

# L22: NFT Metadata and IPFS

## Module C: NFTs & Digital Assets

Blockchain & Cryptocurrency Course

December 2025

By the end of this lesson, you will be able to:

- Understand the JSON metadata format standard for NFTs
- Explain how IPFS content addressing works
- Describe the role of pinning services in NFT permanence
- Compare IPFS and Arweave for decentralized storage
- Evaluate metadata permanence and availability challenges

**Metadata Structure:** OpenSea standard (widely adopted)

**Core Fields:**

- `name` – Display name of the NFT
- `description` – Human-readable description
- `image` – URI to primary visual asset (IPFS, HTTP)
- `external_url` – Link to project website
- `attributes` – Array of trait objects

**Example Metadata JSON:**

```
{  
  "name": "Bored Ape #1234",  
  "image": "ipfs://QmXYZ.../1234.png",  
  "attributes": [{"trait_type": "Background", "value": "Blue"}]  
}
```

**Attributes Array:** Defines traits and properties

**Attribute Object Structure:**

- `trait_type` – Category name (e.g., “Hat”, “Eyes”)
- `value` – Specific value (e.g., “Beanie”, “Laser Eyes”)
- `display_type` (optional) – How to render (number, date, boost)

**Rarity Calculation:**

- Each trait has a frequency distribution in the collection
- Rarer traits (low frequency) increase NFT value
- Tools like Rarity Sniper calculate rarity scores

**Example Rarity Analysis:**

- Background: Blue (20% frequency) vs. Gold (2% frequency)
- Laser Eyes: 1% frequency (highly rare)

**IPFS:** Decentralized peer-to-peer file storage protocol

## Key Concepts:

- **Content Addressing:** Files identified by cryptographic hash
- **CID (Content Identifier):** Unique hash of file content
- **Immutability:** Same content always produces same CID
- **Distributed:** Files stored across multiple nodes

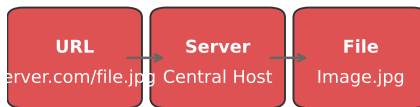
## Example IPFS URI:

- `ipfs://QmXyZ123abc...` (CID)
- Gateway URL: `https://ipfs.io/ipfs/QmXyZ123abc...`

# Content Addressing vs Location Addressing

## Content Addressing vs Location Addressing

### Location Addressing (HTTP)



**Server down = 404 Error**

Content can change at URL

Single point of failure

No integrity guarantee

### Content Addressing (IPFS)



**Any node can serve file**

Same content = Same CID

Distributed retrieval

Cryptographic verification

*IPFS: Same content always produces same CID, retrievable from any node*

**IPFS Garbage Collection:** Nodes delete unpinned files to save space

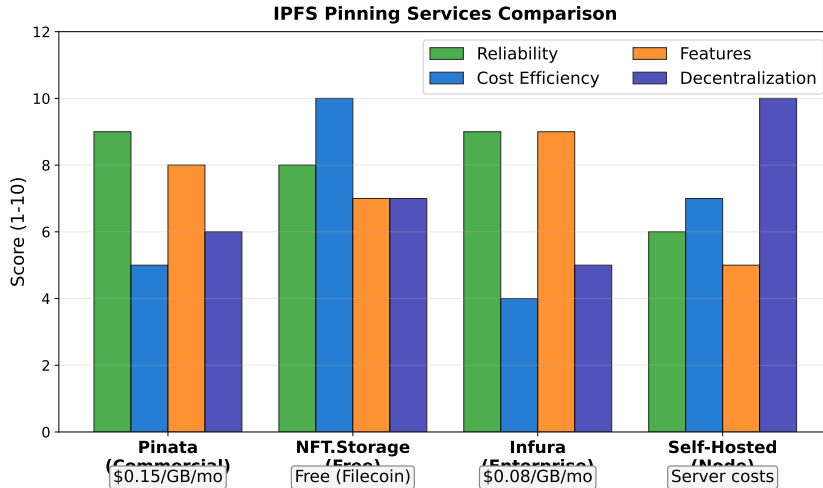
## Without Pinning:

- File may be removed from all nodes (lost)
- NFT metadata/images become unavailable
- Broken image links in wallets and marketplaces

## Pinning Services:

- **Pinata:** Popular commercial pinning service
- **NFT.Storage:** Free pinning for NFT data (funded by Filecoin)
- **Infura IPFS:** Enterprise-grade IPFS infrastructure
- **Self-hosting:** Run your own IPFS node and pin files

**Critical Issue:** If all pinning stops, files may disappear from IPFS



*NFT.Storage offers free pinning backed by Filecoin; Pinata is most popular commercial option*



**Gateway:** HTTP bridge to access IPFS content

## Public Gateways:

- `https://ipfs.io/ipfs/[CID]`
- `https://gateway.pinata.cloud/ipfs/[CID]`
- `https://cloudflare-ipfs.com/ipfs/[CID]`

## Why Gateways Matter:

- Browsers do not natively support `ipfs://` protocol
- Wallets and marketplaces use gateways to display NFTs
- Gateway downtime = NFTs appear broken

## Centralization Risk:

- Most users rely on centralized gateways (ipfs.io, Cloudflare)
- Solution: Native IPFS support in browsers (IPFS Companion extension)

**Arweave:** Blockchain designed for permanent data storage

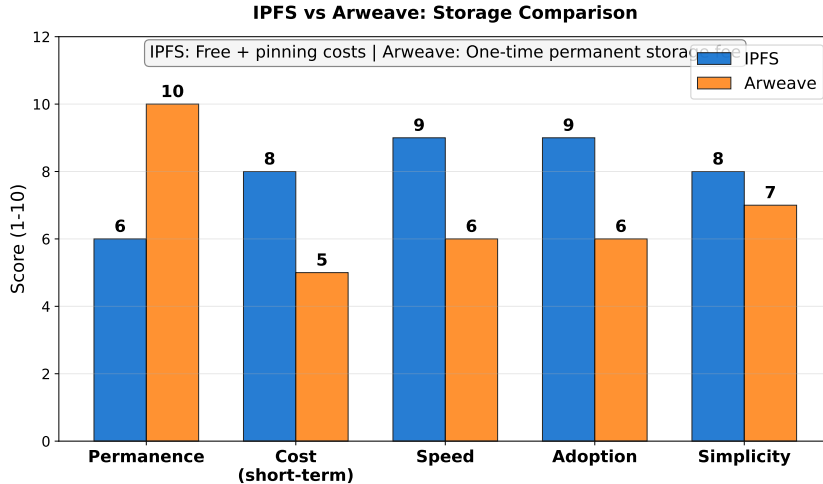
## Key Differences from IPFS:

- **Permanence:** One-time payment for perpetual storage
- **Blockchain-based:** Data stored on Arweave blockchain
- **Economic model:** Storage endowment fund pays miners forever
- **No pinning needed:** Data guaranteed to persist

## Arweave URI:

- `ar://[Transaction ID]`
- Gateway: `https://arweave.net/[Transaction ID]`

**Use Cases:** High-value NFTs requiring guaranteed permanence



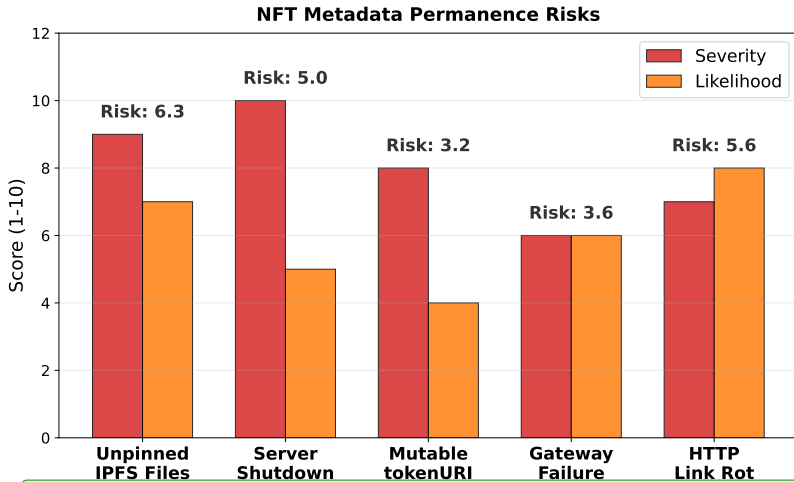
*IPFS for most projects; Arweave for premium NFTs requiring guaranteed permanence*

## Real-World Issues:

- ❶ **Unpinned IPFS files:** Project abandons pinning, files lost
- ❷ **Centralized metadata servers:** Company shuts down, NFTs break
- ❸ **Mutable tokenURI:** Smart contract allows owner to change metadata
- ❹ **Gateway failures:** IPFS gateways go offline, NFTs appear broken
- ❺ **Link rot:** HTTP URLs stop working (404 errors)

## Case Study: Nifty Gateway (2021):

- Platform used centralized servers for metadata
- Outage caused all NFTs to display broken images
- Community backlash led to IPFS migration



Mitigation: Pin to multiple services, use immutable tokenURI, prefer IPFS/Arweave over HTTP

*Server shutdown has highest severity; HTTP link rot is most likely to occur*

## Mutable Metadata:

- Smart contract owner can update `tokenURI`
- Allows bug fixes and metadata improvements
- Risk: Owner could change artwork or traits (rug pull)

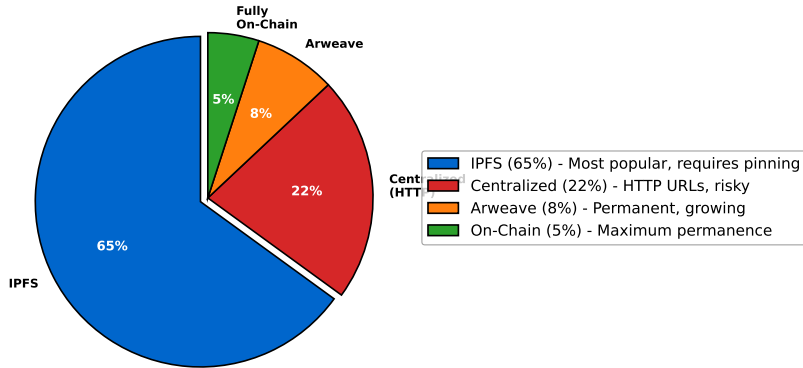
## Immutable Metadata:

- `tokenURI` frozen after minting (contract locked)
- Guarantees metadata cannot be altered
- Standard for high-value collections (e.g., CryptoPunks)

## Verification:

- Check smart contract code for `setTokenURI()` functions
- Verify contract ownership is renounced (no admin control)
- Use Etherscan to audit contract mutability

**NFT Metadata Storage Adoption (2024 Estimate)**



*IPFS dominates NFT storage; Arweave growing for premium projects*

## For NFT Projects:

- 1 **Use IPFS or Arweave:** Avoid centralized servers
- 2 **Pin all files:** Use reputable pinning services (Pinata, NFT.Storage)
- 3 **Freeze metadata:** Make tokenURI immutable after reveal
- 4 **Redundancy:** Pin to multiple services (IPFS + Arweave)
- 5 **Document storage:** Inform buyers where metadata is hosted

## For NFT Buyers:

- Verify metadata is on IPFS/Arweave (not HTTP)
- Check if tokenURI is immutable
- Confirm pinning service reputation



- 1 NFT metadata follows a JSON standard (name, description, image, attributes)
- 2 IPFS uses content addressing (CIDs) for decentralized, immutable storage
- 3 Pinning is critical for IPFS file permanence (unpinned files can be lost)
- 4 Arweave provides guaranteed permanent storage for a one-time fee
- 5 Metadata permanence challenges include unpinned files and mutable URIs
- 6 Best practice: Use IPFS/Arweave, pin to multiple services, freeze metadata

- ❶ What are the trade-offs between IPFS and Arweave for NFT metadata storage?
- ❷ Should NFT metadata be immutable, or is mutability acceptable for bug fixes?
- ❸ How can the NFT community ensure long-term metadata availability?
- ❹ Is fully on-chain metadata the ideal, or are off-chain solutions sufficient?
- ❺ What happens to NFT value if metadata becomes unavailable?

### L23: NFT Marketplaces

We will explore:

- OpenSea, Blur, and Rarible business models
- Listing mechanics and order book systems
- Marketplace fees and royalty enforcement
- Wash trading and market manipulation detection
- Aggregators and cross-marketplace trading

**Preparation:** Create a wallet and browse NFT collections on OpenSea