



## Image Format Conversion Methods for Digital Media

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### ABSTRACT:

Image format conversion is a fundamental process in digital media that involves transforming images from one format to another to optimize storage, compatibility, or performance. With increasing variety of image formats such as JPEG, PNG, WebP, and AVIF, the efficiency, quality considerations, and performance aspects of these formats have become more essential to understanding. This paper presents a comparative study of various image format conversion methods, analyzing their impact on image quality, compression efficiency, and processing time. We evaluate both lossless and lossy formats across different tools and algorithms, highlighting the trade-offs involved in terms of computational resources and output fidelity. The study also explores the relevance of modern format conversion techniques in web applications, machine learning chains, and digital archiving. Our results present real-world information on how to choose the best format conversion techniques according to application needs.

**Keywords:** Image Format Conversion, Compression Efficiency, Digital Media, Image Quality, Lossless and Lossy Formats

### Introduction:

The concept of **image format conversion** has evolved over time, rather than being invented by a single person. However, the origins of **digital image formats** and their conversion can be traced back to the **1960s and 1970s**. **Bell Labs and NASA** were among the first to work on digital image processing for space exploration, although early image formats were **raw bitmap representations** used in scientific and military applications. One of the first widely used image compression techniques was **Run-Length Encoding (RLE)**. However, the term "image format conversion" gained significance around the 1980s with the rise of personal computers, which enabled users to store, edit, and convert images across different formats.

The evolution of image formats has been driven by the growing demand for efficient, high-quality digital images. Early formats like BMP and TIFF prioritized simplicity and uncompressed data storage but resulted in large file sizes. The introduction of JPEG in the 1990s, standardized by the Joint Photographic Experts Group, revolutionized digital imaging with its lossy compression technique, significantly reducing file sizes for web use. PNG emerged as a lossless alternative, offering better transparency support. More recently, formats like WebP and AVIF, supported by organizations like Google and the World Wide Web Consortium (W3C), have introduced advanced compression algorithms, reducing file sizes while maintaining visual fidelity, particularly for web applications.

Since its introduction, the concept of image format conversion has several significant impacts across various domains:

#### **1. Web Development and Digital Marketing:**

Image format conversion plays a crucial role in optimizing websites by reducing image sizes while preserving visual quality. Websites require fast-loading images that maintain quality while being lightweight. Image conversion helps reduce file sizes while maintaining acceptable quality, ensuring smooth website interactions across devices.

#### **2. Social Media and Content Sharing Platforms:**

Social media sites such as Facebook, Instagram, and Twitter employ automatic image format conversion to normalize and optimize user-uploaded images. When a user uploads a high-resolution PNG, the site might convert it to JPEG for storage optimization or WebP for quicker delivery. Additionally, adaptive format conversion techniques are used to deliver lower-resolution images for mobile devices while retaining high-quality versions for desktop or print applications.

#### **3. Healthcare and Medical Imaging:**

Image format conversion in Healthcare and Medical Imaging is essential for transferring images from proprietary scanner formats to DICOM for diagnosis, archiving, and telemedicine applications. Medical images from MRI, CT scans, and X-rays need to be converted for accurate analysis and

secure storage in hospital databases. Here, lossless formats are prioritized to preserve critical medical information and ensure no data loss during the conversion process.

#### **4. Machine Learning and Computer Vision:**

Image format conversion has contributed in Machine learning as Machine learning models require datasets to be in a consistent format for effective training and inference. Image format conversion is used to convert raw images into formats like PNG, JPEG, or WebP depending on the model's requirements.

#### **5. Digital Art and Graphic Design:**

In the field of digital art, format conversion is used to switch between editing and delivery formats. Designers work with high-quality formats like PSD (Photoshop Document) or TIFF during the creative process and convert the final assets into JPEG, PNG, or WebP for publishing. This conversion helps manage file sizes while preserving visual integrity for different platforms, including print, web, and social media.

#### **6. E-commerce and Retail Platforms:**

E-commerce websites use image format conversion to manage thousands of product images in an efficient manner. Product images are usually uploaded in original high-resolution PNG or JPEG formats and then converted into WebP or AVIF to make the site optimized for performance. This process improves website responsiveness, particularly for mobile shoppers, while maintaining clarity in product images for zooming and detailed views. Platforms like Shopify and Amazon automate this conversion to maintain consistency across their vast product inventories.

#### **7. Gaming and AR/VR:**

In gaming and AR/VR applications, image format conversion is critical for performance optimization. Game engines convert textures into formats like DDS (DirectDraw Surface) or KTX (Khronos Texture) to enhance rendering efficiency. This conversion ensures that textures are loaded and rendered more quickly, reducing latency in interactive environments.

#### **8. Surveillance and Security Systems:**

Surveillance systems capture vast amounts of image and video data, often converting footage into formats like MJPEG or H.264 to optimize storage. High-resolution frames are converted to more space-efficient formats without compromising clarity, which is essential for forensic analysis. Additionally Cloud-based surveillance systems also use real-time format conversion to send images between various devices and network conditions

#### **7. Satellite Imaging and Remote Sensing:**

Satellite imaging systems convert images into standardized formats like GeoTIFF or JPEG 2000 to facilitate analysis across different platforms. The conversion process ensures compatibility with GIS (Geographic Information Systems) tools for tasks like environmental monitoring, urban planning, and disaster management. High-resolution raw images are converted into more manageable formats for transmission and storage without significant loss of geospatial information.

#### **8. Digital Archiving and Preservation:**

Digital archives use format conversion to standardize documents and images for long-term storage. Historical photographs and documents are often scanned into high-resolution TIFF files to preserve their original details. Subsequently, these files may be converted to JPEG or PDF/A formats for easier distribution and access.

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### **Methodology:**

This study employs various frameworks, algorithms, and tools to analyze image format conversion techniques across multiple domains. The methodology is categorized into the following sections:

#### **1. Lossless and Lossy Conversion:**

Image format conversion involves two main types of compression techniques: Lossy and Lossless Conversion. These techniques determine how image data is preserved or discarded when converting between different formats. Choosing between them depends on factors such as quality, file size, transparency, and storage efficiency.

##### **i. Lossy Conversion**

Lossy conversion **permanently removes some image details** to reduce file size. This is common in formats like **JPEG** and **WebP**, which apply **lossy compression** by eliminating **less noticeable image data**. Once compressed, the lost details **cannot be restored**, which may introduce **visible artifacts** such as blurring or pixelation. Lossy compression is widely used for **web images, social media, and streaming** where smaller file sizes are prioritized over perfect quality.

#### **Advantages of Lossy Conversion**

Lossy conversion significantly **reduces file size**, making it ideal for **web images, social media uploads, and cloud storage** where space is a concern. **JPEG and WebP** formats compress images efficiently while keeping a visually acceptable quality, enabling **faster loading times** on websites and mobile apps. It is beneficial for **streaming and online sharing**, as smaller images load quickly without consuming excessive bandwidth. For example, converting a **TIFF (50MB) to JPEG (5MB)** allows for easy sharing without major quality concerns. Similarly, **GIF to JPEG** conversion optimizes color representation for digital photography.

#### Disadvantages of Lossy Conversion

The biggest downside of lossy conversion is **permanent loss of image details** due to compression, which can introduce **visible artifacts, blurring, or pixelation**. This becomes problematic in **graphics design, professional photography, and medical imaging**, where precision is required. Additionally, **repeated lossy conversions (JPEG → JPEG)** further degrade quality, making it unsuitable for images that need frequent edits. For example, saving a **high-quality PNG as JPEG** will remove transparency, and multiple edits in JPEG format will progressively worsen the image.

#### When to Use Lossy Conversion?

- When reducing file size is a priority (e.g., for web pages, mobile applications, or emails).
- When a slight loss in quality is acceptable, especially for online images where perfect accuracy isn't required.
- When faster loading times are necessary, such as for web optimization and cloud storage.

#### Examples of Lossy Conversion:

- **PNG → JPEG:** Converts a **lossless PNG** into a **smaller JPEG file**, removing transparency and some fine details.
- **TIFF → JPEG:** Converts **high-quality TIFF** images into **compressed JPEGs**, making large files more manageable with a slight reduction in quality.
- **GIF → JPEG:** Alters **GIF color data** to fit JPEG's format, often resulting in a loss of certain color details.

#### ii. Lossless Conversion

Lossless conversion **preserves all image details** without losing quality. It is used in formats like **PNG, BMP, and TIFF**, which apply **non-destructive compression** methods such as **Run-Length Encoding (RLE), Huffman Coding, and LZW compression**. Lossless compression allows the image to be **compressed and decompressed without losing any data**, making it ideal for **archiving, professional editing, and high-detail images**.

#### Advantages of Lossless Conversion

Lossless conversion **preserves all image details**, making it perfect for **logos, high-resolution artwork, technical diagrams, and print materials**. Formats like **PNG, TIFF, and BMP** ensure that images remain **visually identical to the original**, even after multiple edits or conversions. Lossless formats **support transparency**, which is essential for UI/UX design, digital branding, and professional workflows. For example, converting a **JPEG to PNG** helps retain visible details, while **TIFF to PNG** reduces file size while maintaining accuracy in printing and publishing.

#### Disadvantages of Lossless Conversion

The main drawback of lossless conversion is **larger file sizes**, which require more **storage space and bandwidth**. This makes them **less efficient for web use**, where speed and size matter. For example, a **high-resolution PNG (10MB) may be too large for online use**, while the same image in **JPEG (2MB) loads faster**. Additionally, **not all applications and platforms support lossless formats**, requiring **additional conversions for compatibility**. For instance, **PNG files are unsuitable for digital photography** where JPEG is the standard format.

#### When to Use Lossless Conversion?

- When high-quality images are needed, such as for printing, professional editing, and medical imaging.
- When transparency must be preserved, since formats like PNG and TIFF support transparent backgrounds.
- When future edits or recompression are required, ensuring that the image retains its original quality over multiple conversions.

#### Examples of Lossless Conversion:

- **JPEG → PNG:** Converts a **lossy JPEG** to **PNG**, keeping all visible details but **not restoring any lost data** from JPEG.
- **BMP → PNG:** Maintains the **same image quality**, but PNG allows **smaller file sizes with efficient compression**.
- **TIFF → PNG:** Preserves the **high quality of TIFF images** while reducing file size using lossless compression.

FEATURE	LOSSY CONVERSION	LOSSLESS CONVERSION
Definition	Removes some image details permanently to reduce file size.	Keeps all image details while changing the format.
File Size	Smaller	Larger
Quality Loss	Yes, reduces quality	No, maintains original quality
Transparency Support	No (JPEG removes transparency)	Yes (PNG, TIFF support transparency)
Best For	Web use, social media, faster loading	Print, editing, high-quality storage
Examples	PNG → JPEG, TIFF → JPEG	BMP → PNG, TIFF → PNG

## 2. Re-Encoding (Direct Compression) in Image Format Conversion

Re-encoding, also known as **direct compression**, is the process of converting image data from one format to another by using a different encoding algorithm. This is a fundamental technique in **image format conversion**, where images are transformed between different compression methods to optimize **storage, compatibility, and quality**. It is widely used in cases such as **PNG to JPEG conversion**, where a lossless format (PNG) is converted into a lossy format (JPEG) to reduce file size significantly while maintaining reasonable visual quality.

Re-encoding plays a crucial role in image format conversion, offering several benefits such as storage optimization, where lossy formats like JPEG and WebP significantly reduce file size compared to lossless formats like PNG and BMP, making them ideal for storage-constrained environments. It also ensures format compatibility, as different applications require specific formats, such as JPEG for web images and TIFF for printing. Additionally, re-encoding enables efficient transmission, as compressed images load faster on web pages and mobile applications, improving user experience and reducing bandwidth usage. However, it also has limitations, including loss of quality, where converting from lossless to lossy formats (e.g., PNG to JPEG) results in data loss, particularly in high-frequency details, and generation loss, where multiple re-encodings (e.g., JPEG to JPEG) cause progressive degradation due to repeated lossy compression. Despite these drawbacks, re-encoding remains a powerful tool in image processing and optimization, balancing quality, storage efficiency, and usability across various applications.

### Tools Used for Re-Encoding

Several libraries in Python allow direct image format conversion through re-encoding:

#### 1. OpenCV (cv2):

OpenCV is widely used for **image processing and format conversion**. The `cv2.imwrite()` function saves images with specified compression parameters.

#### 2. Pillow (PIL - Python Imaging Library)

Pillow provides powerful image conversion capabilities, allowing format changes and compression level adjustments.

Re-encoding involves decoding the original image, applying a new compression algorithm, and encoding it into a different format. This process can be broken down into several steps:

Example Process: PNG to JPEG Conversion

- a. Decode PNG: PNG is a lossless format that uses zlib-based DEFLATE compression. The image is first decompressed to retrieve raw pixel data.
- b. Apply JPEG Compression: JPEG uses the Discrete Cosine Transform (DCT) to convert spatial image data into frequency components, allowing efficient compression with lossy approximation.
- c. Re-encode into JPEG: The processed data is encoded into the JPEG format, applying quantization and Huffman coding to further reduce file size.

## 3. Bit Depth Reduction in Image Format Conversion

The technique of reducing the numbers of bits used to represent colors in an image is called bit depth reduction, sometimes referred to as color depth reduction or bits per pixel (bpp) reduction. This is commonly done to save storage space, optimize image processing, and enhance compatibility with

older or limited-display devices. While primarily a technical means of format conversion, it is also used as an aesthetic effect and is frequently found in digital artwork and graphics with a retro feel.

Customizing color depth in an image can significantly change how it looks by defining the number of bits of data used to represent colors. reaConverter's latest editions allows you to do batch modification of color depth for as many images as you want, in no more than 3 simple steps.

Also defined as bit depth or bits per pixel (bpp), color depth can be determined by the device used to view a certain image and expresses the accuracy with which colors are rendered on screen. This feature implies the number of color shades and tones that you can view on a particular type of screen. For example, until mid-1990s computers supported an 8-bit color system, which enabled them to display a total of 256 colors. Nowadays, most PCs support a "true color" or 24-bit color rendering, which means they can display almost 17 million color combinations between hundreds of shades of red, green and blue.

Bit depth defines how many **unique colors** can be represented in an image. For example:

- **1-bit (Monochrome)** → Only **black and white** (2 colors).
- **8-bit (Indexed Color)** → Up to **256 colors** (used in **GIFs**).
- **24-bit (True Color)** → Over **16.7 million colors** (standard for **PNG, JPEG**).

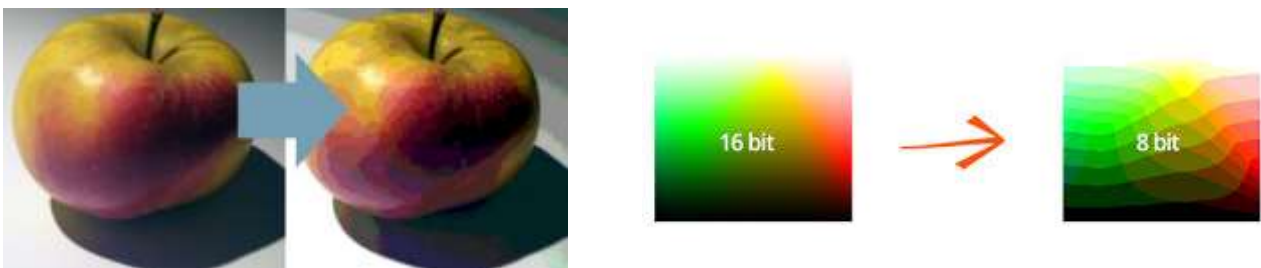
#### **Techniques Used in Bit Depth Reduction:**

##### ***i. Palette-Based Compression in Bit Depth Reduction***

Palette-based compression is an approach that approximates the appearance of the original image while significantly reducing storage space requirements by mapping an image's colors to a predefined fixed palette. Instead of storing full RGB values per pixel, the image retains only indexed references to a color palette with a limited number of colors. This is commonly used when converting high-bit-depth images (24-bit PNG, BMP) to indexed color formats like GIF or 8-bit PNG, which support a maximum of 256 colors. For example, GIF images do not store millions of colors; instead, they map each pixel to one of the 256 available colors in the palette, reducing file size while maintaining visual similarity. This technique can lead to a loss of color integrity even if it is quite effective at compression and storage, particularly for images with great color variation or smooth gradients.

##### ***ii. Dithering (Floyd-Steinberg Algorithm) in Bit Depth Reduction***

Dithering is a technique used to prevent visible banding effects when reducing an image's color depth, particularly in gradients and complex color transitions. Banding occurs when an image has limited colors, causing sudden changes in color shades instead of smooth transitions. Dithering adds missing colors by adding minor noise patterns to the image, which gives the transitions a more realistic appearance. One of the most widely used dithering algorithms is Floyd-Steinberg dithering, which distributes quantization errors across neighboring pixels, creating a smoother gradient effect. This technique is commonly applied when converting high-bit-depth images (24-bit or 32-bit RGB) to indexed color formats like 8-bit PNG or GIF, ensuring the visual quality remains acceptable despite the reduced color range. Although dithering enhances the look of limited-color images, it occasionally adds a rough texture that might not be suitable for all uses.



## **4. Color Space Conversion**

Color space conversion is the translation of the representation of a color from one basis to another. This typically occurs in the context of converting an image that is represented in one color space to another color space, the goal being to make the translated image look as similar as possible to the original.

Image mode conversion allows transformation between different color models, such as RGB to CMYK (used for printing) or Grayscale to RGB (restoring color channels). It is essential for accurate color reproduction in photography, printing, and digital imaging. One common technique is sRGB to Adobe RGB conversion, which expands the color gamut for richer tones, while YCbCr conversion (used in JPEG compression) separates luminance (Y) from chrominance (Cb, Cr) for efficient storage. While these conversions enable better compatibility and color accuracy, they can sometimes result in color loss due to differences in gamut and bit depth.

The **Pillow (PIL) library** in Python provides various image modes (color models) to store and manipulate images efficiently. Each mode represents pixel data differently, influencing how colors, transparency, and brightness are stored. Below is a **detailed explanation** of the five image modes you mentioned:

### 1. RGBA (Red, Green, Blue, Alpha):

RGBA is a 4-channel image mode including Red, Green, Blue, and Alpha (transparency), where each value ranges from 0 to 255. The Alpha channel controls opacity, with 0 being fully transparent and 255 fully opaque (e.g., (255, 0, 0, 128) is semi-transparent red). It is widely used in PNG images, logos, and game sprites, allowing background blending and overlays. Pillow provides easy manipulation using `Image.new("RGBA", (width, height), (R, G, B, A))`, making it essential for image compositing and web graphics.

### 2. RGB (Red, Green, Blue):

RGB is a 3-channel mode storing Red, Green, and Blue values without transparency. Each pixel is represented as (R, G, B), such as (255, 0, 0) for pure red. This is the standard color model for photographs, digital displays, and JPEG images. RGB images are used in photo editing, digital art, and video rendering, as screens naturally use this color system. It is memory-efficient but lacks opacity control, making it less suitable for transparent images.

### 3. L (Luminance / Grayscale):

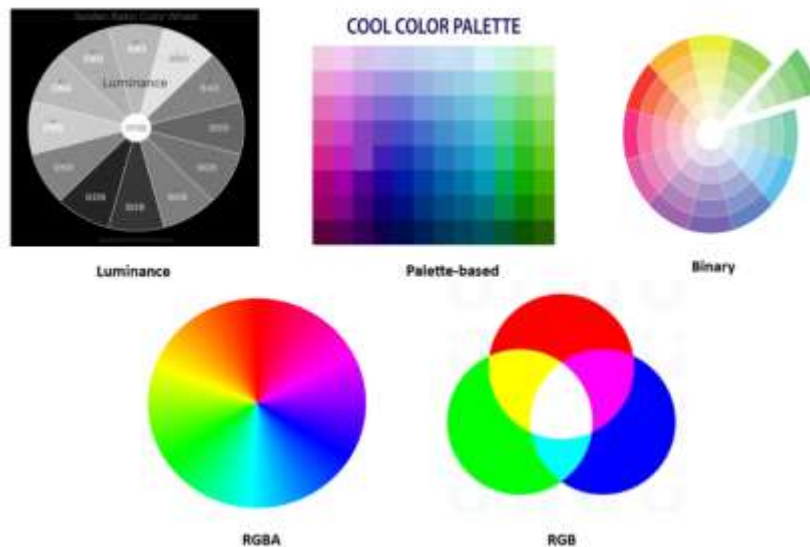
L mode is a single-channel grayscale format that stores only brightness values (0–255), where 0 is black, 255 is white, and intermediate values represent shades of gray. It is commonly used for black-and-white photography, document scanning, medical imaging (X-rays), and computer vision tasks. Since grayscale images are lighter in size and simpler to process, they are widely used in image analysis and threshold-based operations.

### 4. P (Palette-based / Indexed Color):

P mode is an **indexed-color format**, storing **only color indices (0–255) referencing a predefined palette** instead of full RGB values. It is mainly used in **GIFs, retro video games, and compressed images**, as it reduces file size while maintaining visual quality within the **256-color limit**. While memory-efficient, it is unsuitable for **high-quality images** due to color limitations.

### 5. 1 (Binary / Monochrome):

1 mode is a **1-bit per pixel** format where each pixel is either **black (0) or white (1)**. It is used in **fax machines, scanned documents, QR codes, barcodes, and high-contrast images**. Since it lacks grayscale or color, it is extremely **lightweight and efficient** but limited in detail. Conversions often use **thresholding**, turning grayscale images into **pure black-and-white** versions.



## Results

### The Evolution and Current Impact of Image Format Conversion

Image format conversion has become an essential process in digital media, playing a critical role in various industries such as web development, healthcare, machine learning, e-commerce, and digital archiving. Over the years, image formats have evolved from simple bitmap storage (BMP, TIFF) to highly efficient compressed formats like JPEG, PNG, WebP, and AVIF. The introduction of AI-driven optimization techniques and cloud-based image processing has further improved efficiency.

Today, the demand for optimized images is higher than ever due to the growing reliance on digital platforms, mobile applications, and artificial intelligence (AI). Social media platforms automatically convert images for faster delivery, e-commerce websites optimize images for improved load times, and machine learning models require consistent formats for better training accuracy. Healthcare imaging continues to depend on lossless formats like DICOM to ensure data integrity in medical diagnostics.

One of the major shifts in recent years has been the widespread adoption of **WebP and AVIF**, formats that significantly reduce file sizes while maintaining high visual quality. Google's push for WebP as a web-optimized format and AVIF's growing presence, thanks to its better compression and quality, have reshaped how images are stored and transferred online. Despite this, traditional formats like JPEG and PNG remain dominant due to their widespread compatibility.

### Technological Advances in Image Format Conversion

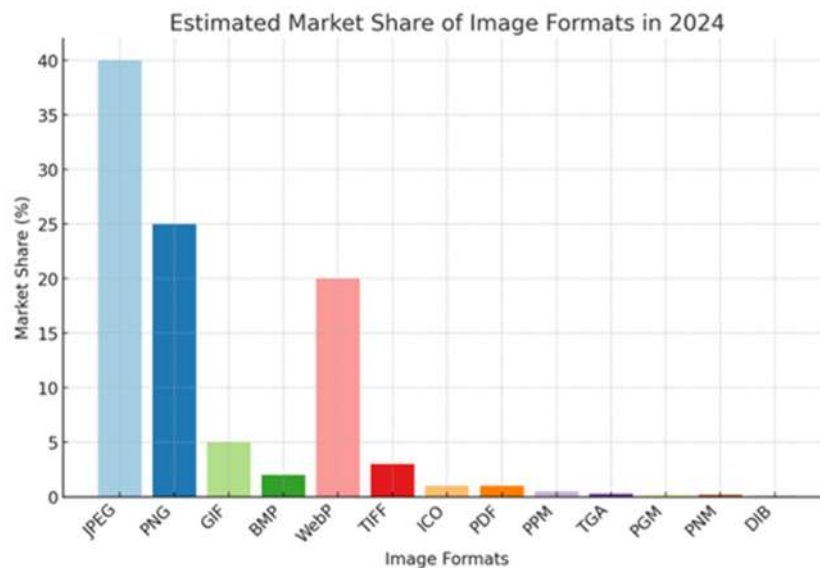
The latest advancements in image format conversion leverage artificial intelligence and deep learning techniques to enhance efficiency. AI-powered compression algorithms, such as those integrated into **Google's Guetzli** (JPEG encoder) and **Facebook's AI-powered image compression**, have improved image quality retention while reducing file sizes. Additionally, **neural network-based super-resolution** methods allow low-resolution images to be upscaled without significant quality loss.

Another emerging trend is **real-time image format adaptation**, where web servers dynamically convert images to the most suitable format based on the user's device and network conditions. Services like Cloudinary and ImageKit use AI-driven optimization to serve images in WebP, AVIF, or JPEG XR depending on browser support and bandwidth availability.

Additionally, **blockchain-based image verification** is an emerging concept that ensures authenticity and prevents image manipulation by embedding cryptographic metadata into image files. This technology could be crucial for journalism, legal documentation, and intellectual property protection.

### User Adoption of Image Formats (2024 Statistics)

The usage of different image formats varies across industries and applications. The following graph represents the estimated user adoption of popular image formats in 2024 based on web analytics and industry reports.



**Bar graph** representing the estimated market share of different image formats in 2024.

- **JPEG and PNG** remain dominant due to their broad compatibility and quality.
- **WebP** is rapidly growing, especially in web and mobile applications.
- **GIF** is declining but still used for animations.
- **TIFF and BMP** are mainly used in professional and archival applications.
- **Less common formats** like **ICO, PPM, TGA, PGM, PNM, and DIB** have very limited usage in specific scenarios.

### Conclusion:

Image format conversion seen remarkable advancements, evolving from basic bitmap storage to more effective and optimized formats suitable for many industries. The early reliance on **BMP and TIFF** gave way to **JPEG and PNG**, which became the standard due to their balance of quality and compression. The demand for faster and more efficient web performance led to the development of **WebP and AVIF**, which now dominate modern applications due to their superior compression and quality retention.

The shift toward **AI-driven optimization** and **real-time format conversion** has further enhanced image processing capabilities. Machine learning algorithms now assist in **lossless and lossy compression**, ensuring optimal trade-offs between file size and visual fidelity. **Cloud-based image processing**

**platforms** like Cloudinary and ImageKit dynamically convert images into the best-suited formats based on device compatibility and network conditions, optimizing performance without compromising quality.

Moreover, industries such as **healthcare, digital archiving, and satellite imaging** continue to rely on **lossless formats** to preserve critical data integrity. Meanwhile, **e-commerce and social media platforms** have automated image conversion pipelines to enhance user experience and storage efficiency.

Moving forward, **blockchain-based image verification** could ensure authenticity, while **neural network-driven super-resolution techniques** will allow high-quality upscaling with minimal data loss. The growing adoption of **high-efficiency formats like AVIF and JPEG XL** indicates a future where image formats will be more adaptive, intelligent, and integrated with AI-based enhancements.

As digital media continues to expand, the approach to image format conversion will emphasize **efficiency, real-time adaptability, and AI-powered automation**, ensuring the best quality while maintaining minimal storage and bandwidth consumption. The evolution of image formats remains a continuous process, adapting to the ever-growing needs of modern digital ecosystems.

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