momina Masood, Mariam Nawaz, Khalid Mahmood Malik, Ali Javed, Aun Irtaza, and Hafiz Malik. Deepfakes generation and detection: State-of-the-art, open challenges, countermeasures, and way forward. *Applied intelligence*, 53(4):3974–4026, 2023.

Changtao Miao, Qi Chu, Zhentao Tan, Zhenchao Jin, Tao Gong, Wanyi Zhuang, Yue Wu, Bin Liu, Honggang Hu, and Nenghai Yu. Multi-spectral class center network for face manipulation detection and localization. *arXiv preprint arXiv:2305.10794*, 2023.

Changtao Miao, Qi Chu, Tao Gong, Zhentao Tan, Zhenchao Jin, Wanyi Zhuang, Man Luo, Honggang Hu, and Nenghai Yu. Mixture-of-noises enhanced forgery-aware predictor for multi-face manipulation detection and localization. *arXiv preprint arXiv:2408.02306*, 2024.

Midjourney, Inc. Midjourney. `https://www.midjourney.com/`, 2022. Accessed: 2025-08-29.

NewsNation. Newsnation, 2023. URL `https://www.newsnationnow.com/`. American cable news television channel.

T-T Ng and S-F Chang. A model for image splicing. In *2004 International Conference on Image Processing, 2004. ICIP'04.*, volume 2, pp. 1169–1172. IEEE, 2004.

Quang Nguyen, Truong Vu, Trong-Tung Nguyen, Yuxin Wen, Preston K Robinette, Taylor T Johnson, Tom Goldstein, Anh Tran, and Khoi Nguyen. Editscout: Locating forged regions from diffusion-based edited images with multimodal llm. *arXiv preprint arXiv:2412.03809*, 2024.

Alex Nichol, Prafulla Dhariwal, Aditya Ramesh, Pranav Shyam, Pamela Mishkin, Bob McGrew, Ilya Sutskever, and Mark Chen. Glide: Towards photorealistic image generation and editing with text-guided diffusion models. *arXiv preprint arXiv:2112.10741*, 2021.

Yuval Nirkin, Yosi Keller, and Tal Hassner. FSGANv2: Improved subject agnostic face swapping and reenactment. IEEE, 2022.

Utkarsh Ojha, Yuheng Li, and Yong Jae Lee. Towards universal fake image detectors that generalize across generative models. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 24480–24489, 2023.

Maxime Oquab, Timothée Darcet, Théo Moutakanni, Huy Vo, Marc Szafraniec, Vasil Khalidov, Pierre Fernandez, Daniel Haziza, Francisco Massa, Alaaeldin El-Nouby, et al. Dinov2: Learning robust visual features without supervision. *arXiv preprint arXiv:2304.07193*, 2023.

Gan Pei, Jiangning Zhang, Menghan Hu, Zhenyu Zhang, Chengjie Wang, Yunsheng Wu, Guangtao Zhai, Jian Yang, Chunhua Shen, and Dacheng Tao. Deepfake generation and detection: A benchmark and survey. *arXiv preprint arXiv:2403.17881*, 2024.

Ivan Perov, Daiheng Gao, Nikolay Chervoniy, Kunlin Liu, Sugasa Marangonda, Chris Umé, Carl Shift Facenheim, Luis RP, Jian Jiang, Sheng Zhang, et al. Deepfacelab: Integrated, flexible and extensible face-swapping framework. *arXiv preprint arXiv:2005.05535*, 2020.

Dustin Podell, Zion English, Kyle Lacey, Andreas Blattmann, Tim Dockhorn, Jonas Müller, Joe Penna, and Robin Rombach. Sdxl: Improving latent diffusion models for high-resolution image synthesis. *arXiv preprint arXiv:2307.01952*, 2023.

KR Prajwal, Rudrabha Mukhopadhyay, Vinay P Namboodiri, and CV Jawahar. A lip sync expert is all you need for speech to lip generation in the wild. In *Proceedings of the 28th ACM international conference on multimedia*, pp. 484–492, 2020.

Chenfan Qu, Yiwu Zhong, Chongyu Liu, Guitao Xu, Dezhi Peng, Fengjun Guo, and Lianwen Jin. Towards modern image manipulation localization: A large-scale dataset and novel methods. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 10781–10790, 2024.

Colin Raffel, Noam Shazeer, Adam Roberts, Katherine Lee, Sharan Narang, Michael Matena, Yanqi Zhou, Wei Li, and Peter J Liu. Exploring the limits of transfer learning with a unified text-to-text transformer. *Journal of machine learning research*, 21(140):1–67, 2020.

Aditya Ramesh, Mikhail Pavlov, Gabriel Goh, Scott Gray, Chelsea Voss, Alec Radford, Mark Chen, and Ilya Sutskever. Zero-shot text-to-image generation. In *International conference on machine learning*, pp. 8821–8831. Pmlr, 2021.

Aditya Ramesh, Prafulla Dhariwal, Alex Nichol, Casey Chu, and Mark Chen. Hierarchical text-conditional image generation with clip latents. *arXiv preprint arXiv:2204.06125*, 1(2):3, 2022.

Hanoona Rasheed, Muhammad Maaz, Sahal Shaji, Abdelrahman Shaker, Salman Khan, Hisham Cholakkal, Rao M Anwer, Eric Xing, Ming-Hsuan Yang, and Fahad S Khan. Glamm: Pixel grounding large multimodal model. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 13009–13018, 2024.

Anton Razzhigaev, Arseniy Shakhmatov, Anastasia Maltseva, Vladimir Arkhipkin, Igor Pavlov, Ilya Ryabov, Angelina Kuts, Alexander Panchenko, Andrey Kuznetsov, and Denis Dimitrov. Kandinsky: an improved text-to-image synthesis with image prior and latent diffusion. *arXiv preprint arXiv:2310.03502*, 2023.

Reuters. Reuters news archive, 2023. URL `https://www.reuters.com/`. News articles and financial data.

Jonas Ricker, Denis Lukovnikov, and Asja Fischer. Aeroblade: Training-free detection of latent diffusion images using autoencoder reconstruction error. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 9130–9140, 2024.

Robin Rombach, Andreas Blattmann, Dominik Lorenz, Patrick Esser, and Björn Ommer. High-resolution image synthesis with latent diffusion models. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 10684–10695, 2022a.

Robin Rombach, Andreas Blattmann, Dominik Lorenz, Patrick Esser, and Björn Ommer. High-resolution image synthesis with latent diffusion models. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 10684–10695, 2022b.

Andreas Rössler, Davide Cozzolino, Luisa Verdoliva, Christian Riess, Justus Thies, and Matthias Nießner. FaceForensics++: Learning to detect manipulated facial images. In *International Conference on Computer Vision (ICCV)*, 2019.

Andreas Rossler, Davide Cozzolino, Luisa Verdoliva, Christian Riess, Justus Thies, and Matthias Nießner. Faceforensics++: Learning to detect manipulated facial images. In *Proceedings of the IEEE/CVF international conference on computer vision*, pp. 1–11, 2019.

Hugo Ruiz, Marc Chaumont, Mehdi Yedroudj, Ahmed Oulad Amara, Frédéric Comby, and Gérard Subsol. Analysis of the scalability of a deep-learning network for steganography "into the wild". In *Pattern Recognition. ICPR International Workshops and Challenges: Virtual Event, January 10–15, 2021, Proceedings, Part VI*, pp. 439–452. Springer, 2021.

Nataniel Ruiz, Yuanzhen Li, Varun Jampani, Yael Pritch, Michael Rubinstein, and Kfir Aberman. Dreambooth: Fine tuning text-to-image diffusion models for subject-driven generation. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 22500–22510, 2023.

Chitwan Saharia, William Chan, Saurabh Saxena, Lala Li, Jay Whang, Emily L Denton, Kamyar Ghasemipour, Raphael Gontijo Lopes, Burcu Karagol Ayan, Tim Salimans, et al. Photorealistic text-to-image diffusion models with deep language understanding. *Advances in neural information processing systems*, 35:36479–36494, 2022.

Christoph Schuhmann, Romain Beaumont, Richard Vencu, Cade Gordon, Ross Wightman, Mehdi Cherti, Theo Coombes, Aarush Katta, Clayton Mullis, Mitchell Wortsman, et al. Laion-5b: An open large-scale dataset for training next generation image-text models. *Advances in neural information processing systems*, 35:25278–25294, 2022.

Zeyang Sha, Zheng Li, Ning Yu, and Yang Zhang. De-fake: Detection and attribution of fake images generated by text-to-image generation models. In *Proceedings of the 2023 ACM SIGSAC conference on computer and communications security*, pp. 3418–3432, 2023.

Rui Shao, Tianxing Wu, and Ziwei Liu. Detecting and grounding multi-modal media manipulation. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 6904–6913, 2023.

Rui Shao, Tianxing Wu, Jianlong Wu, Liqiang Nie, and Ziwei Liu. Detecting and grounding multi-modal media manipulation and beyond. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, 46 (8):5556–5574, 2024.

Yichen Shi, Yuhao Gao, Yingxin Lai, Hongyang Wang, Jun Feng, Lei He, Jun Wan, Changsheng Chen, Zitong Yu, and Xiaochun Cao. Shield: An evaluation benchmark for face spoofing and forgery detection with multimodal large language models. *arXiv preprint arXiv:2402.04178*, 2024.

Jiaming Song, Chenlin Meng, and Stefano Ermon. Denoising diffusion implicit models. *arXiv preprint arXiv:2010.02502*, 2020a.

Qi Song, Ziyuan Luo, and Renjie Wan. Creating blank canvas against ai-enabled image forgery. *arXiv preprint arXiv:2511.22237*, 2025.

Xiufeng Song, Xiao Guo, Jiache Zhang, Qirui Li, Lei Bai, Xiaoming Liu, Guangtao Zhai, and Xiaohong Liu. On learning multi-modal forgery representation for diffusion generated video detection. *arXiv preprint arXiv:2410.23623*, 2024.

Yang Song, Jascha Sohl-Dickstein, Diederik P Kingma, Abhishek Kumar, Stefano Ermon, and Ben Poole. Score-based generative modeling through stochastic differential equations. *arXiv preprint arXiv:2011.13456*, 2020b.

Joel Stehouwer, Hao Dang, Feng Liu, Xiaoming Liu, and Anil Jain. On the detection of digital face manipulation. *arXiv*, pp. arXiv–1910, 2019.

Andreas Steiner, André Susano Pinto, Michael Tschannen, Daniel Keysers, Xiao Wang, Yonatan Bitton, Alexey Gritsenko, Matthias Minderer, Anthony Sherbondy, Shangbang Long, et al. Paligemma 2: A family of versatile vlms for transfer. *arXiv preprint arXiv:2412.03555*, 2024.

Yixuan Su, Tian Lan, Huayang Li, Jialu Xu, Yan Wang, and Deng Cai. Pandagpt: One model to instruction-follow them all. *arXiv preprint arXiv:2305.16355*, 2023.

Ke Sun, Bin Xiao, Dong Liu, and Jingdong Wang. Deep high-resolution representation learning for human pose estimation. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 5693–5703, 2019.

Zhihao Sun, Haoran Jiang, Haoran Chen, Yixin Cao, Xipeng Qiu, Zuxuan Wu, and Yu-Gang Jiang. Forgerysleuth: Empowering multimodal large language models for image manipulation detection. *arXiv preprint arXiv:2411.19466*, 2024.

Roman Suvorov, Elizaveta Logacheva, Anton Mashikhin, Anastasia Remizova, Arsenii Ashukha, Aleksei Silvestrov, Naejin Kong, Harshith Goka, Kiwoong Park, and Victor Lempitsky. Resolution-robust large mask inpainting with fourier convolutions. In *Proceedings of the IEEE/CVF winter conference on applications of computer vision*, pp. 2149–2159, 2022.

Mingxing Tan and Quoc Le. Efficientnet: Rethinking model scaling for convolutional neural networks. In *International conference on machine learning*, pp. 6105–6114. PMLR, 2019.

Gemini Team, Rohan Anil, Sebastian Borgeaud, Jean-Baptiste Alayrac, Jiahui Yu, Radu Soricut, Johan Schalkwyk, Andrew M Dai, Anja Hauth, Katie Millican, et al. Gemini: a family of highly capable multimodal models. *arXiv preprint arXiv:2312.11805*, 2023.

Gemma Team, Morgane Riviere, Shreya Pathak, Pier Giuseppe Sessa, Cassidy Hardin, Surya Bhupatiraju, Léonard Hussenot, Thomas Mesnard, Bobak Shahriari, Alexandre Ramé, et al. Gemma 2: Improving open language models at a practical size. *arXiv preprint arXiv:2408.00118*, 2024.

Lang-SAM Team. Lang-segment-anything. https://github.com/luca-medeiros/lang-segment-anything, 2024. Accessed: 2024-11-15.

Justus Thies, Michael Zollhofer, Marc Stamminger, Christian Theobalt, and Matthias Nießner. Face2face: Real-time face capture and reenactment of rgb videos. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pp. 2387–2395, 2016.

Justus Thies, Michael Zollhöfer, and Matthias Nießner. Deferred neural rendering: Image synthesis using neural textures. *Acm Transactions on Graphics (TOG)*, 38(4):1–12, 2019.

Aaron Van Den Oord, Oriol Vinyals, et al. Neural discrete representation learning. *Advances in neural information processing systems*, 30, 2017.

Ashish Vaswani, Noam Shazeer, Niki Parmar, Jakob Uszkoreit, Llion Jones, Aidan N Gomez, Łukasz Kaiser, and Illia Polosukhin. Attention is all you need. *Advances in neural information processing systems*, 30, 2017a.

Ashish Vaswani, Noam Shazeer, Niki Parmar, Jakob Uszkoreit, Llion Jones, Aidan N Gomez, Łukasz Kaiser, and Illia Polosukhin. Attention is all you need. *Advances in neural information processing systems*, 30, 2017b.

Luisa Verdoliva. Media forensics and deepfakes: an overview. *IEEE journal of selected topics in signal processing*, 14(5):910–932, 2020.

Sheng-Yu Wang, Oliver Wang, Richard Zhang, Andrew Owens, and Alexei A Efros. Cnn-generated images are surprisingly easy to spot... for now. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 8695–8704, 2020.

Wenhai Wang, Enze Xie, Xiang Li, Deng-Ping Fan, Kaitao Song, Ding Liang, Tong Lu, Ping Luo, and Ling Shao. Pvt v2: Improved baselines with pyramid vision transformer. *Computational visual media*, 8(3): 415–424, 2022a.

Yinhuai Wang, Jiwen Yu, and Jian Zhang. Zero-shot image restoration using denoising diffusion null-space model. *arXiv preprint arXiv:2212.00490*, 2022b.

Zhendong Wang, Jianmin Bao, Wengang Zhou, Weilun Wang, Hezhen Hu, Hong Chen, and Houqiang Li. Dire for diffusion-generated image detection. In *Proceedings of the IEEE/CVF International Conference on Computer Vision*, pp. 22445–22455, 2023.

Zhenting Wang, Vikash Sehwag, Chen Chen, Lingjuan Lyu, Dimitris N Metaxas, and Shiqing Ma. How to trace latent generative model generated images without artificial watermark? *arXiv preprint arXiv:2405.13360*, 2024.

Sanghyun Woo, Shoubhik Debnath, Ronghang Hu, Xinlei Chen, Zhuang Liu, In So Kweon, and Saining Xie. Convnext v2: Co-designing and scaling convnets with masked autoencoders. In *Proceedings of the IEEE/CVF conference on computer vision and pattern recognition*, pp. 16133–16142, 2023.

Yixin Wu, Feiran Zhang, Tianyuan Shi, Ruicheng Yin, Zhenghua Wang, Zhenliang Gan, Xiaohua Wang, Changze Lv, Xiaoqing Zheng, and Xuanjing Huang. Explainable synthetic image detection through diffusion timestep ensembling. *arXiv preprint arXiv:2503.06201*, 2025.

Enze Xie, Wenhai Wang, Zhiding Yu, Anima Anandkumar, Jose M Alvarez, and Ping Luo. Segformer: Simple and efficient design for semantic segmentation with transformers. *Advances in neural information processing systems*, 34:12077–12090, 2021.

Qijie Xu, Defang Chen, Jiawei Chen, Siwei Lyu, and Can Wang. Recent advances on generalizable diffusion-generated image detection. *arXiv preprint arXiv:2502.19716*, 2025.

Zhipei Xu, Xuanyu Zhang, Runyi Li, Zecheng Tang, Qing Huang, and Jian Zhang. Fakeshield: Explainable image forgery detection and localization via multi-modal large language models. *arXiv preprint arXiv:2410.02761*, 2024.

Shilin Yan, Ouxiang Li, Jiayin Cai, Yanbin Hao, Xiaolong Jiang, Yao Hu, and Weidi Xie. A sanity check for ai-generated image detection. *arXiv preprint arXiv:2406.19435*, 2024a.

Zhiyuan Yan, Yong Zhang, Xinhang Yuan, Siwei Lyu, and Baoyuan Wu. Deepfakebench: A comprehensive benchmark of deepfake detection. *arXiv preprint arXiv:2307.01426*, 2023.

Zhiyuan Yan, Taiping Yao, Shen Chen, Yandan Zhao, Xinghe Fu, Junwei Zhu, Donghao Luo, Chengjie Wang, Shouhong Ding, Yunsheng Wu, et al. Df40: Toward next-generation deepfake detection. *Advances in Neural Information Processing Systems*, 37:29387–29434, 2024b.

Peter Young, Alice Lai, Micah Hodosh, and Julia Hockenmaier. From image descriptions to visual denotations: New similarity metrics for semantic inference over event descriptions. *Transactions of the association for computational linguistics*, 2:67–78, 2014.

Jiahui Yu, Zhe Lin, Jimei Yang, Xiaohui Shen, Xin Lu, and Thomas S Huang. Free-form image inpainting with gated convolution. In *Proceedings of the IEEE/CVF international conference on computer vision*, pp. 4471–4480, 2019.

Peipeng Yu, Jianwei Fei, Hui Gao, Xuan Feng, Zhihua Xia, and Chip Hong Chang. Unlocking the capabilities of large vision-language models for generalizable and explainable deepfake detection. *arXiv preprint arXiv:2503.14853*, 2025a.

Peipeng Yu, Jianwei Fei, Hui Gao, Xuan Feng, Zhihua Xia, and Chip Hong Chang. Unlocking the capabilities of vision-language models for generalizable and explainable deepfake detection. *arXiv preprint arXiv:2503.14853*, 2025b.

Xiaomin Yu, Yezhaohui Wang, Yanfang Chen, Zhen Tao, Dinghao Xi, Shichao Song, Simin Niu, and Zhiyu Li. Fake artificial intelligence generated contents (faigc): A survey of theories, detection methods, and opportunities. *arXiv preprint arXiv:2405.00711*, 2024a.

Zeqin Yu, Jiangqun Ni, Yuzhen Lin, Haoyi Deng, and Bin Li. Diffforensics: Leveraging diffusion prior to image forgery detection and localization. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pp. 12765–12774, 2024b.

Yu Zeng, Zhe Lin, Huchuan Lu, and Vishal M Patel. Cr-fill: Generative image inpainting with auxiliary contextual reconstruction. In *Proceedings of the IEEE/CVF international conference on computer vision*, pp. 14164–14173, 2021.

Haoyuan Zhang, Xiangyu Zhu, Li Gao, Jiawei Pan, Kai Pang, Guoying Zhao, Stan Z Li, and Zhen Lei. Concept discovery in deep neural networks for explainable face anti-spoofing. *arXiv preprint arXiv:2412.17541*, 2024a.

Kai Zhang, Wangmeng Zuo, Yunjin Chen, Deyu Meng, and Lei Zhang. Beyond a gaussian denoiser: Residual learning of deep cnn for image denoising. *IEEE transactions on image processing*, 26(7):3142–3155, 2017.

Kai Zhang, Lingbo Mo, Wenhu Chen, Huan Sun, and Yu Su. Magicbrush: A manually annotated dataset for instruction-guided image editing. *Advances in Neural Information Processing Systems*, 36:31428–31449, 2023.

Li Zhang, Mingliang Xu, Dong Li, Jianming Du, and Rujing Wang. Catmullrom splines-based regression for image forgery localization. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 38, pp. 7196–7204, 2024b.

Xuanyu Zhang, Zecheng Tang, Zhipei Xu, Runyi Li, Youmin Xu, Bin Chen, Feng Gao, and Jian Zhang. Omniguard: Hybrid manipulation localization via augmented versatile deep image watermarking. *arXiv preprint arXiv:2412.01615*, 2024c.

Yue Zhang, Ben Colman, Xiao Guo, Ali Shahriyari, and Gaurav Bharaj. Common sense reasoning for deepfake detection. In *European Conference on Computer Vision*, pp. 399–415. Springer, 2024d.

Hengrun Zhao, Yunzhi Zhuge, Yifan Wang, Lijun Wang, Huchuan Lu, and Yu Zeng. Learning universal features for generalizable image forgery localization. *arXiv preprint arXiv:2504.07462*, 2025.

Lianmin Zheng, Wei-Lin Chiang, Ying Sheng, Siyuan Zhuang, Zhanghao Wu, Yonghao Zhuang, Zi Lin, Zhuohan Li, Dacheng Li, Eric Xing, et al. Judging llm-as-a-judge with mt-bench and chatbot arena. *Advances in Neural Information Processing Systems*, 36:46595–46623, 2023.

Bolei Zhou, Hang Zhao, Xavier Puig, Sanja Fidler, Adela Barriuso, and Antonio Torralba. Scene parsing through ade20k dataset. In *Proceedings of the IEEE conference on computer vision and pattern recognition*, pp. 633–641, 2017.

Ziyin Zhou, Yunpeng Luo, Yuanchen Wu, Ke Sun, Jiayi Ji, Ke Yan, Shouhong Ding, Xiaoshuai Sun, Yunsheng Wu, and Rongrong Ji. Aigi-holmes: Towards explainable and generalizable ai-generated image detection via multimodal large language models. *arXiv preprint arXiv:2507.02664*, 2025.

Hao Zhu, Wayne Wu, Wentao Zhu, Liming Jiang, Siwei Tang, Li Zhang, Ziwei Liu, and Chen Change Loy. Celebv-hq: A large-scale video facial attributes dataset. In *European conference on computer vision*, pp. 650–667. Springer, 2022.

Jiaying Zhu, Dong Li, Xueyang Fu, Gang Yang, Jie Huang, Aiping Liu, and Zheng-Jun Zha. Learning discriminative noise guidance for image forgery detection and localization. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 38, pp. 7739–7747, 2024.

Jun-Yan Zhu, Taesung Park, Phillip Isola, and Alexei A Efros. Unpaired image-to-image translation using cycle-consistent adversarial networks. In *Proceedings of the IEEE international conference on computer vision*, pp. 2223–2232, 2017.

Mingjian Zhu, Hanting Chen, Qiangyu Yan, Xudong Huang, Guanyu Lin, Wei Li, Zhijun Tu, Hailin Hu, Jie Hu, and Yunhe Wang. Genimage: A million-scale benchmark for detecting ai-generated image. *Advances in Neural Information Processing Systems*, 36:77771–77782, 2023.

Xuekang Zhu, Xiaochen Ma, Lei Su, Zhuohang Jiang, Bo Du, Xiwen Wang, Zeyu Lei, Wentao Feng, Chi-Man Pun, and Ji-Zhe Zhou. Mesoscopic insights: orchestrating multi-scale & hybrid architecture for image manipulation localization. In *Proceedings of the AAAI Conference on Artificial Intelligence*, volume 39, pp. 11022–11030, 2025.

Bojia Zi, Minghao Chang, Jingjing Chen, Xingjun Ma, and Yu-Gang Jiang. Wilddeepfake: A challenging real-world dataset for deepfake detection. In *Proceedings of the 28th ACM International Conference on Multimedia*, pp. 2382–2390, 2020.

Yueying Zou, Peipei Li, Zekun Li, Huaibo Huang, Xing Cui, Xuannan Liu, Chenghanyu Zhang, and Ran He. Survey on ai-generated media detection: From non-mllm to mllm. *arXiv preprint arXiv:2502.05240*, 2025.

Dragoș-Constantin Țânțaru, Elisabeta Oneață, and Dan Oneață. Weakly-supervised deepfake localization in diffusion-generated images. In *Proceedings of the IEEE/CVF Winter Conference on Applications of Computer Vision*, pp. 6258–6268, 2024.