Clownfish: Edge and Cloud Symbiosis for Video Stream Analytics

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Motivation: Video Stream Analytics

- Applications such as **augmented reality**, **public safety** at airport need accurate analytics in real time

- Higher accuracy due to advanced (DNN-based) computer vision algorithms

- Increased computational complexity of DNNs hurts real-time objective

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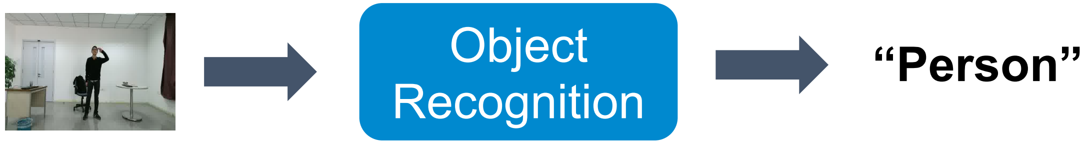
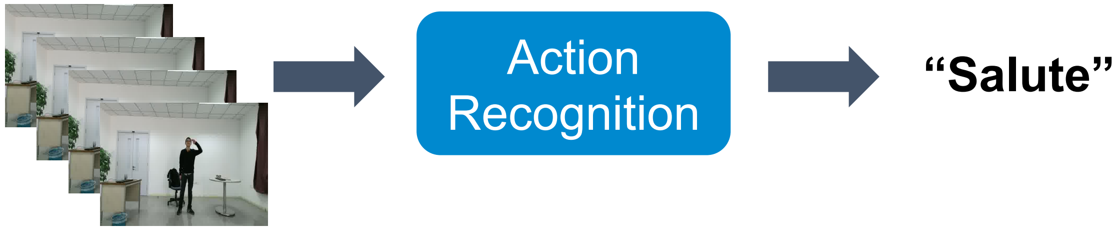
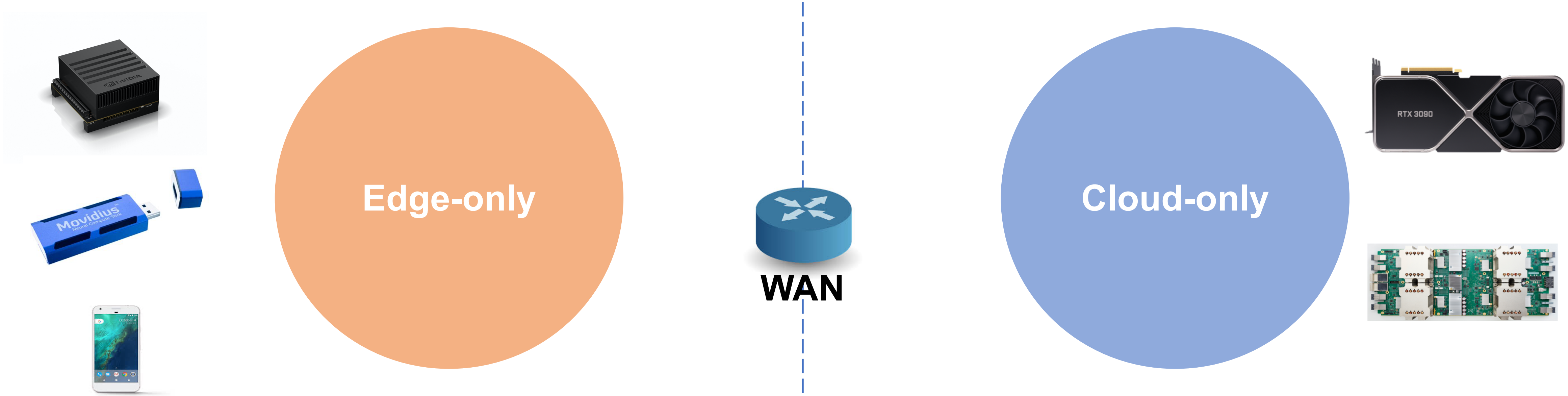


(a) Frame-based inference



(b) Window-based inference

Motivation: Design Choices



Edge-only

WAN

Cloud-only

- Faster response time
- Resource limitations; Smaller models, often lower accuracy

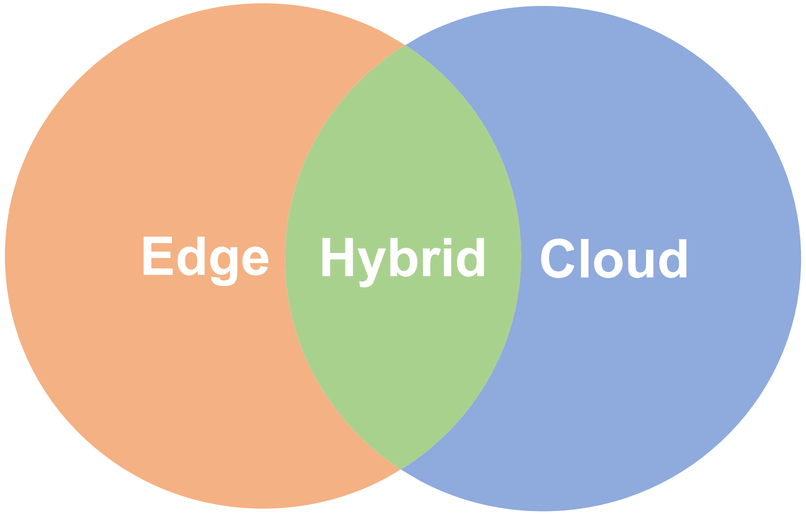
- Higher accuracy
- Streaming over WAN; Highly variable and long response time

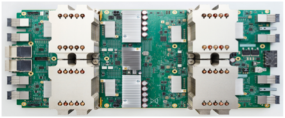
[ParkMaster, SEC’17], [Efficient-3DCNNs, CVPR’19], [Skynet, MLSys’20]

[Chameleon, SIGCOMM’18], [AWStream, SIGCOMM’18], [Nexus, SOSP’19]

Motivation: Design Choices

- How to benefit from both worlds?





- Fast response time
- High accuracy

[Glimpse, SenSys’15], [Neurosurgeon, ASPLOS’17], [FilterForward, SysML’19]

Motivation: Leverage Temporal Correlations

- Video has significant temporal correlation across frames
  e.g., an **action** may span across several frames

- Common frames across overlapping windows in window-based inference

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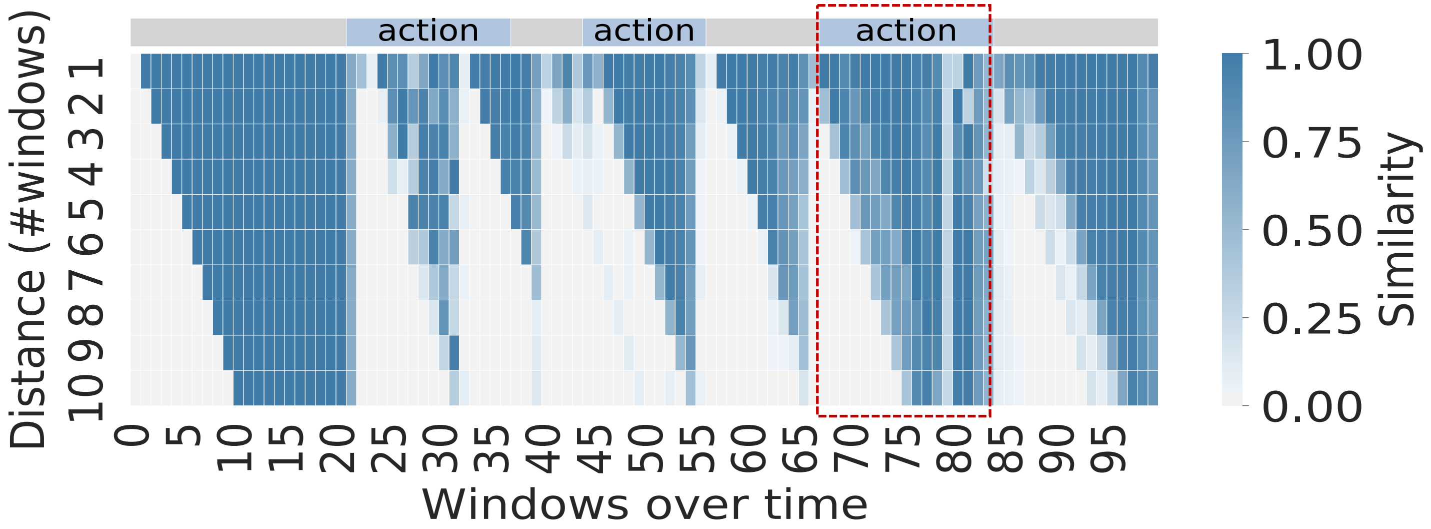


Measured using Cosine similarity

Video Stream

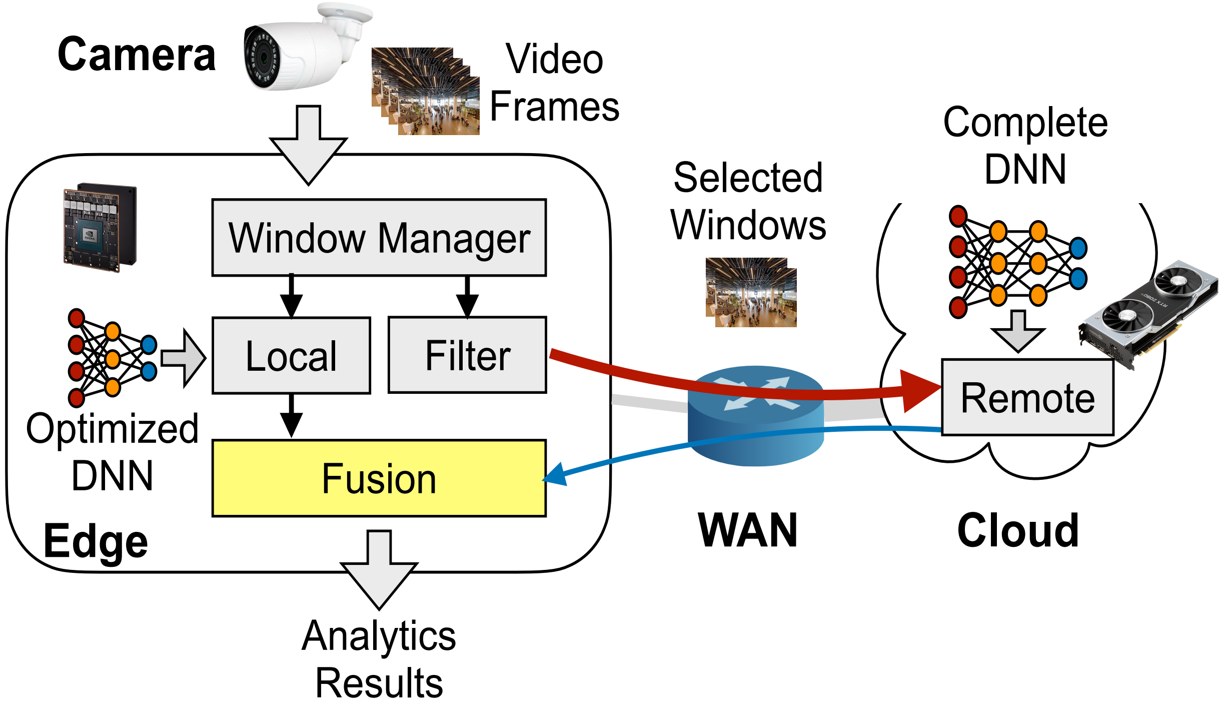
Clownfish: Architecture

Goal:

- Achieve symbiosis between edge and cloud for real-time video stream analytics

Challenges:

- How to fuse the cloud analytics results with the edge results?
- Which frames to send to the cloud?



Clownfish: Components

Edge node:

- Window Manager

  Generates frame windows

- Local

  Runs optimized (or smaller) DNN model

- Filter

  Filters out windows to be sent to cloud

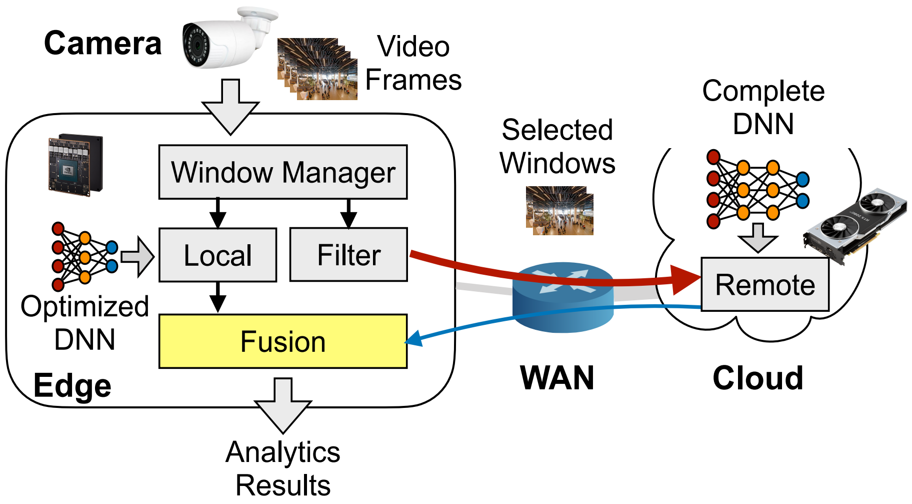
- **Fusion**

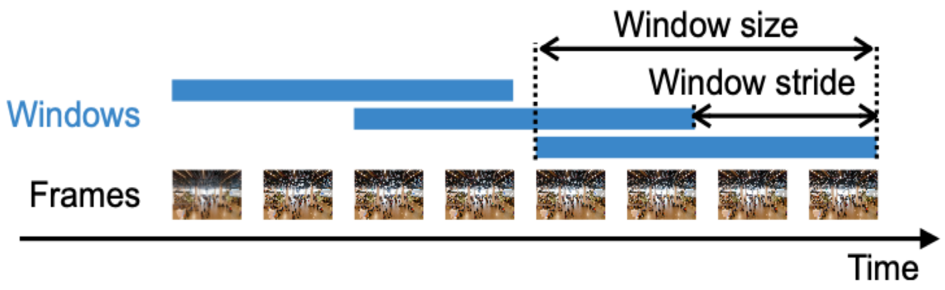
  Fuses analytics results from cloud with that of edge

Cloud node:

- Remote

  Runs complete (or bigger) DNN model

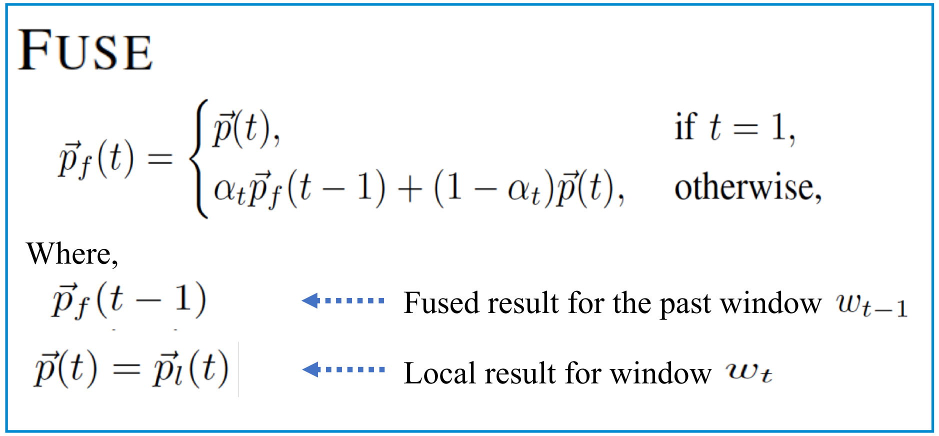




Windows generated by **Window Manager**

Clownfish: Fusion Method

- A lightweight method that runs on the edge node
- Exponential Smoothing (ES) approach to fuse past result and current local result
- $\alpha_t \in [0, 1]$ is a weight (correlation) parameter in ES for previous fused result and current local result
- Two main procedures,
  - **FUSE:** Used for real-time results fusion
  - **REINFORCE:** Updates state when remote result becomes available



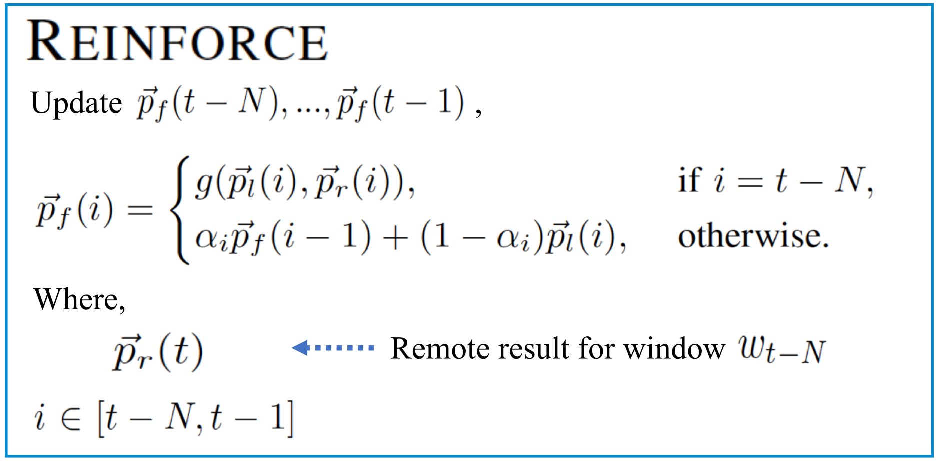
FUSE

$$\vec{p}_f(t) = \begin{cases} \vec{p}(t), & \text{if } t = 1, \\ \alpha_t \vec{p}_f(t-1) + (1-\alpha_t)\vec{p}(t), & \text{otherwise,} \end{cases}$$

Where,

$\vec{p}_f(t-1)$ ← Fused result for the past window w_{t-1}

$\vec{p}(t) = \vec{p}_l(t)$ ← Local result for window w_t



REINFORCE

Update $\vec{p}_f(t-N), ..., \vec{p}_f(t-1)$,

$$\vec{p}_f(i) = \begin{cases} g(\vec{p}_l(i), \vec{p}_r(i)), & \text{if } i = t-N, \\ \alpha_i \vec{p}_f(i-1) + (1-\alpha_i)\vec{p}_l(i), & \text{otherwise.} \end{cases}$$

Where,

$\vec{p}_r(t)$ ← Remote result for window w_{t-N}

$i \in [t-N, t-1]$

Fusion Method: Estimating Temporal Correlations

How to set value α_t ?

- Estimate correlation parameter using similarity score between two consecutive windows

- When score is high, windows have similar context
  - Assign relatively larger value for α_t , i.e., larger weight to the previous fused result

- Traditional similarity functions based on vector distance such as **Cosine**, **Euclidean** may give
  - Low correlation for the same context
  - High correlation for different contexts at context transition

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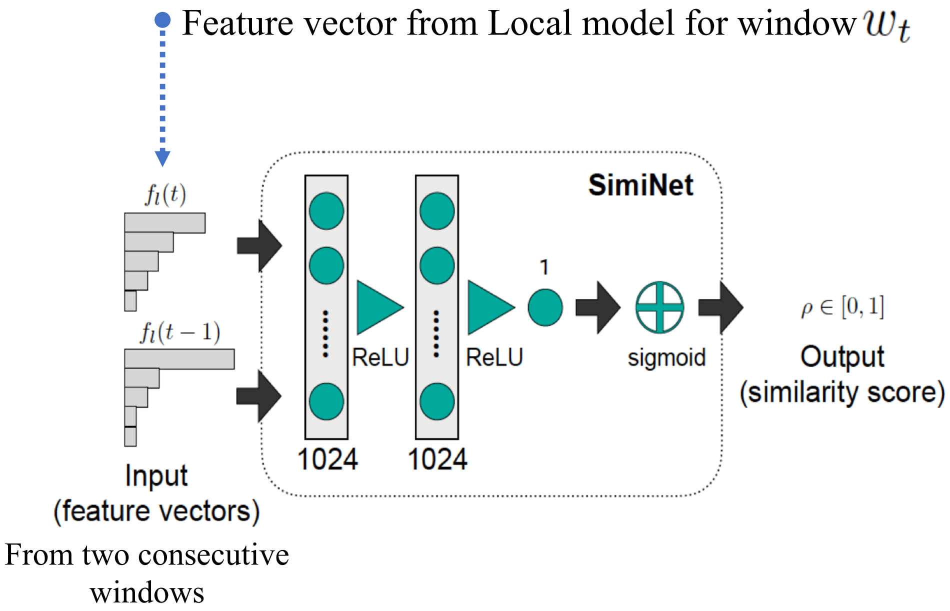

- Context similarity function using learning-based approach to capture (dis)similarity of contexts.

Clownfish: Filter

When to send windows to remote cloud?

Two context-aware policy,

- Send a window at the **start of context**.
    - Leverage similarity score to identify context transition, i.e., $\rho_t - \rho_{t-1} \geq 0.5$

- **Periodically send** windows within same context and restart periodic timer at context transition

Evaluation

Setup:

- Local model: 3D Resnet-18
- Remote model: 3D Resnext-101
- Dataset: PKU-MMD
- Task: Action Recognition

How effective is our SimiNet-based fusion method?

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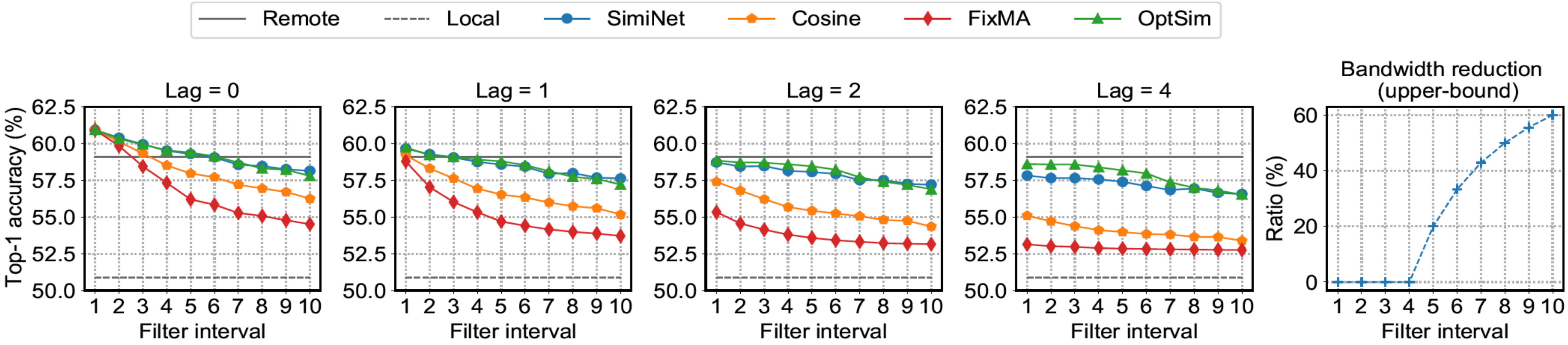

- Our **SimiNet-based** fusion method performs close to remote and accuracy gap is within 2%
- Substantial bandwidth reduction with limited penalty on accuracy

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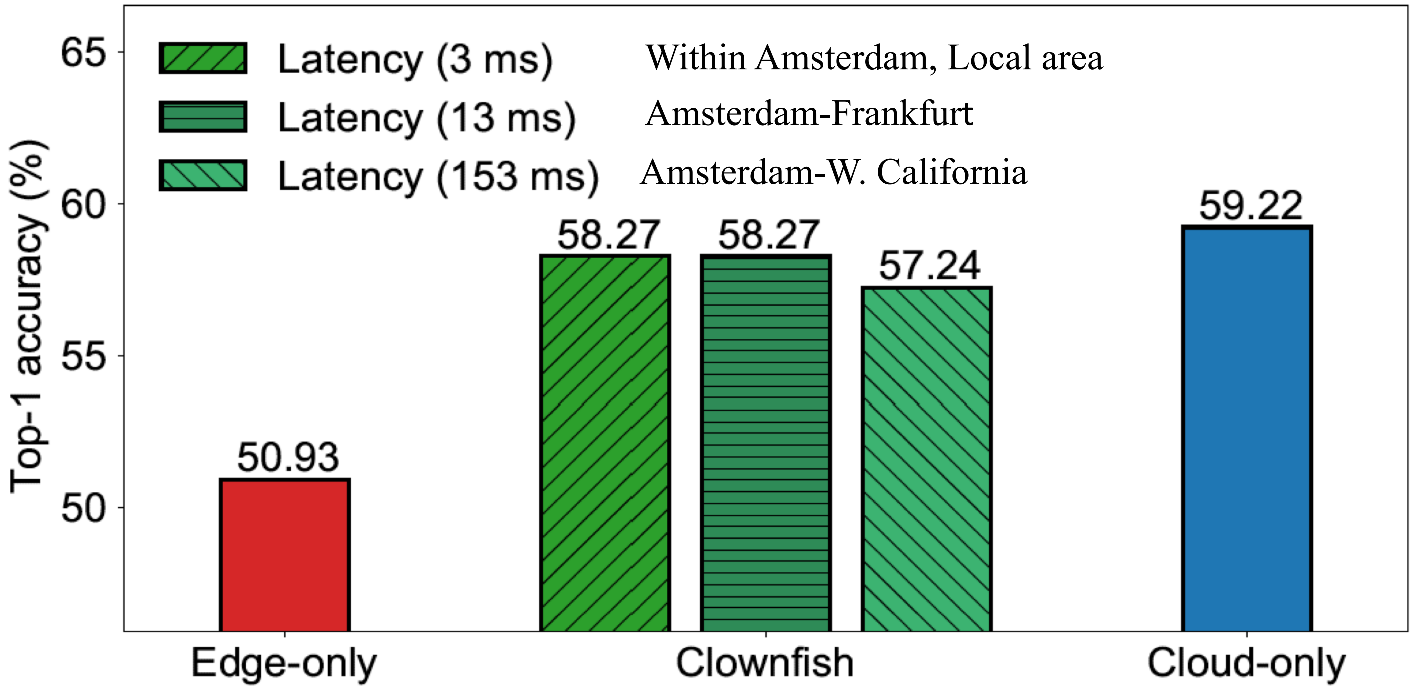
Evaluation

How does network latency affect accuracy of Clownfish?



Within Amsterdam, Local area

Amsterdam-Frankfurt

Amsterdam-W. California

- Network latency has a negligible impact on the achieved accuracy of Clownfish

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How do bandwidth conditions affect Clownfish?

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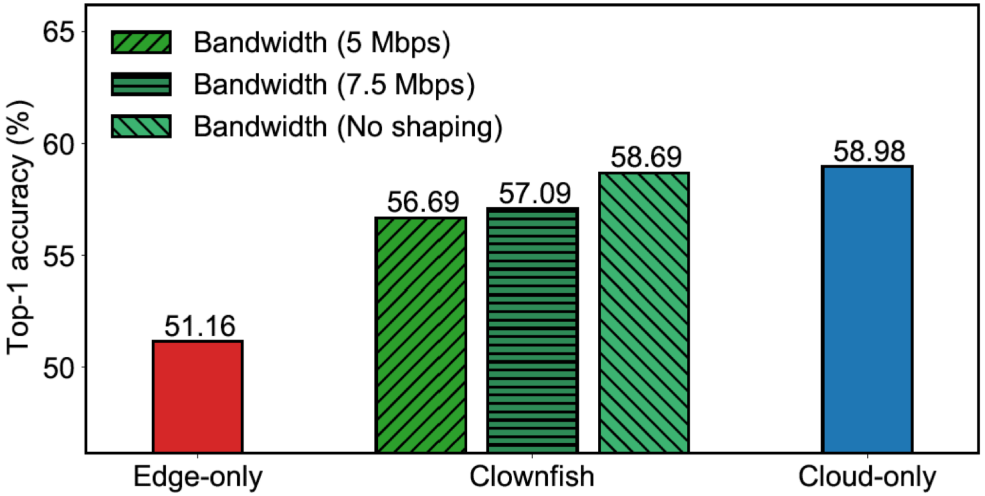
Accuracy



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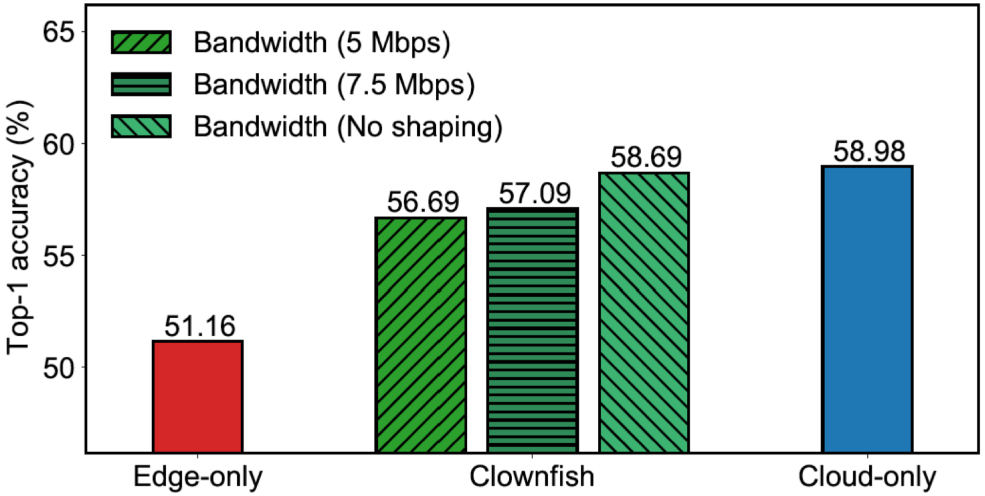
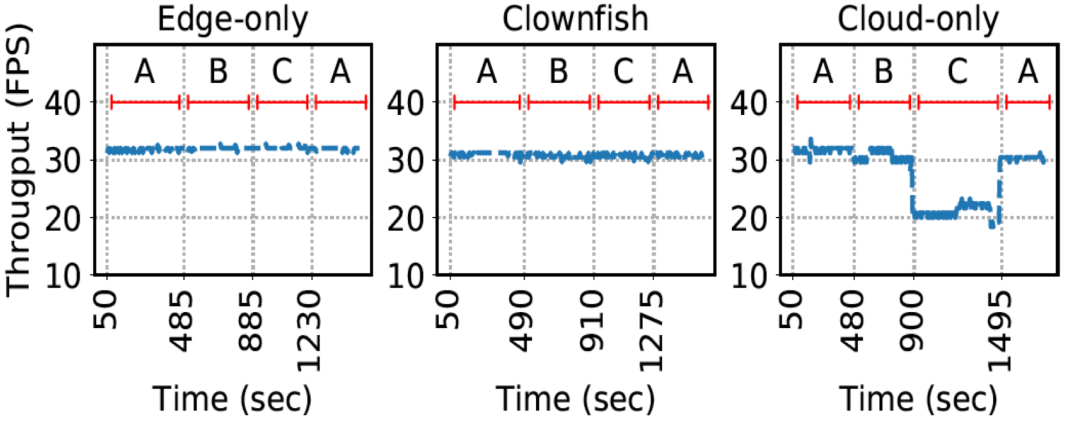


Throughput



(A: no shaping, B: 7.5Mbps, C: 5Mbps)

- Accuracy is comparable to that of cloud-only solution
- Maintains stable throughput (FPS) similar to the edge-only solution

Evaluation

How does Clownfish perform when compared to filtering-based approach, e.g., EarlyDiscard[1]?

[1] Wang, Junjue, et al. "Bandwidth-efficient live video analytics for drones via edge computing." IEEE/ACM SEC. 2018.

Evaluation

How does Clownfish perform when compared to filtering-based approach, e.g., EarlyDiscard[1]?

Solution	Accuracy
Edge-only	51.16%
EarlyDiscard	55.48%
Clownfish (7.5Mbps)	57.09%
Cloud-only	58.98%

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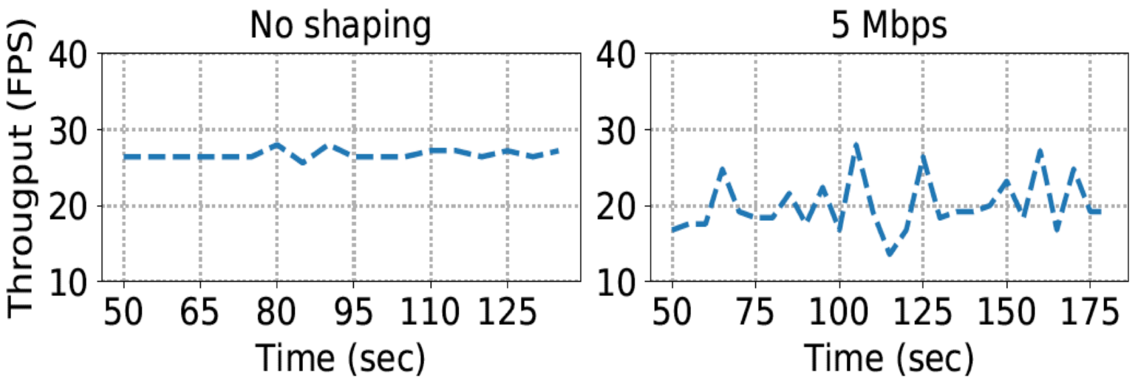
EarlyDiscard Throughput



- Clownfish outperforms EarlyDiscard in terms of accuracy and throughput

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Summary

- **Clownfish**, a hybrid framework for real-time video stream analytics that takes the benefits of edge and cloud
- Clownfish fusion method based on exponential smoothing exploits temporal correlation categorized using learning-based similarity model
- Clownfish always operates in real time like an edge-only solution and achieves high accuracy comparable to a cloud-only solution

Summary

- **Clownfish**, a hybrid framework for real-time video stream analytics that takes the benefits of edge and cloud
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For more details,

- Source code: https://github.com/vuhpdc/clownfish
- Contact: v.v.nigade@vu.nl

Thank You!