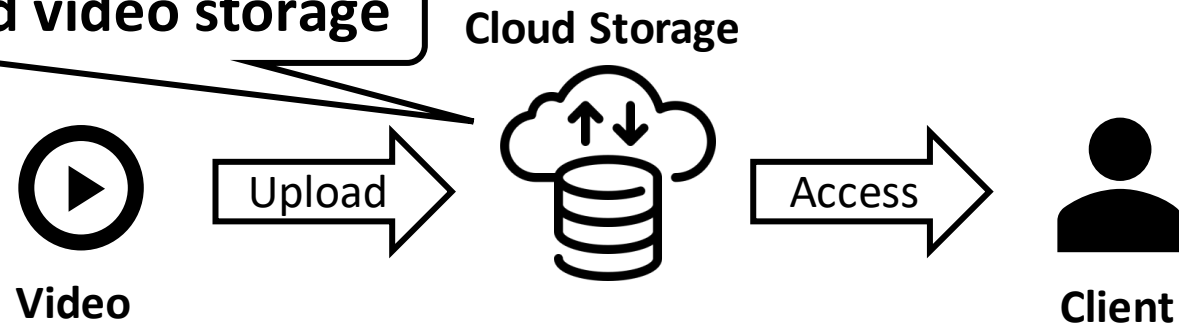# Neural Cloud Storage: Innovative Cloud Storage Solution for Cold Video

Jinyeong Lim, Juncheol Ye, Jaehong Kim, Hwijoon Lim, Hyunho Yeo, Dongsu Han

Cloud Video Storage System
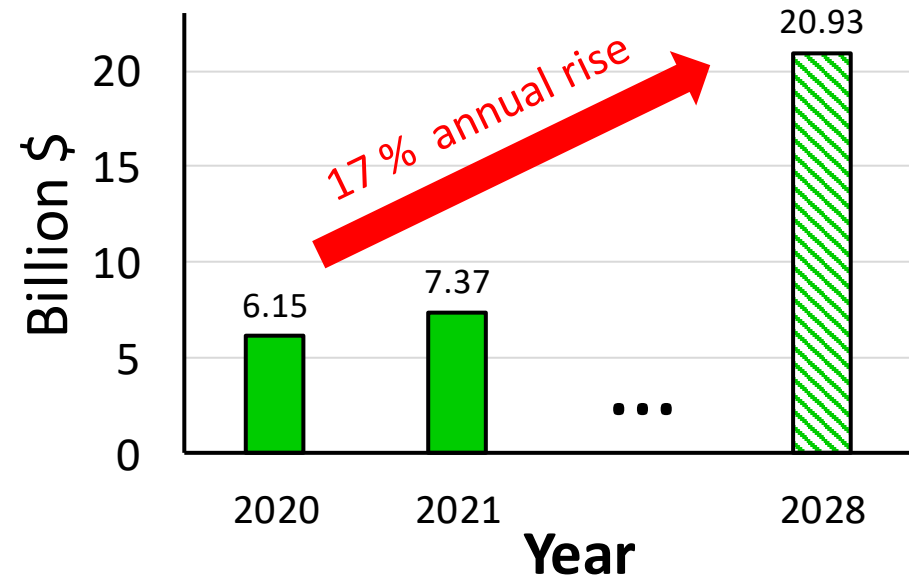

1. The growth of cloud video storage

Cloud Storage

Video → Upload → Access → Client

Video Platform → Store video → Cloud Provider

The Global Cloud Video Storage Market Size

17 % annual rise

Year	Billion $
2020	6.15
2021	7.37
2028	20.93

Cloud Video Storage System

1. **The growth of cloud video storage**

Cloud Storage

2. **Saturated cloud storage pricing**

Upload → Access →

Video → Cloud Storage → **Client**

Cloud Storage Price

$ / GB * time (month)

Saturated
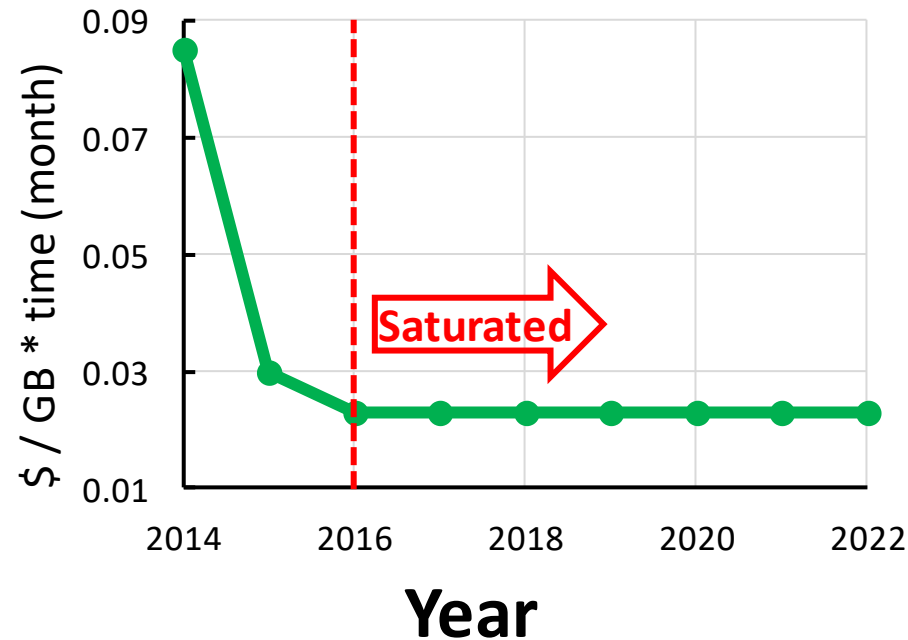
Amazon Web Service(AWS)
S3 Standard

Year

Problem: Expensive Total Cost of Ownership(TCO)

1. The growth of cloud video storage

Cloud Storage

2. Saturated cloud storage pricing

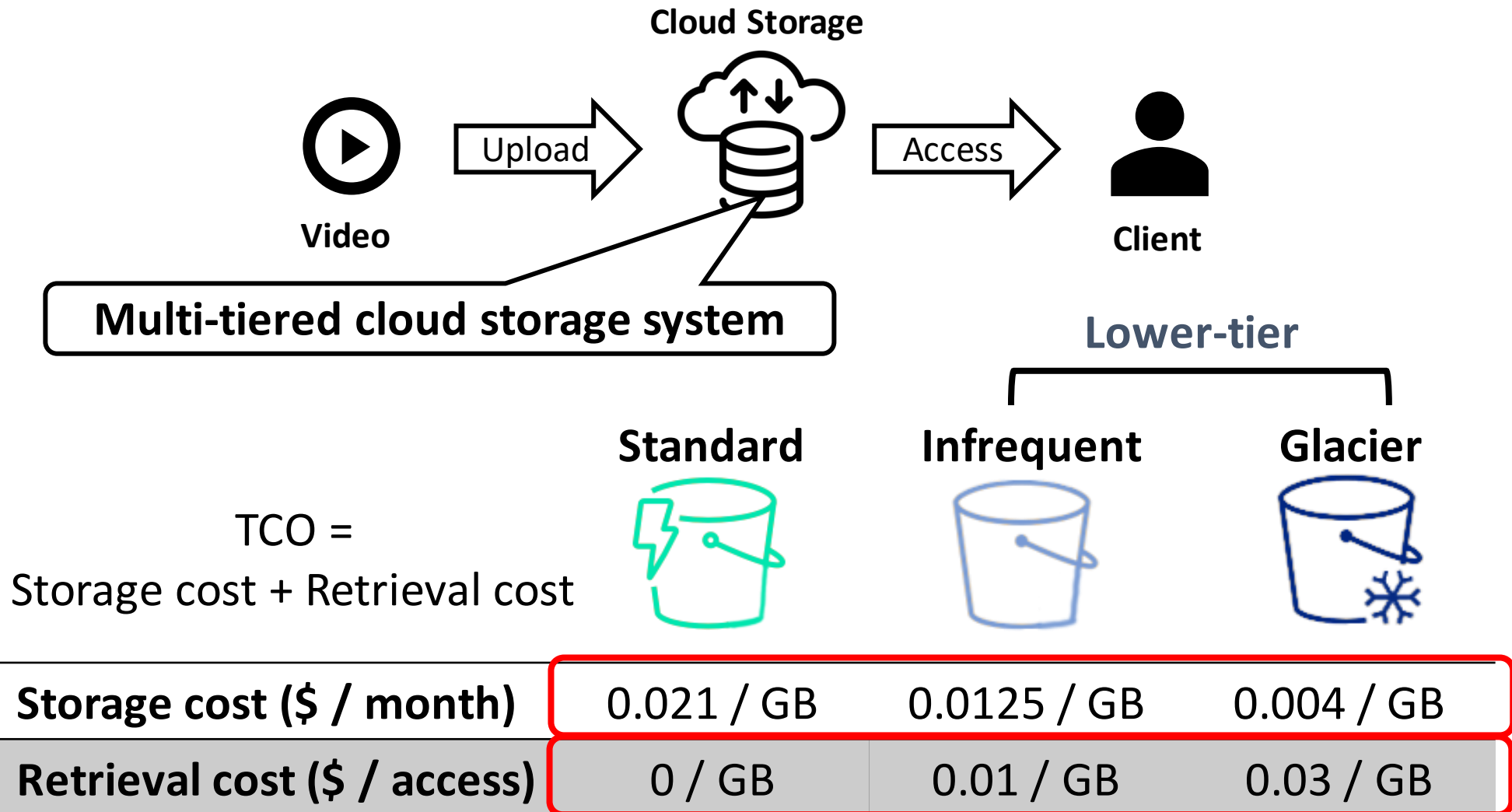Video → Upload → (Cloud Storage) → Access → Client
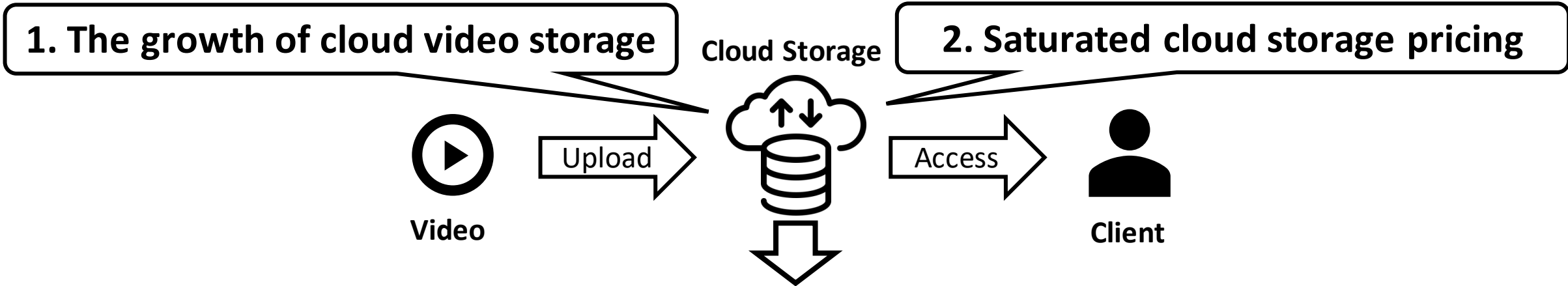
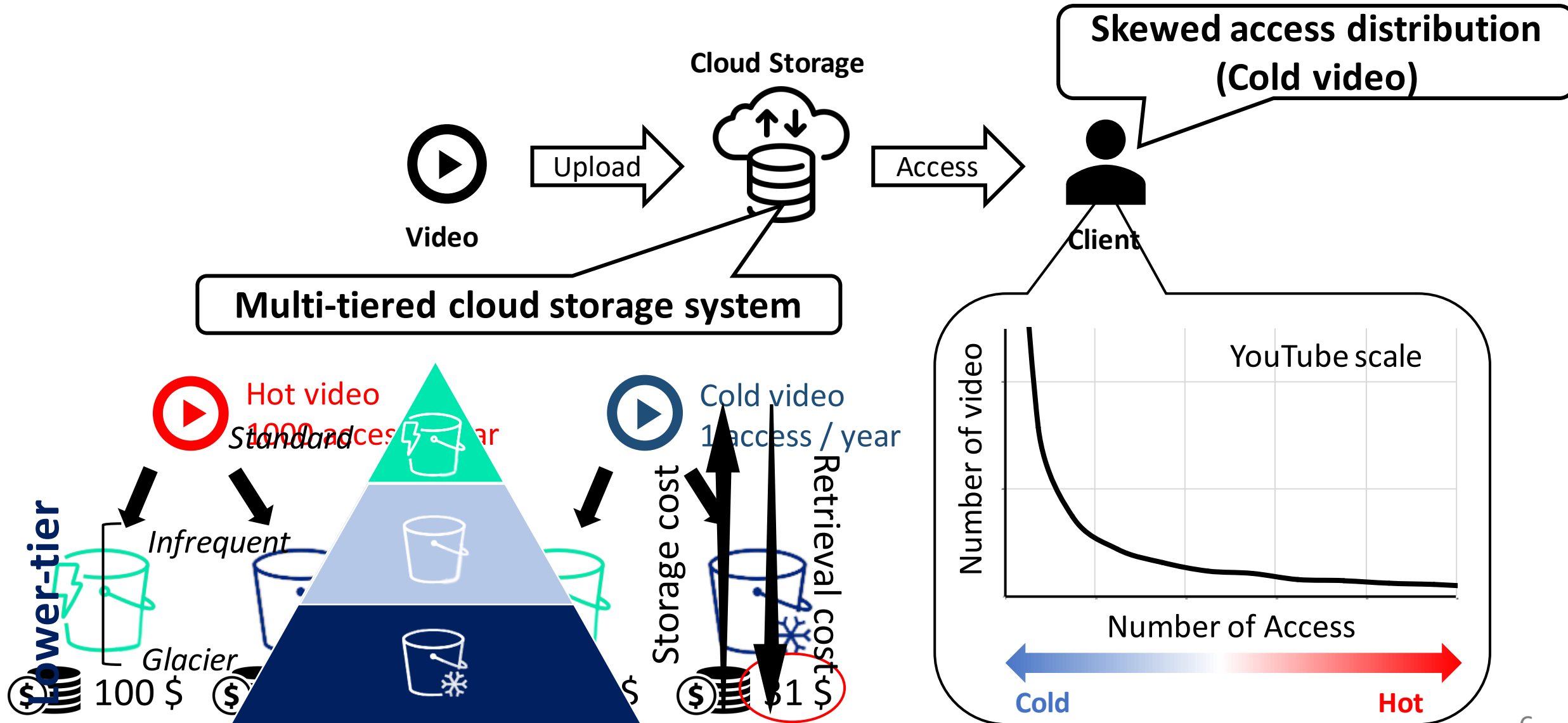Exponential growth of the TCO in cloud video storage
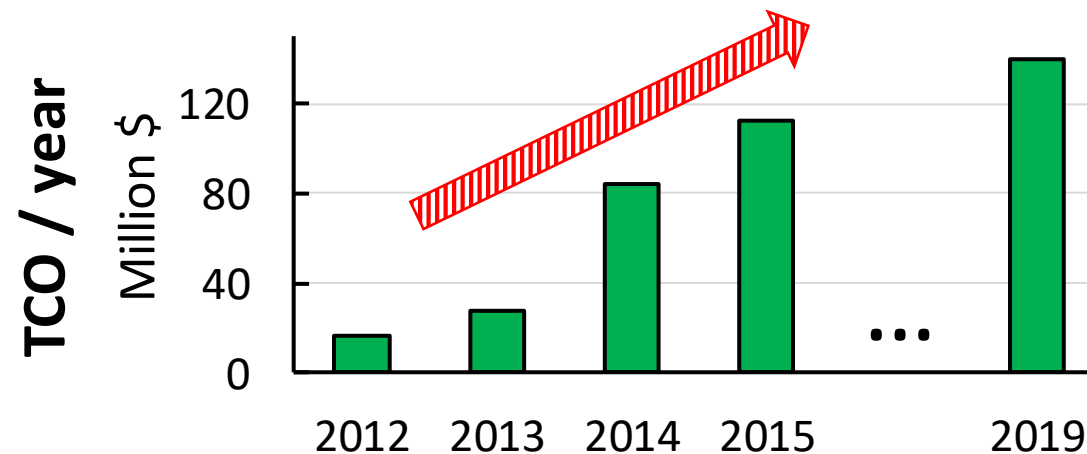
Estimation of TCO of cloud video storage on YouTube

Existing approach: Multi-tiered cloud storage

Cloud Storage

Video → Upload → [Cloud Storage] → Access → Client

Multi-tiered cloud storage system

Lower-tier

TCO =
Storage cost + Retrieval cost

	Standard	**Infrequent**	**Glacier**
Storage cost ($ / month)	0.021 / GB	0.0125 / GB	0.004 / GB
Retrieval cost ($ / access)	0 / GB	0.01 / GB	0.03 / GB

Existing approach: Multi-tiered cloud storage

Cloud Storage

Skewed access distribution (Cold video)

Upload

Access

Video

Client

Multi-tiered cloud storage system

Hot video
1000 access / year

Standard

Infrequent

Lower-tier

Glacier

Cold video
1 access / year

Storage cost

Retrieval cost

100 $

$ $ 31 $

YouTube scale

Number of video

Number of Access

Cold

Hot

Limitation: Restricted gain coverage

Cloud Storage

Skewed access distribution
(Cold video)

Video

Upload

Access

Client

Multi-tiered cloud storage system

Normalized TCO

Gain range of
Lower-tier Storage

Gain

Lower-tier

Standard

3   10   30   100

Access / year

YouTube scale

Number of video

25%

10   Number of Access

Cold   Hot
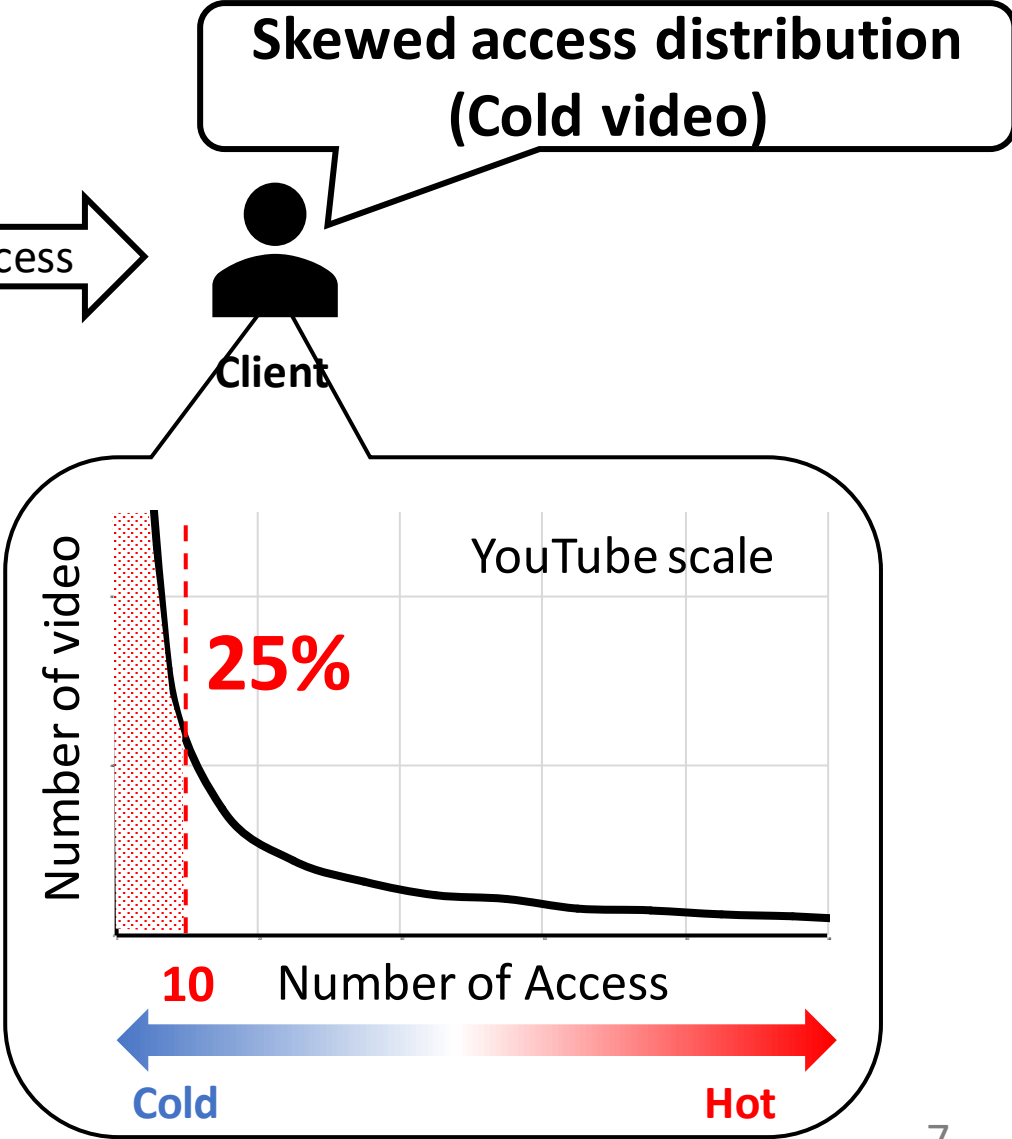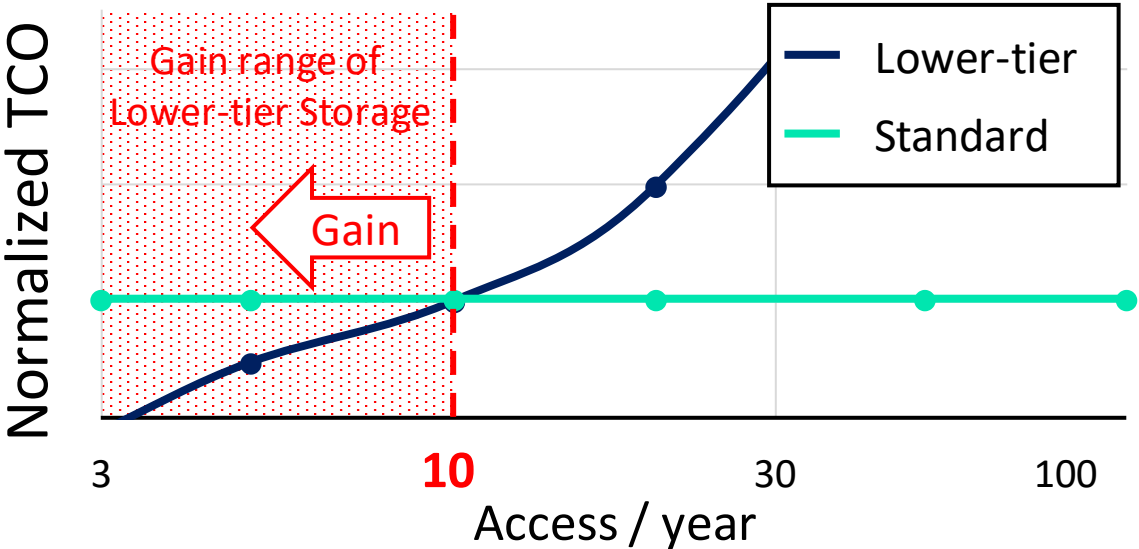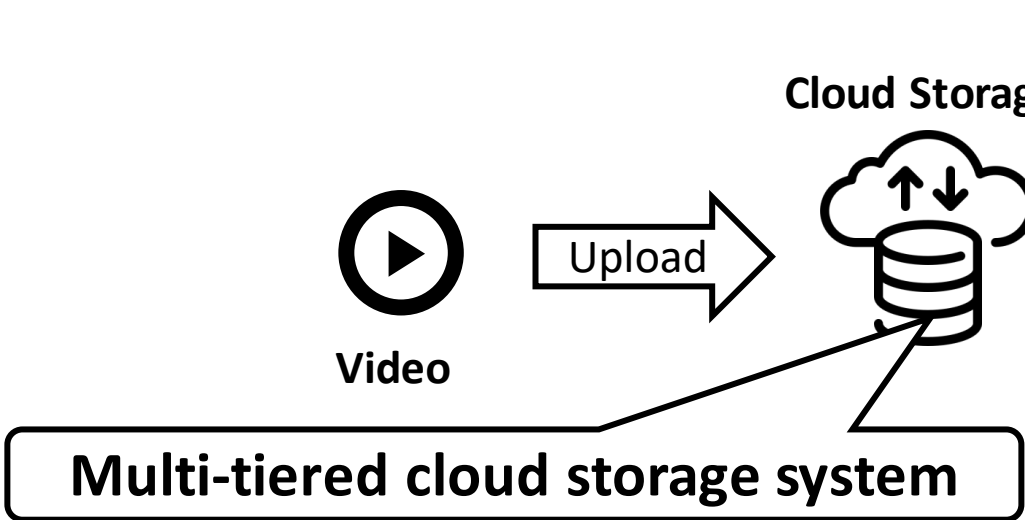
New Opportunity on Cloud Video Storage System

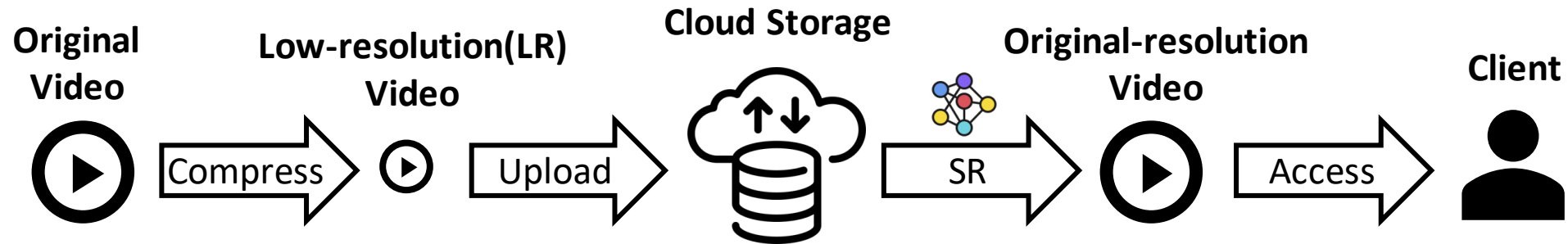Problem: Significant TCO for cloud video storage system

Observation

1. Most videos are accessed infrequently(cold video)

2. Gain of multi-tiered storage is limited
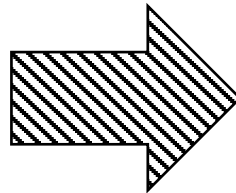
New approach:
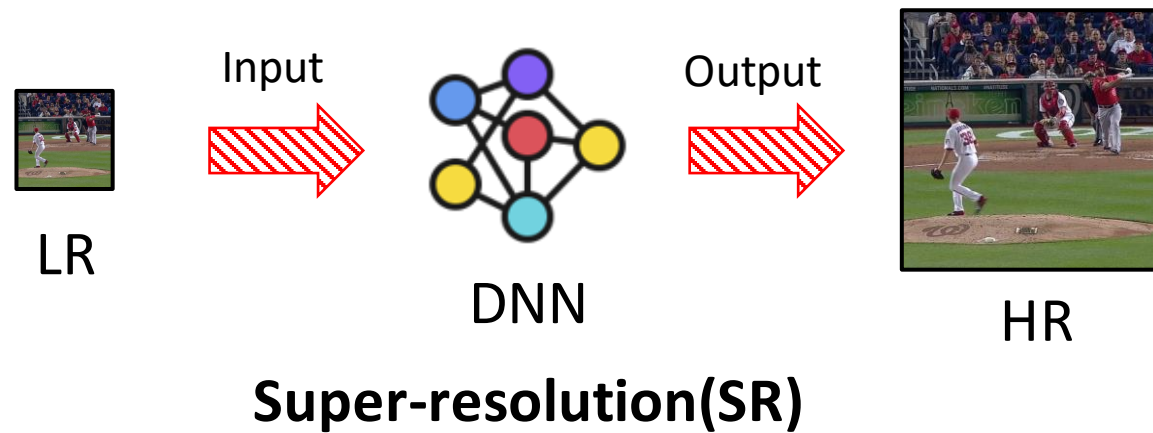Neural Cloud Storage

Our approach: Neural Cloud Storage(**NCS**)

Original Video → Compress → **Low-resolution(LR) Video** → Upload → **Cloud Storage** → SR → **Original-resolution Video** → Access → **Client**

Goal: Reduce TCO of cloud video storage system
- Use neural enhancement to reduce storage cost
  - Content-aware super-resolution
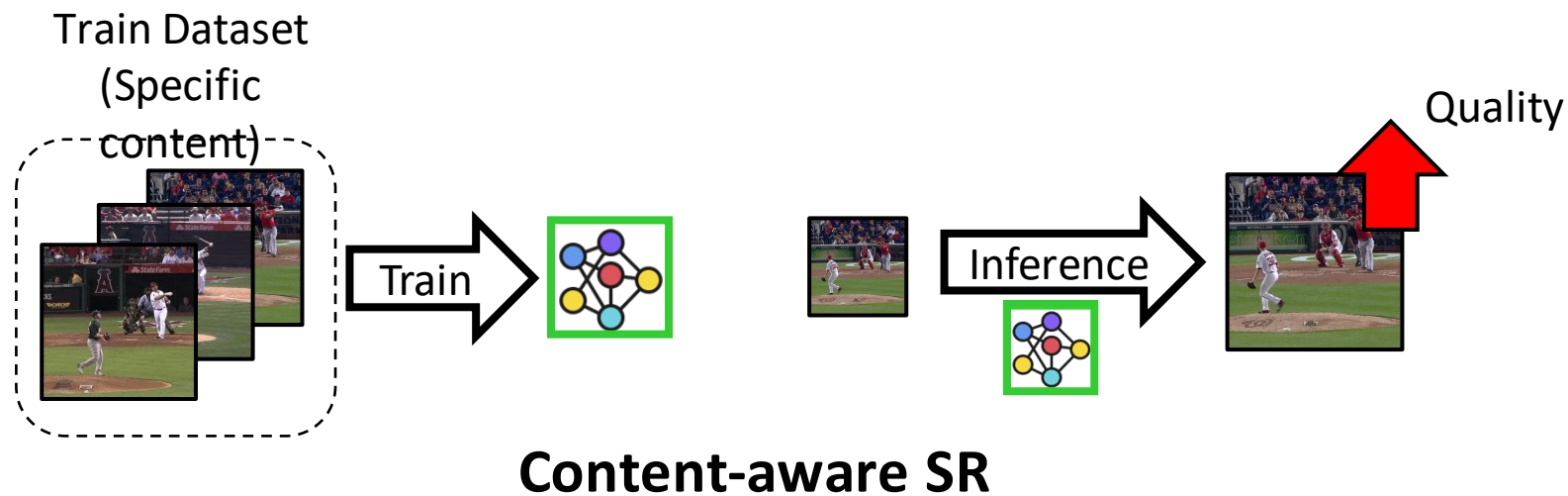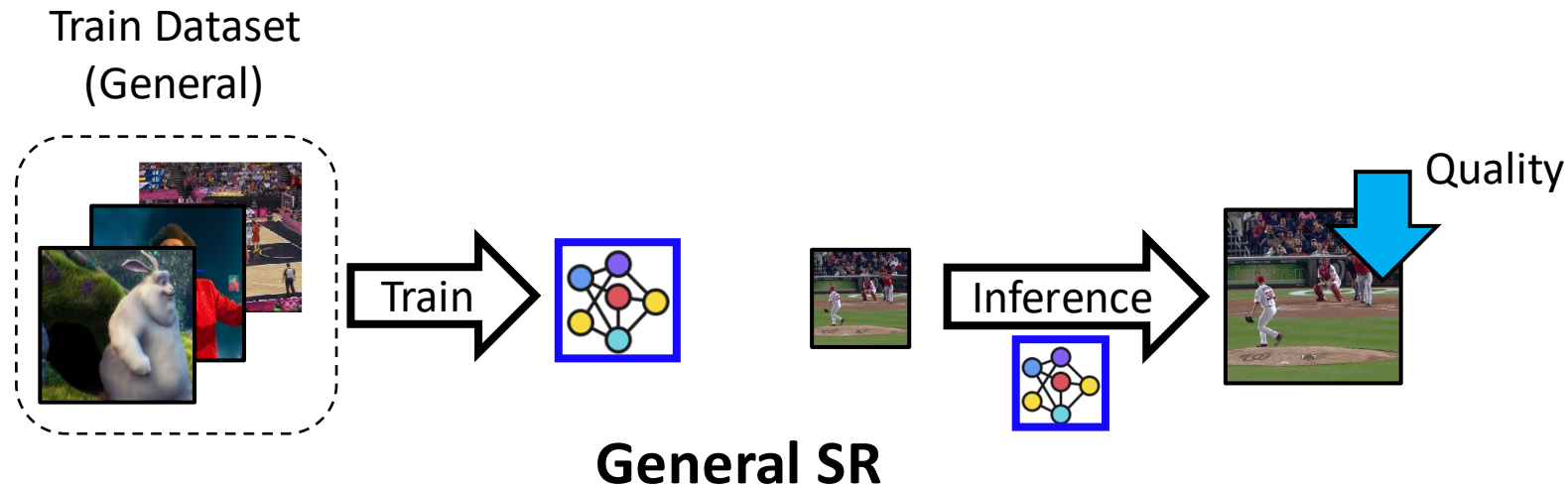- Target video with low access frequency (cold video)

Content-aware Super-resolution

Super-resolution(SR)

- Enhances low-resolution(LR) videos to high-resolution(HR) versions
- Neural enhancement provides an opportunity to achieve high-quality SR

LR →Input→ DNN →Output→ HR

Super-resolution(SR)

Content-aware Super-resolution

Train Dataset
(General)

Train

General SR

Inference

Quality

Train Dataset
(Specific content)

Train

Content-aware SR

Inference

Quality

Content-aware SR

- Fine-tuning DNN for each content

- Better performance than general SR
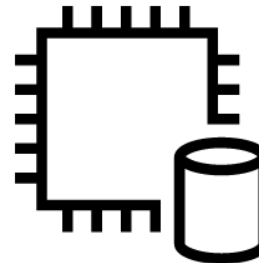
Why Content-aware Super-resolution?

Motivation

Reduce storage cost effectively
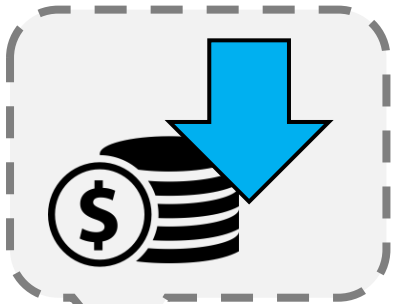
Favorable for storing cold video
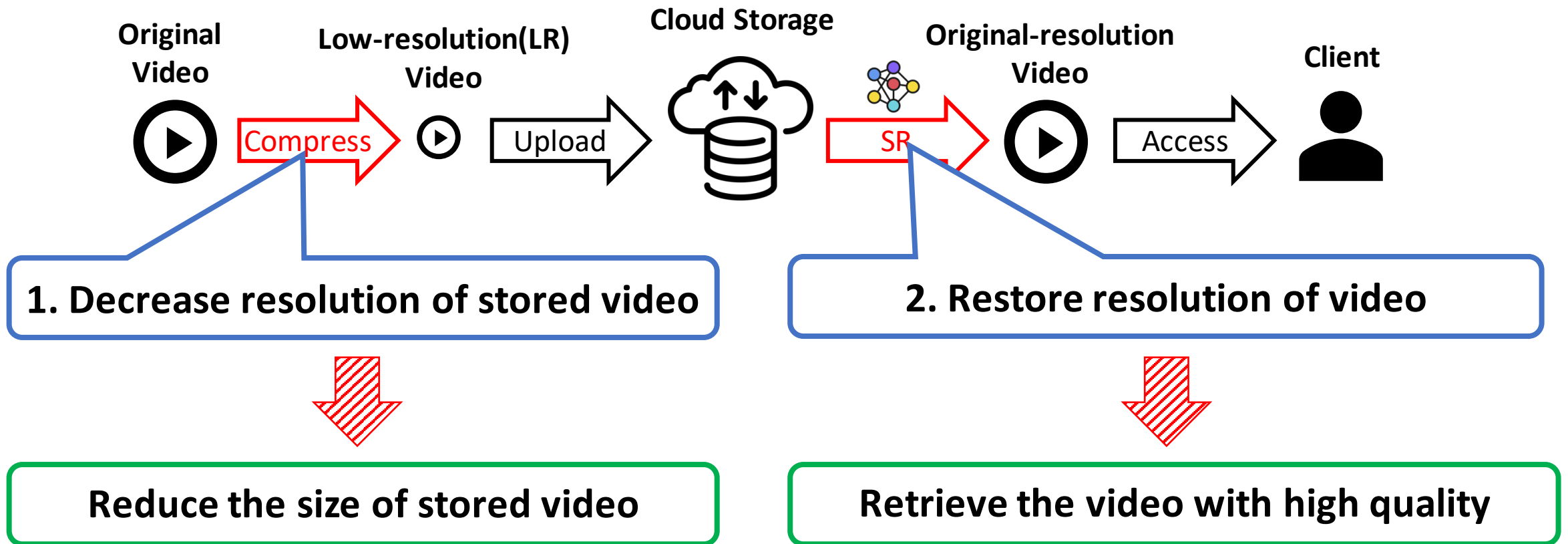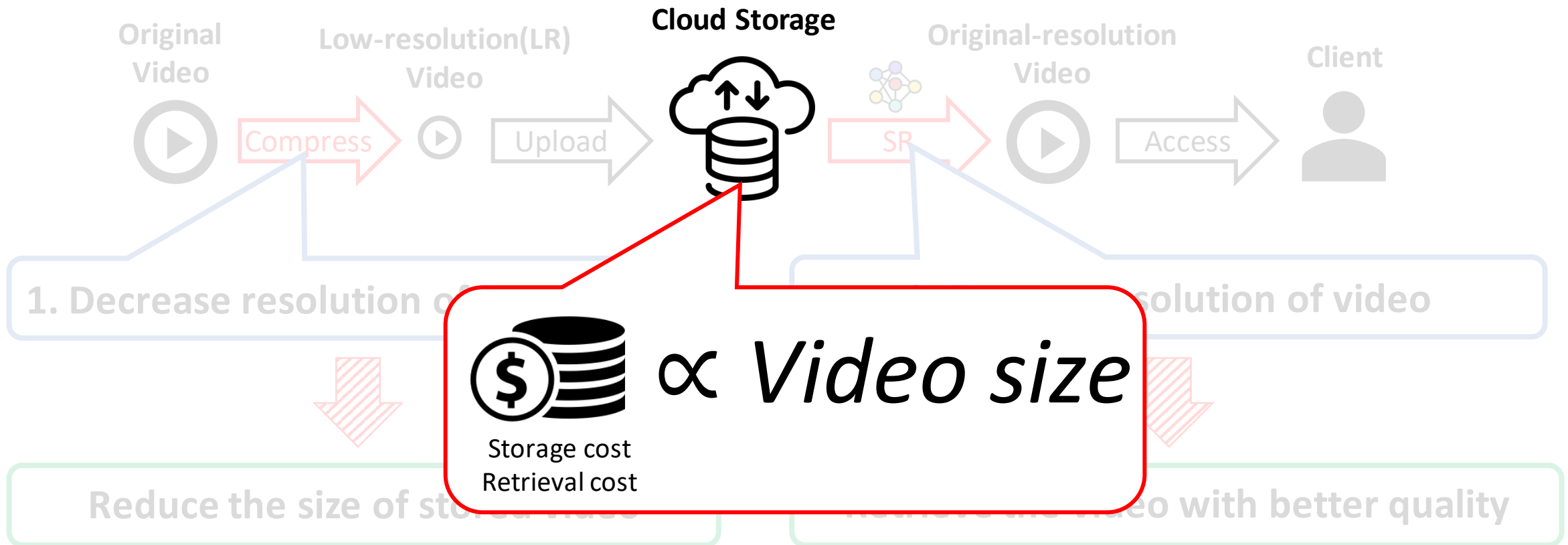
Cold video

Decreased computing pricing

Clustering

1. Content-aware super-resolution reduce storage cost

1. Decrease resolution of stored video

2. Restore resolution of video

Reduce the size of stored video

Retrieve the video with high quality

1. Content-aware super-resolution reduce storage cost

Cloud Storage

Storage cost
Retrieval cost
$\propto Video\ size$

1. Content-aware super-resolution reduce storage cost

Without content-aware SR

With content-aware SR

= 1.17 GB

~34% size reduction

= 0.77 GB

≅ 0.1 MB

1. Content-aware super-resolution reduce storage cost

Original Video → Compress → **Low-resolution(LR) Video** → Upload → **Cloud Storage** → SR → **Original-resolution Video** → Access → **Client**

1. Decrease resolution of stored video

2. Restore resolution of video

Reduce the size of stored video

Retrieve the video with high quality

Reduce storage cost with high video quality

Computing overhead of Content-aware SR

Original Video → Compress → **Low-resolution(LR) Video** → Upload → **Cloud Storage** → SR → **Original-resolution Video** → Access → **Client**

Cloud Computing Instance — *Training cost* — Train

Cloud Computing Instance — *Inference cost* — Inference
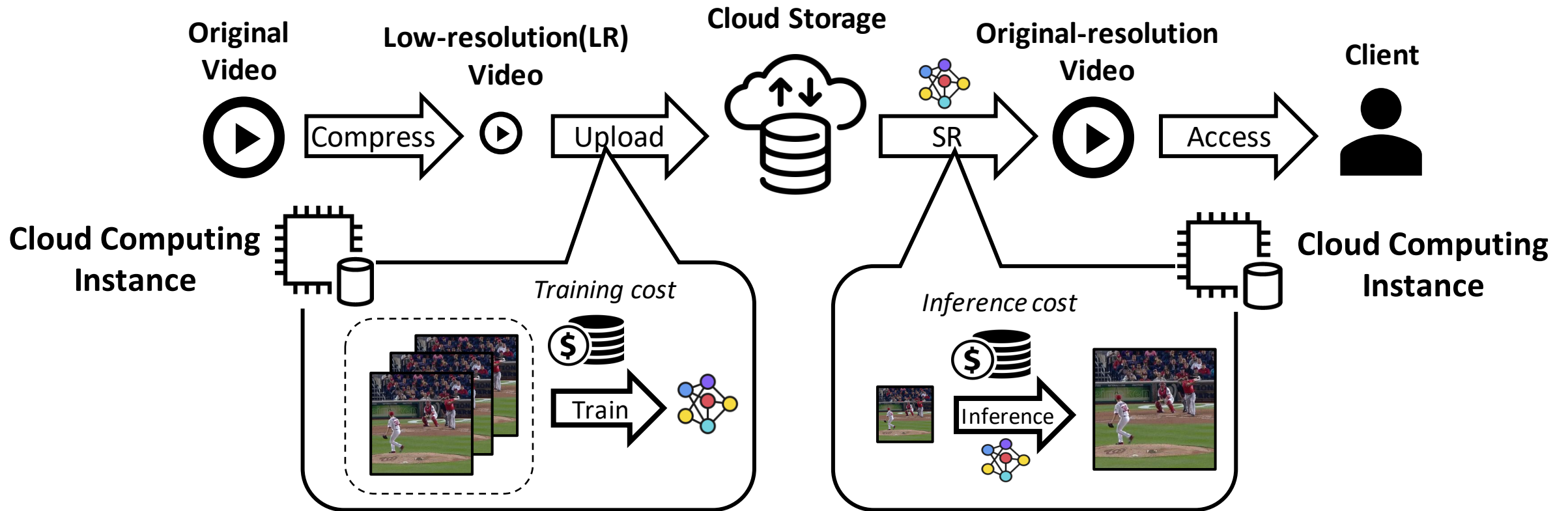
$$\textcolor{red}{Computing\ overhead} = Training\ cost + Inference\ cost \times Number\ of\ Accesses$$
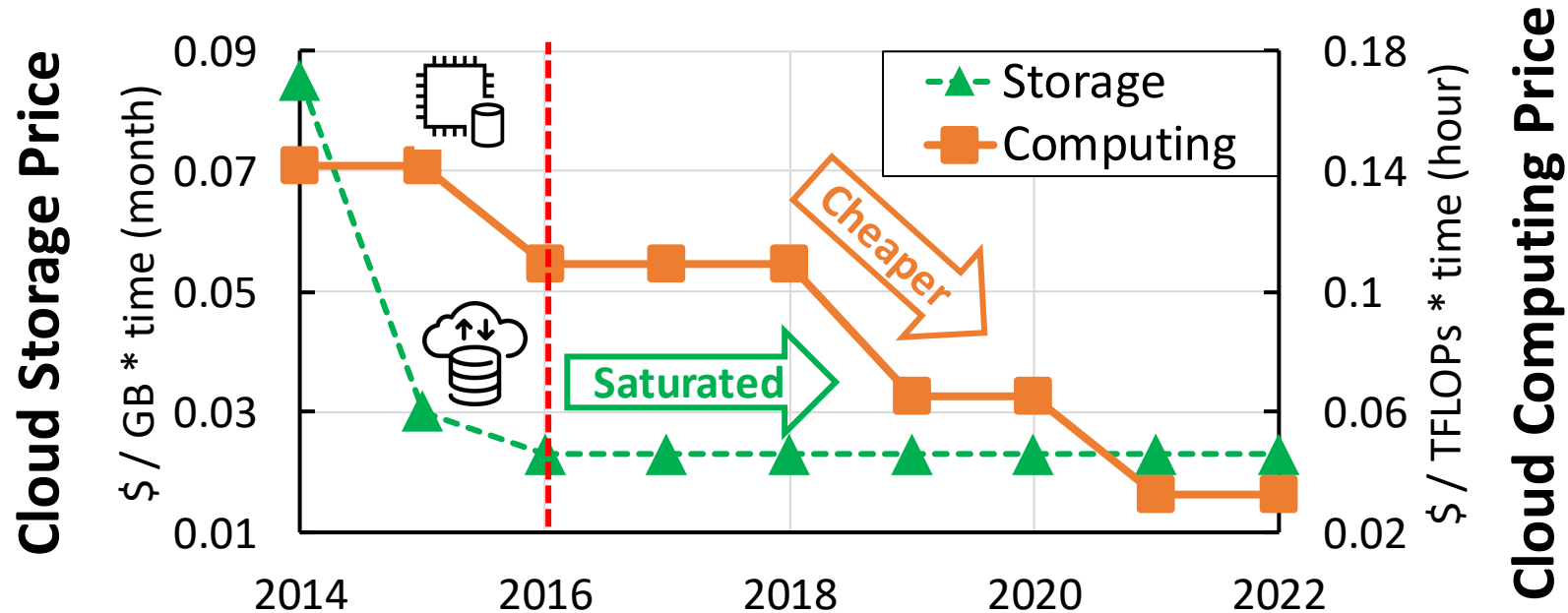
2. Favorable for storing cold video
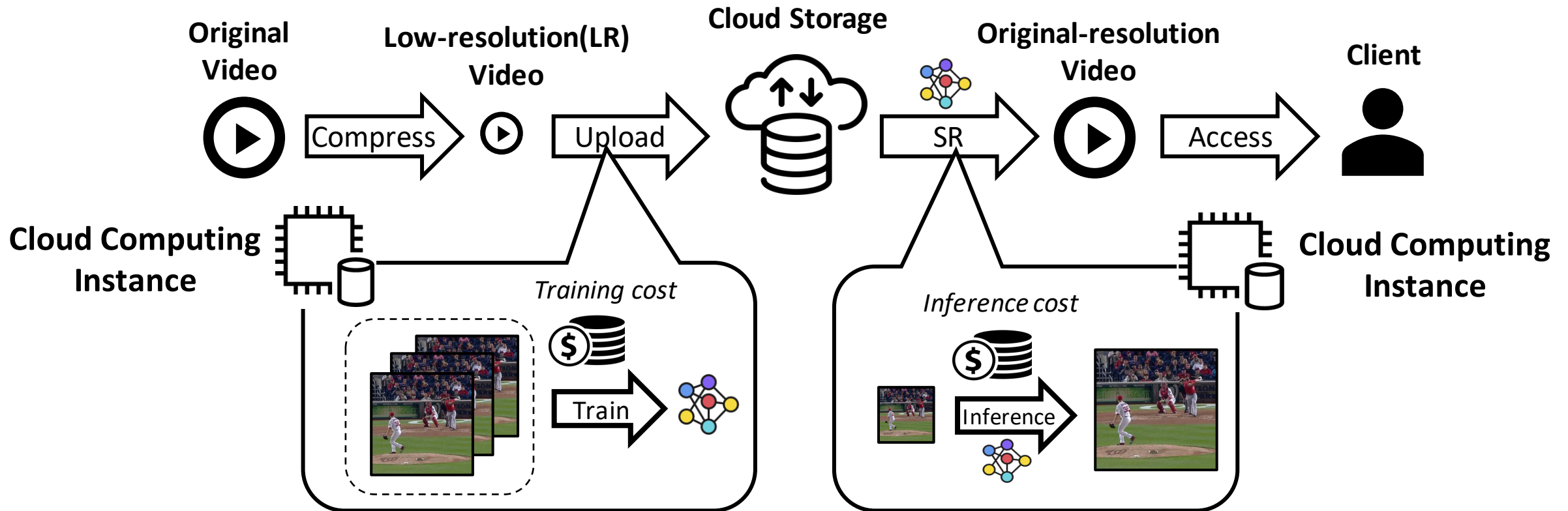
$$Computing\ overhead = Training\ cost + Inference\ cost \times \textbf{\textit{Number of Accesses}}$$

Less computing overhead for storing cold video

3. The price of computing is decreasing

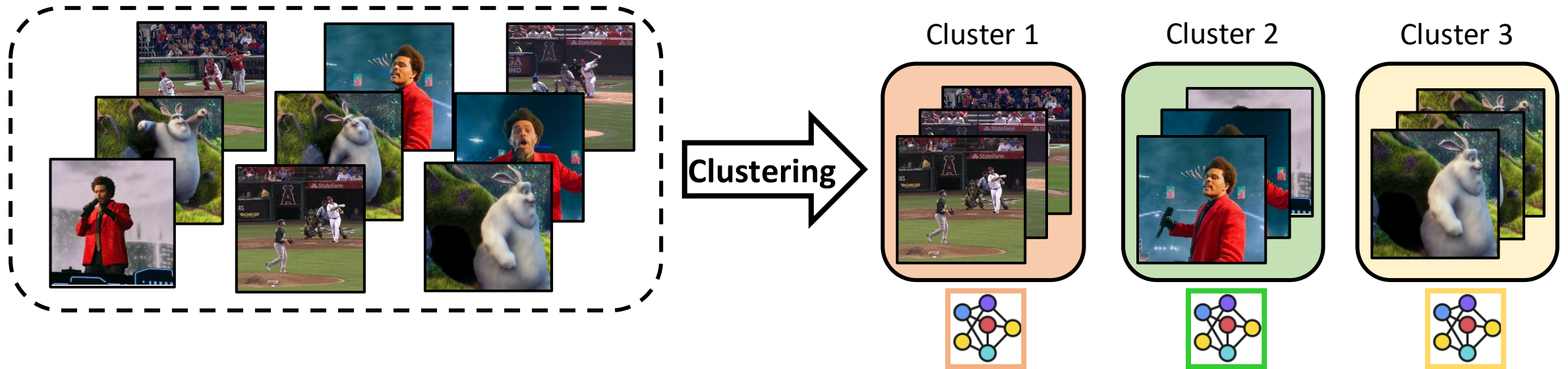The price trend of storage and computing instance of cloud provider(AWS)

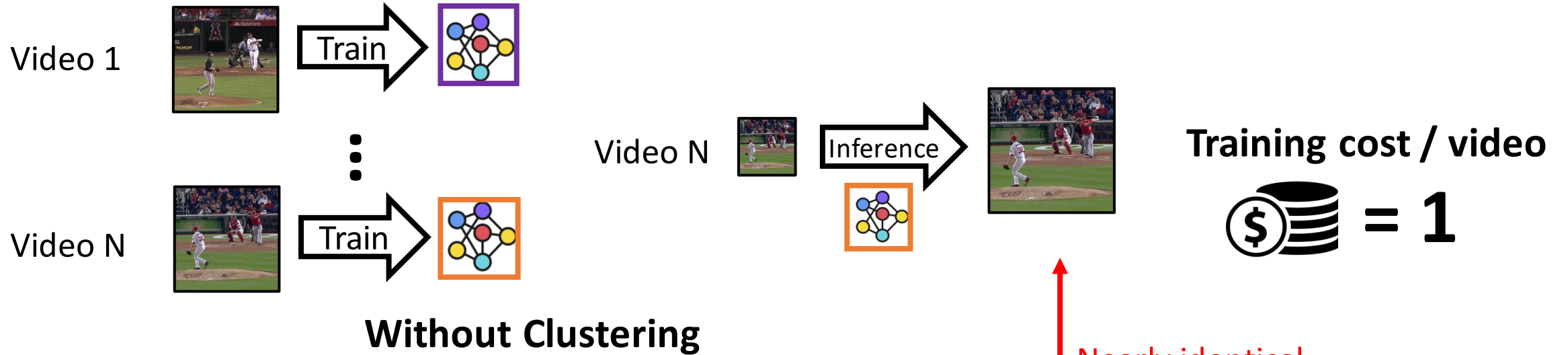**Using content-aware SR becomes more and more cost-effective**

4. Clustering: Amortize training cost

Clustering: grouping videos with similar content(content redundancy)

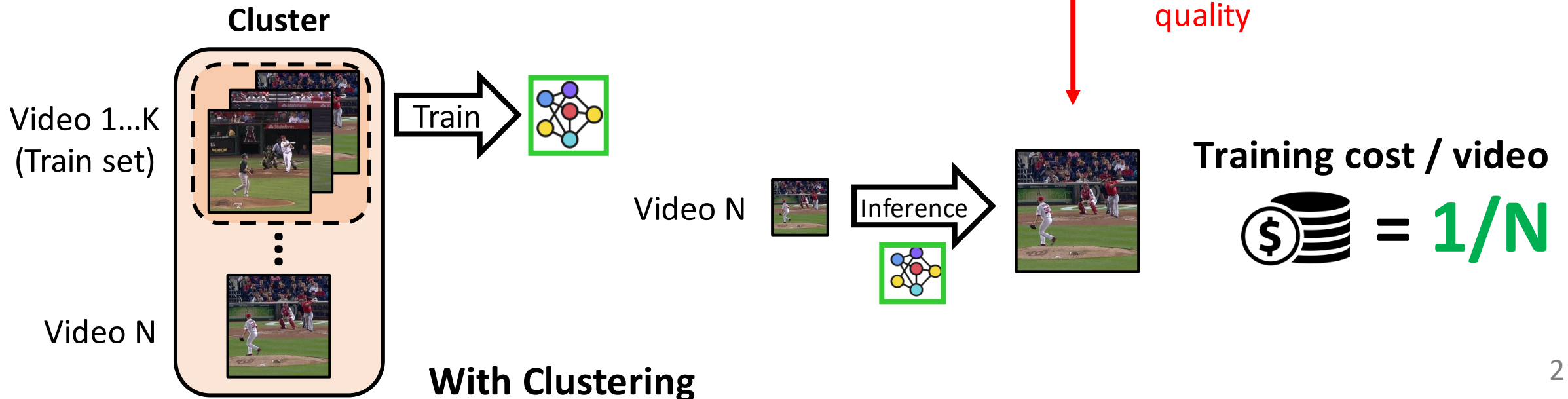Large number of videos in video platform -> clustering well
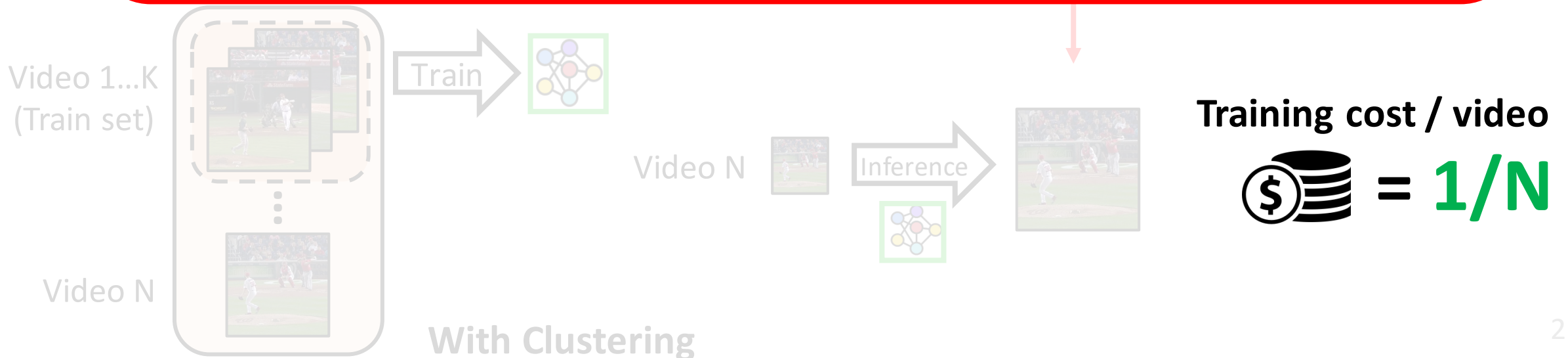
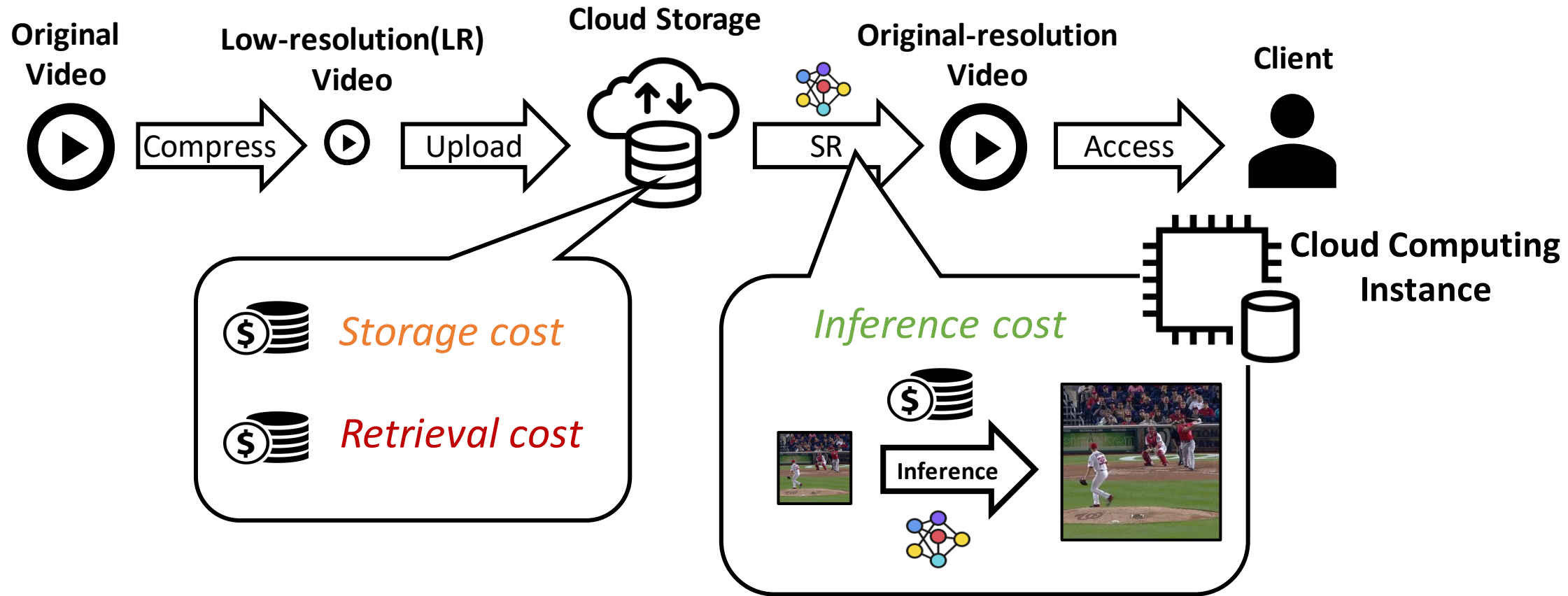# 4. Clustering: Amortize training cost

Video 1

Train

Video N

Train

Video N

Inference

Training cost / video

$= 1$

Without Clustering

- -

Nearly identical quality

Cluster

Video 1...K
(Train set)

Train

Video N

Video N

Inference

Training cost / video

$= 1/N$

With Clustering

4. Clustering: Amortize training cost

Training cost can be amortized with large amount of videos on video platform

Video 1

Video 1...K
(Train set)

Train

Video N

Inference
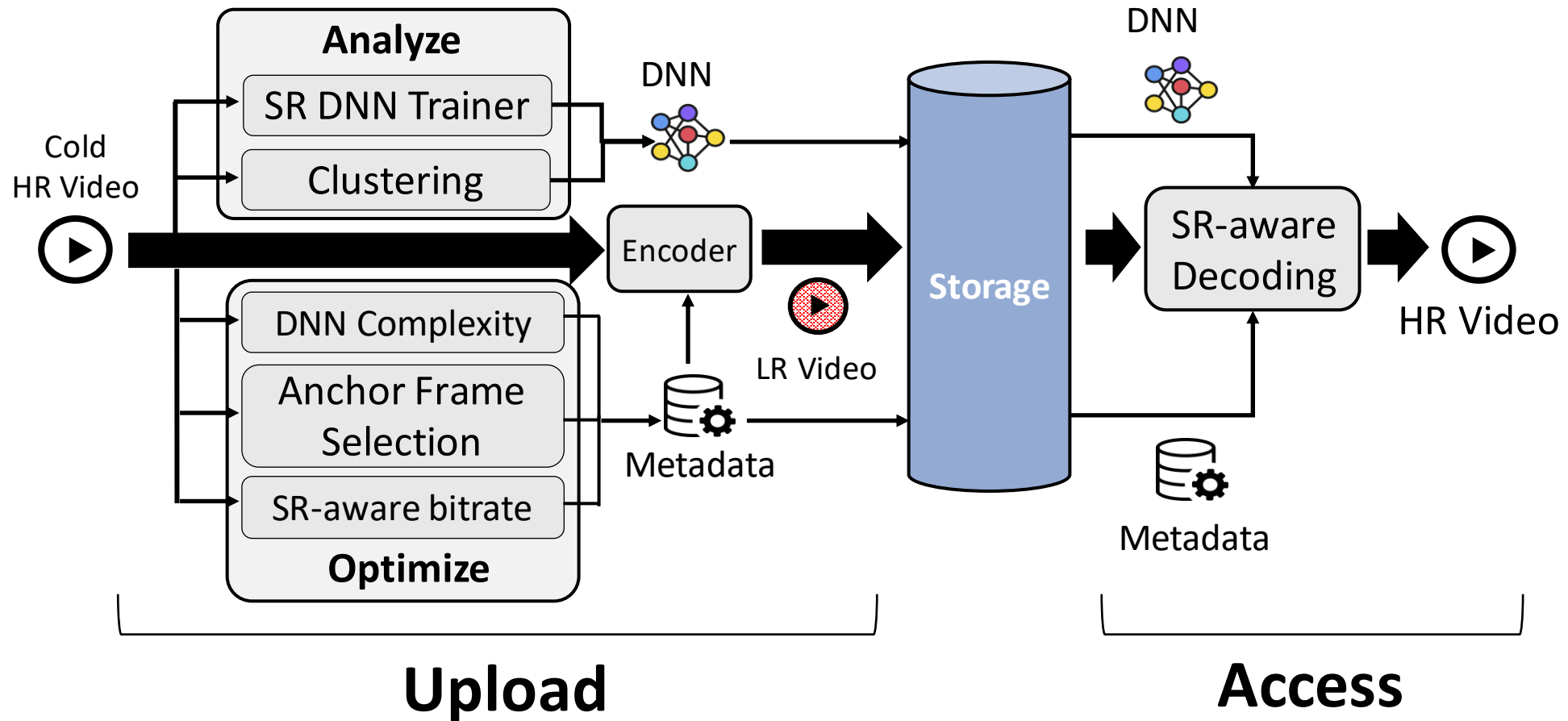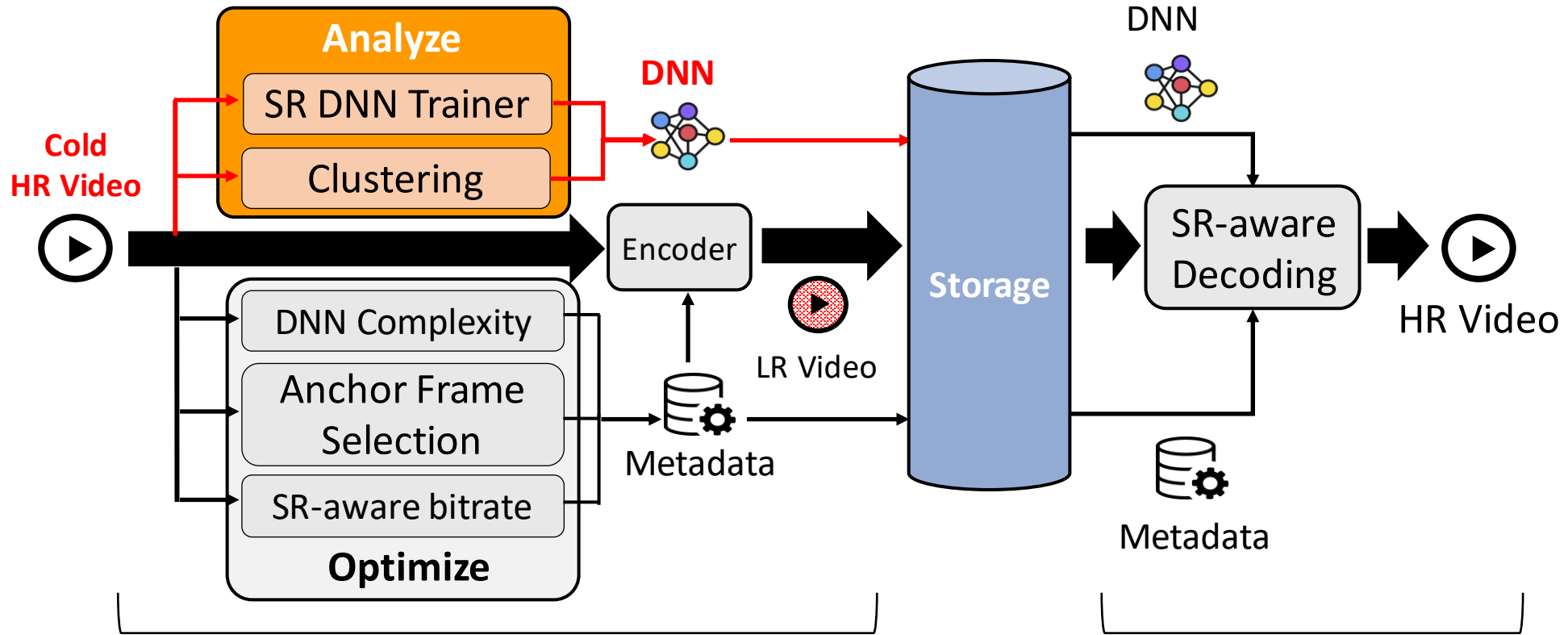
Training cost / video

= **1/N**

Video N

With Clustering

Total Cost of Ownership(TCO) of NCS

$$TCO_{NCS} = Storage\ cost + Retrieval\ cost + Inference\ cost$$
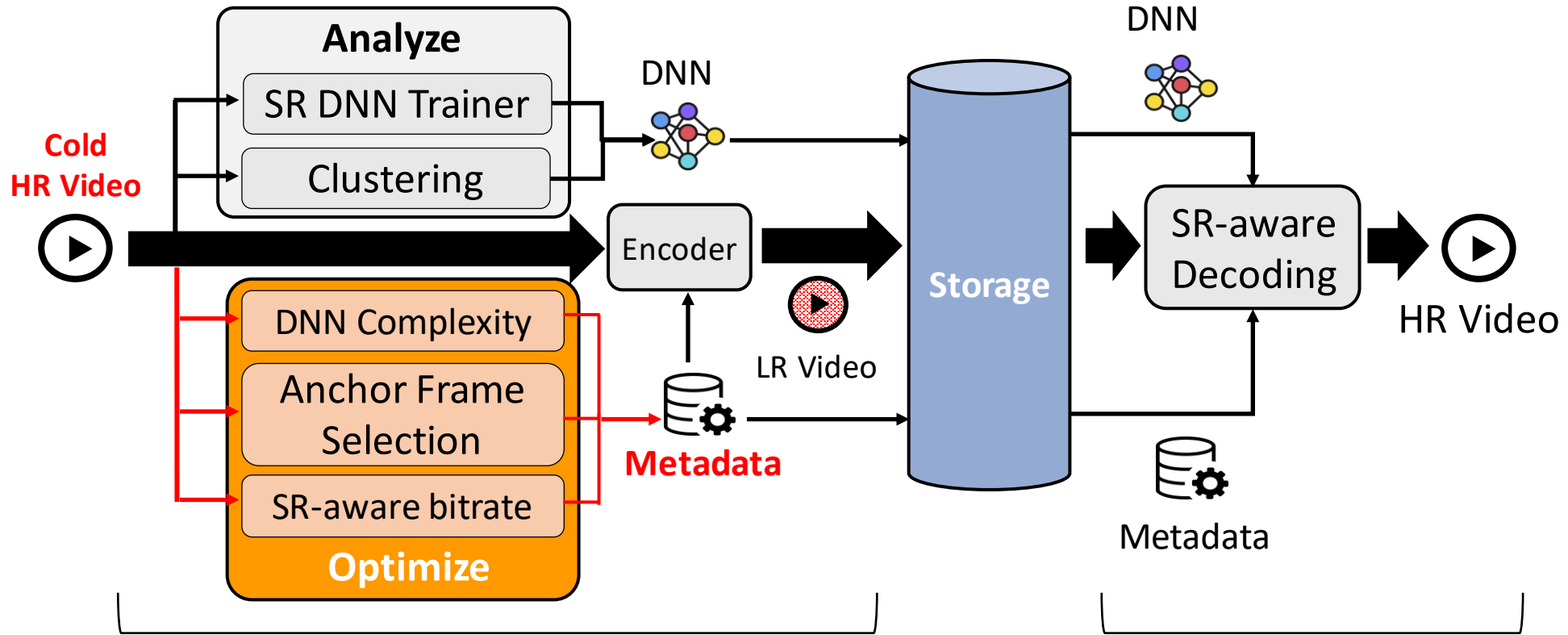
NCS: High-level Overview

Workflow of NCS

1. Analyze

- Analyze video content and find cluster of the content
- If the cluster does not existed, create new cluster and train content-aware SR DNN
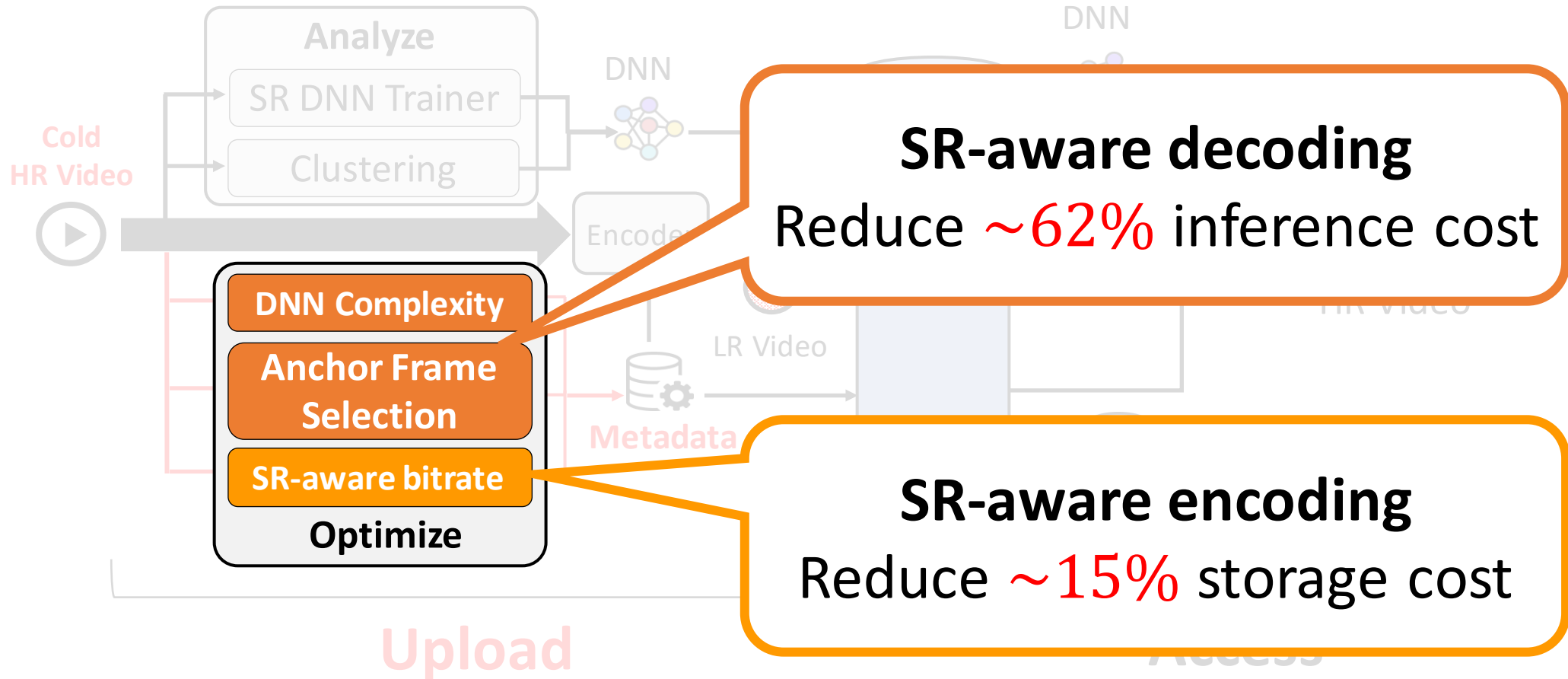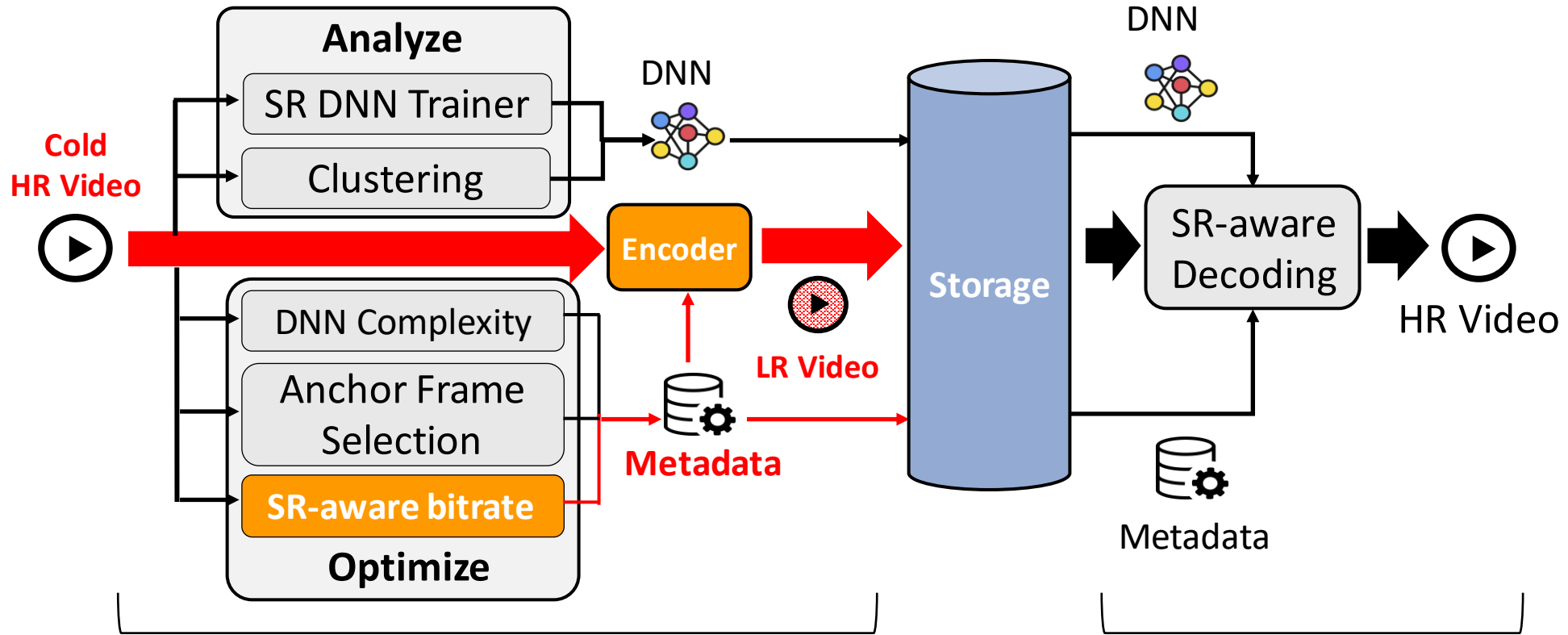
Workflow of NCS

2. Optimize
- Profile video and generate metadata for SR-aware encoding/decoding
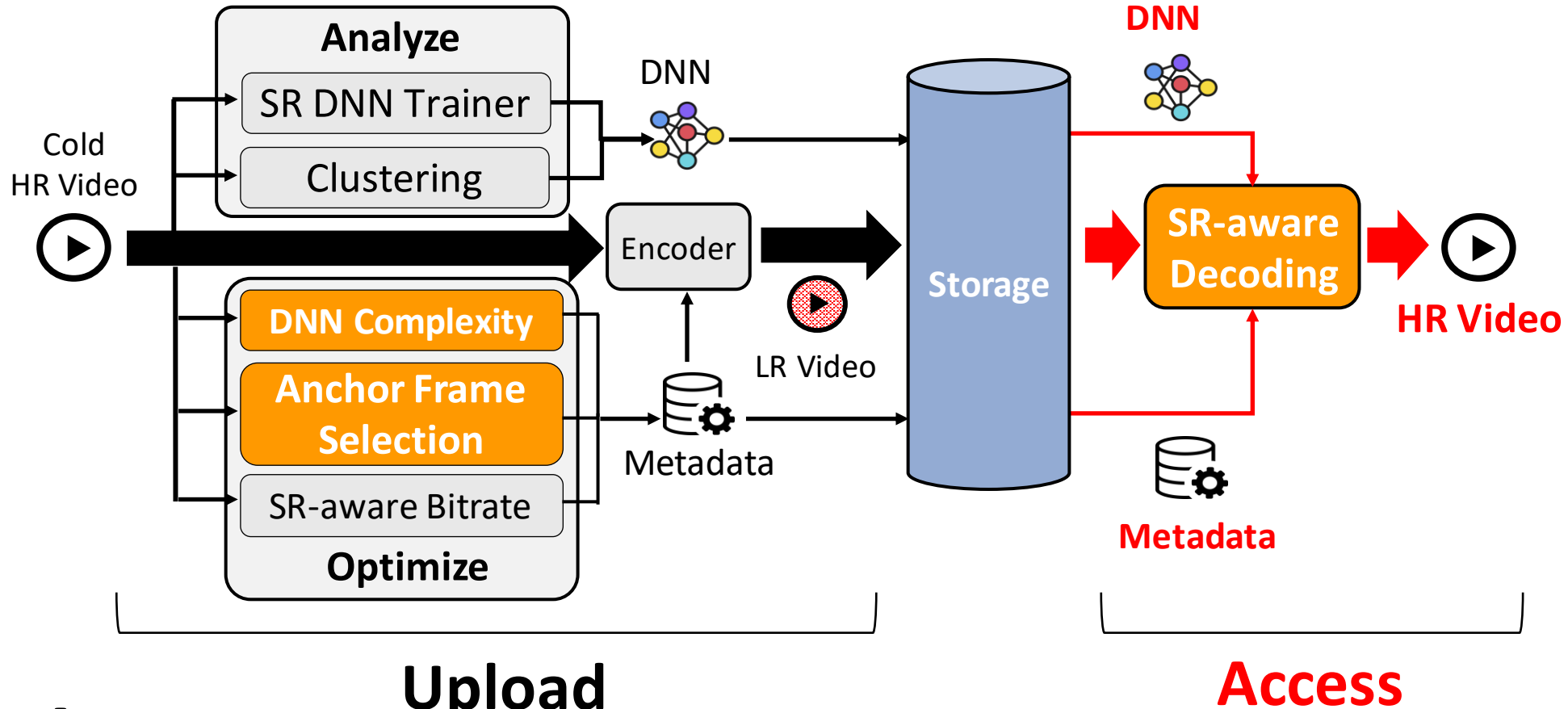- The metadata is used for minimizing TCO of NCS

Optimization

DNN Complexity

Anchor Frame Selection

SR-aware bitrate

Optimize

SR-aware decoding
Reduce ~62% inference cost

SR-aware encoding
Reduce ~15% storage cost

Workflow of NCS

Upload

Access

3. Encode

- Compress video into low-resolution with <u>SR-aware encoding</u>
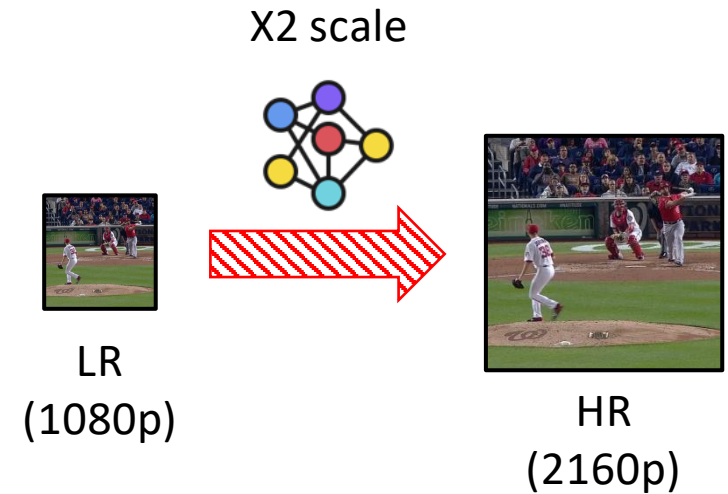
Workflow of NCS

4. Access
- Restore video resolution by SR DNN
- Apply SR-aware decoding

Evaluation setting

X2 scale

Dataset: Random videos on YouTube

   Resolution of video: 1080p(FHD) $\rightarrow$ 2160p(4k)

LR
(1080p)

HR
(2160p)

Cloud : Amazon Web Service(AWS)

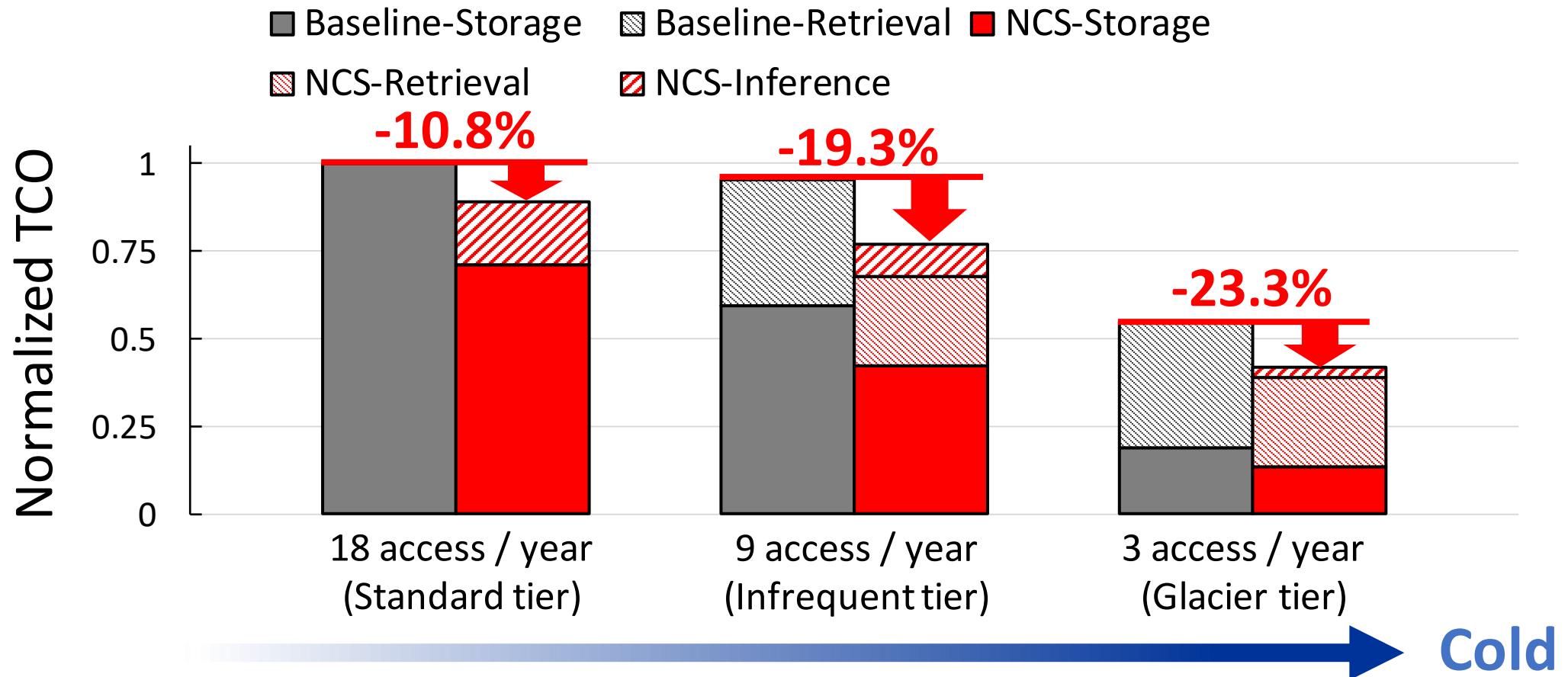**Baseline**: AWS multi-tiered storage (Standard, Infrequent, Glacier)

Metric: Total cost of ownership (TCO)

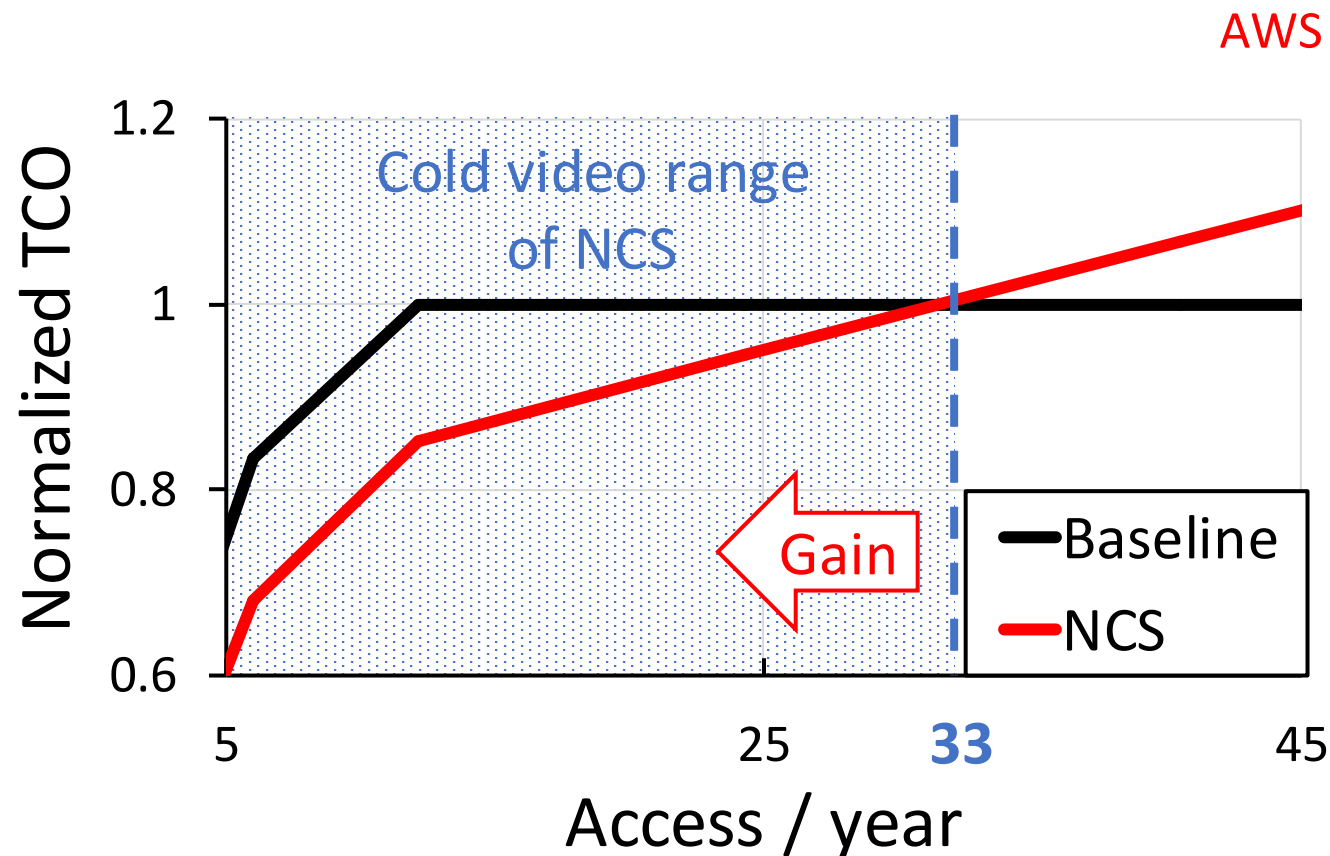$$TCO_{NCS} = Storage\ cost + Retrieval\ cost + Inference\ cost$$

Cost-benefit analysis of NCS

- NCS get more TCO gain with cold video

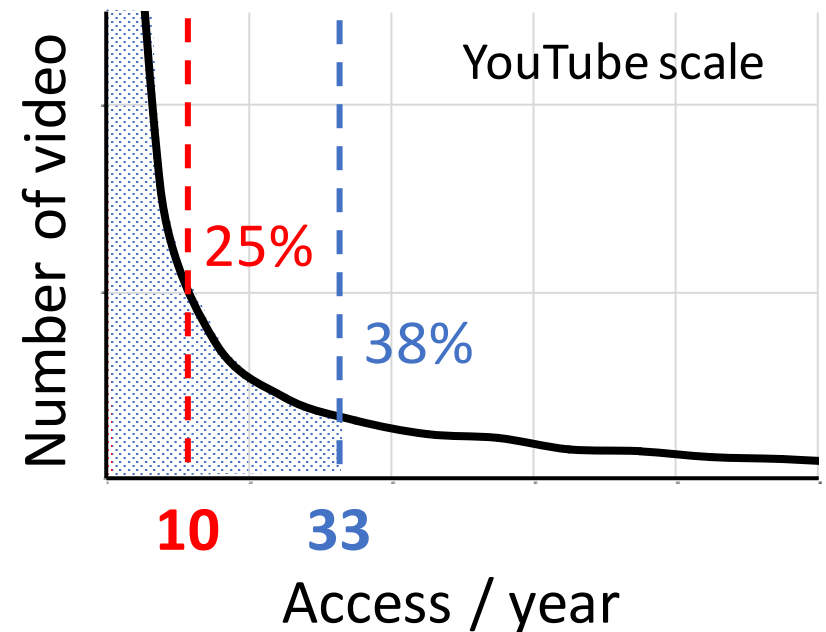Legend: ■ Baseline-Storage   ▨ Baseline-Retrieval   ■ NCS-Storage   ▨ NCS-Retrieval   ▨ NCS-Inference

Normalized TCO chart:
- 18 access / year (Standard tier): -10.8%
- 9 access / year (Infrequent tier): -19.3%
- 3 access / year (Glacier tier): -23.3%

Cold →

Cost-benefit analysis of NCS

- NCS offers cost-effective storage for more cold videos
  (< 33 access / year)

Cost-benefit analysis of NCS

- NCS can save 14% TCO than baseline on these cold videos
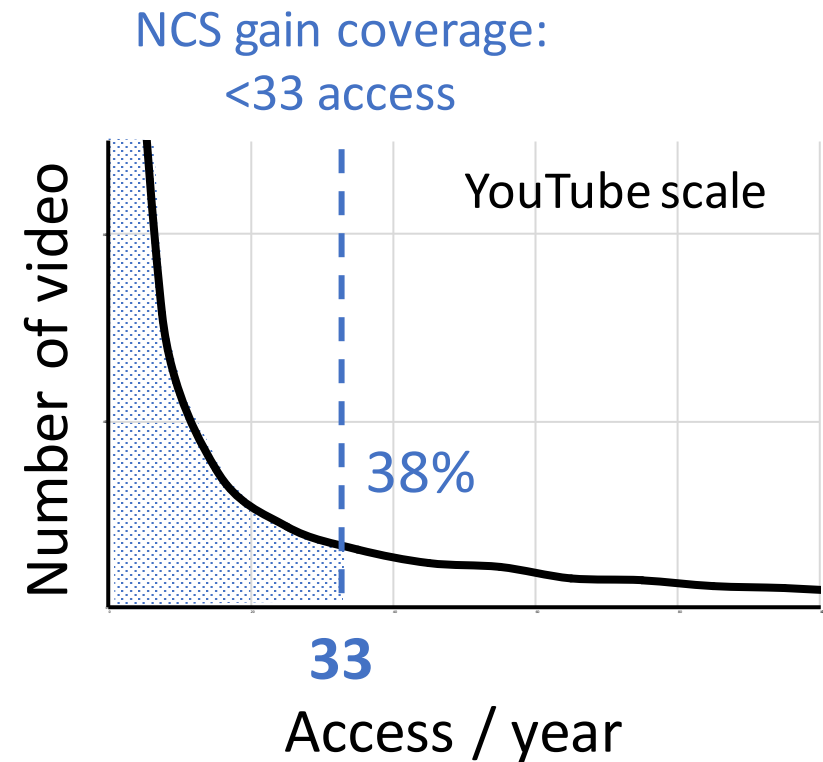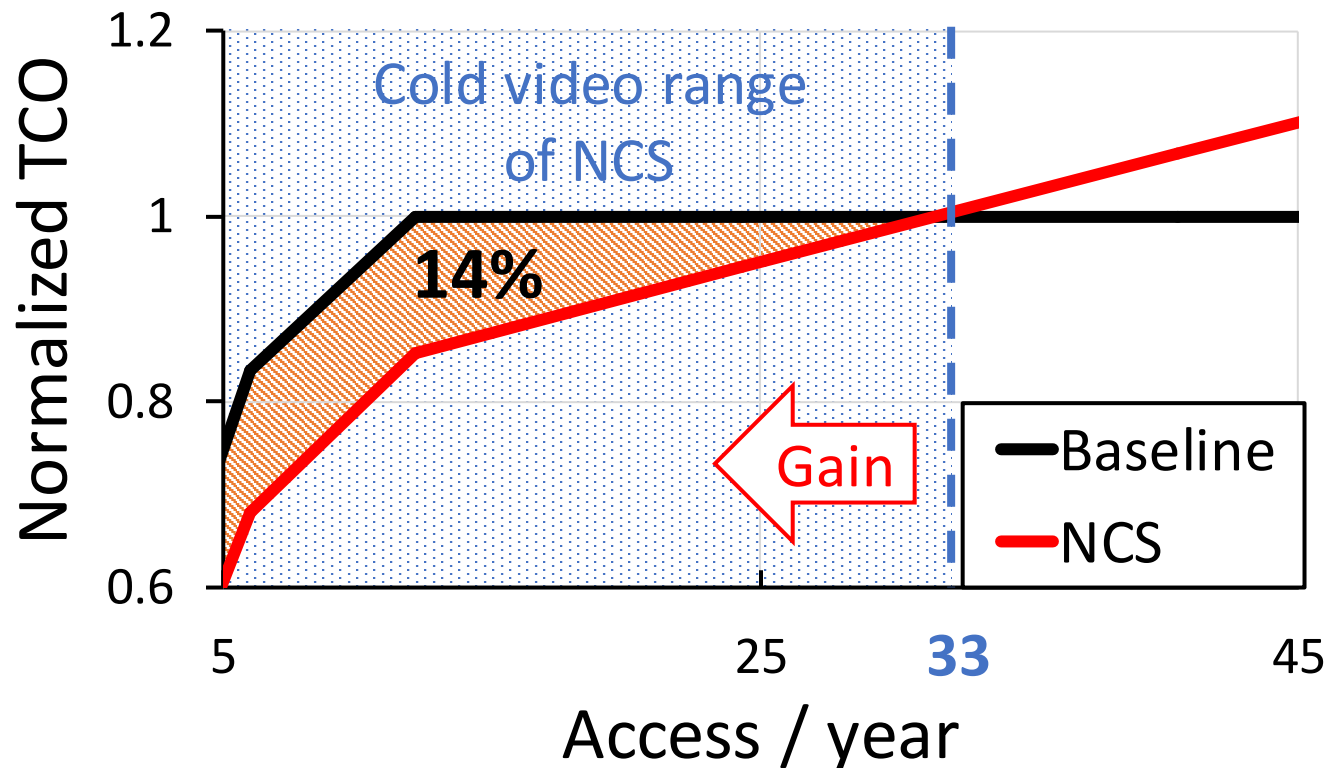
Conclusion

- Content-aware super-resolution brings new opportunity for storing video in cloud storage cost-effectively

- We propose Neural Cloud Storage(NCS) that a cost-effective cloud storage solution for cold video

- We envision the prototype of NCS and its potential with a cost-benefit analysis

Thank you

Q&A