

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: Defining Rarity

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:

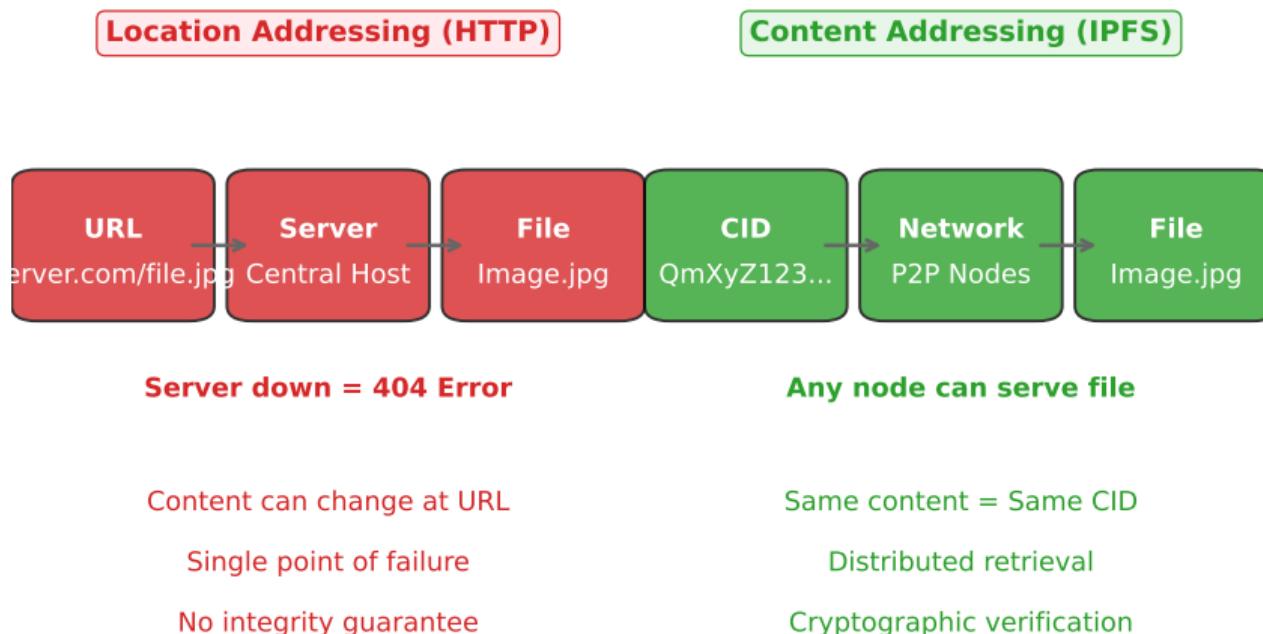
- **Content Addressing:** Files identified by cryptographic hash
- **CID (Content Identifier):** Unique hash of file content
- **Immutability:** Same content always produces same CID
- **Distributed:** Files stored across multiple nodes

Example IPFS URI:

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

Content Addressing vs Location Addressing

Content Addressing vs Location Addressing



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

Pinning: Ensuring Availability

IPFS Garbage Collection: Nodes delete unpinned files to save space

Without Pinning:

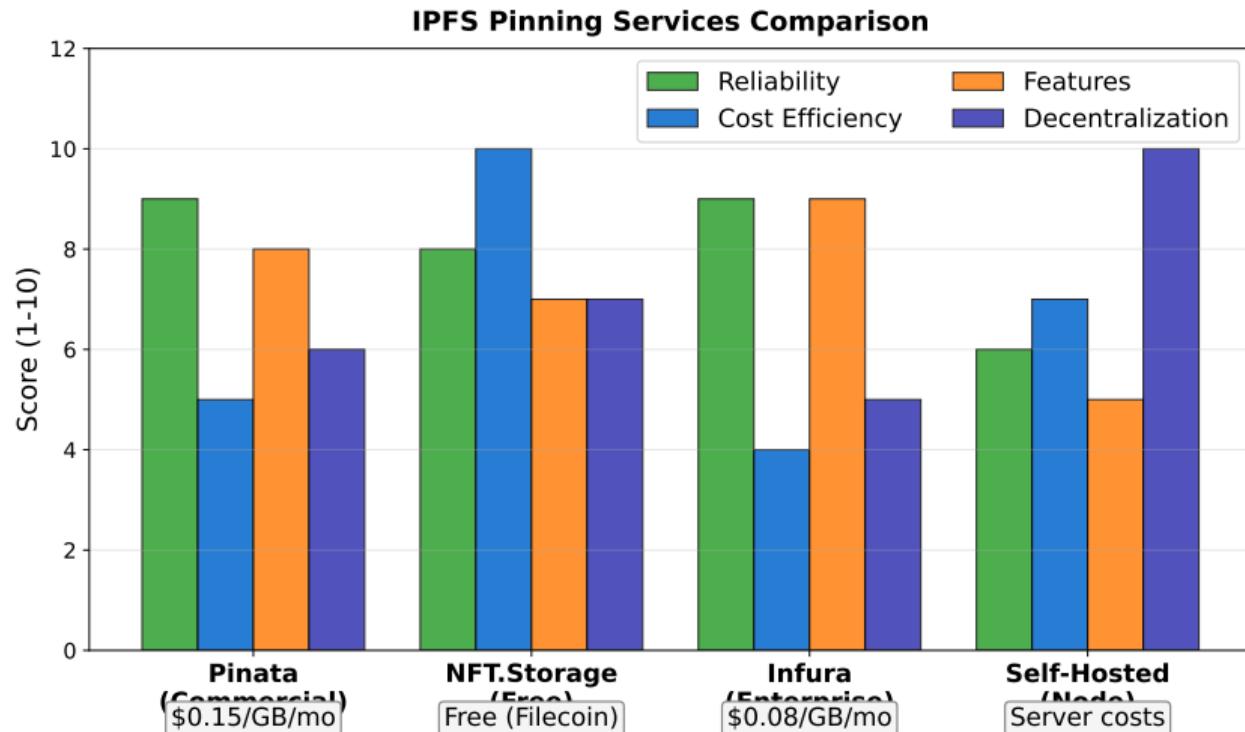
- File may be removed from all nodes (lost)
- NFT metadata/images become unavailable
- Broken image links in wallets and marketplaces

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

Pinning Services Comparison



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://ipfs.io/ipfs/[CID])
- [https://gateway.pinata.cloud/ipfs/\[CID\]](https://gateway.pinata.cloud/ipfs/[CID])
- [https://cloudflare-ipfs.com/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

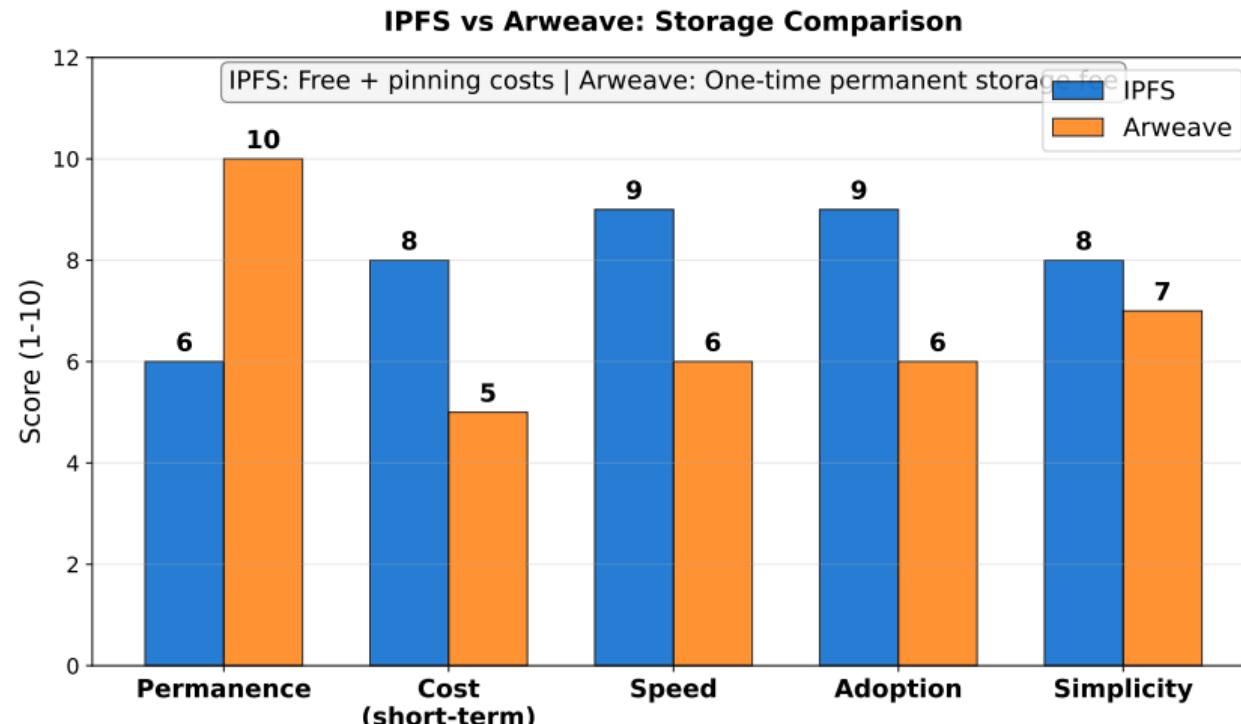
Key Differences from IPFS:

- **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/\[Transaction ID\]](https://arweave.net/[Transaction ID])

Use Cases: High-value NFTs requiring guaranteed permanence



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

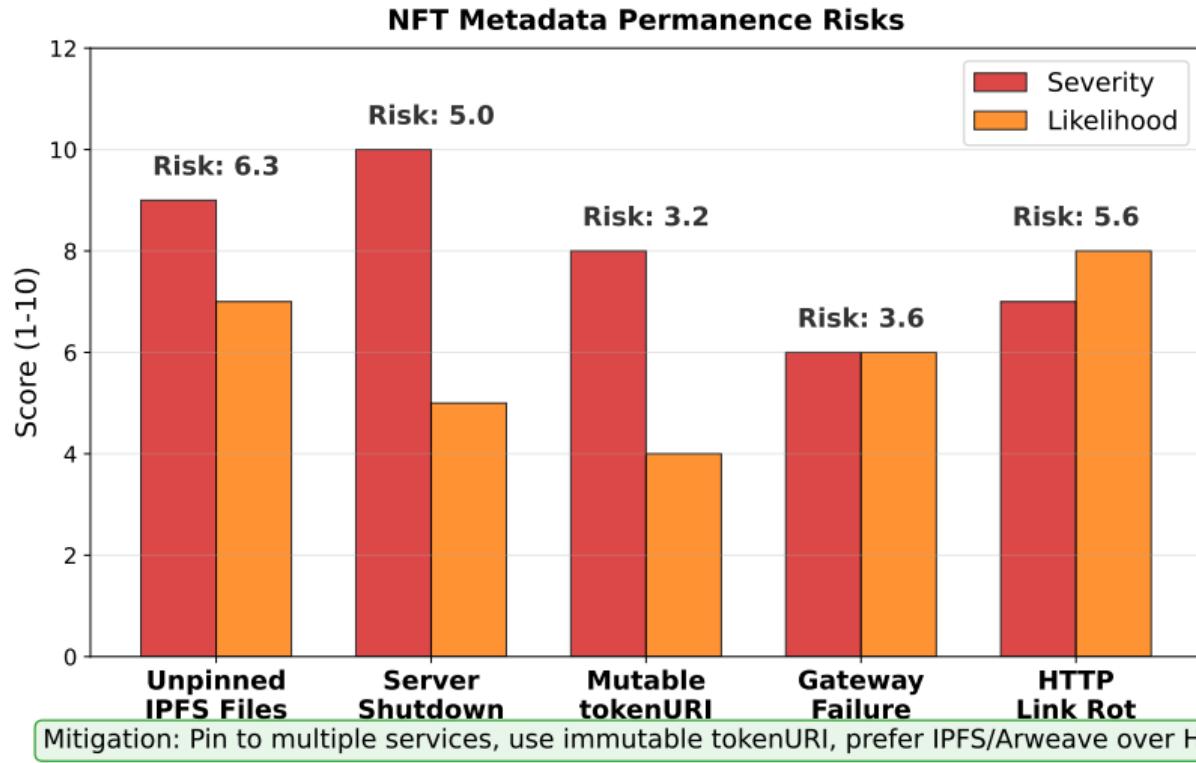


Real-World Issues:

- ① **Unpinned IPFS files:** Project abandons pinning, files lost
- ② **Centralized metadata servers:** Company shuts down, NFTs break
- ③ **Mutable tokenURI:** Smart contract allows owner to change metadata
- ④ **Gateway failures:** IPFS gateways go offline, NFTs appear broken
- ⑤ **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



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:

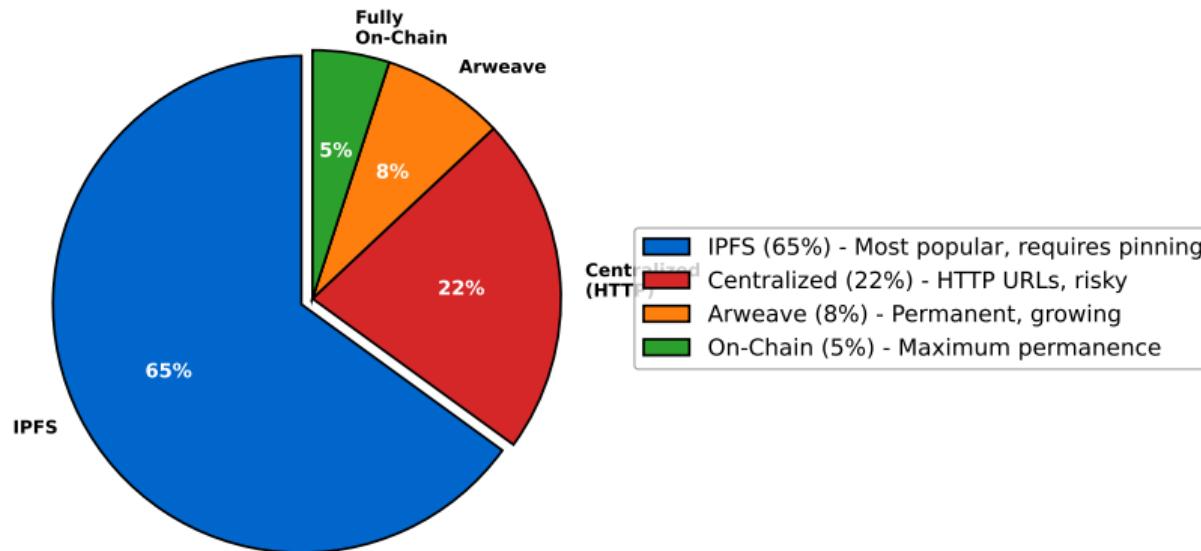
- tokenURI frozen after minting (contract locked)
- Guarantees metadata cannot be altered
- Standard for high-value collections (e.g., CryptoPunks)

Verification:

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

NFT Storage Adoption

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

Key Takeaways

- 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

Discussion Questions

- ① What are the trade-offs between IPFS and Arweave for NFT metadata storage?
- ② Should NFT metadata be immutable, or is mutability acceptable for bug fixes?
- ③ How can the NFT community ensure long-term metadata availability?
- ④ Is fully on-chain metadata the ideal, or are off-chain solutions sufficient?
- ⑤ 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