EECE5512
Networked XR Systems

Credits: Some content from VIVO and GROOT papers

Recap

- 360-Degree Video Streaming
  - Viewport Adaptation
  - Viewport Prediction
  - Tiled streaming

Lecture Outline for Today

- 4D Point Cloud Streaming to XR Devices
- Quiz
- 4D Mesh Streaming to XR Devices

Point Clouds - Recap

- A point cloud is a discrete set of data points in space.
- Or a set of 3D independent points
- Each Point (X, Y, Z) + Attributes
- Attributes: Color, Alpha, Reflectance

Point Clouds - Recap

- Representation
  - Each Point is a floating-point number – 32 bits
  - <X, Y, Z> : 96 bits
  - RGB: 3 channels: 24 bits
  - Also, has other attributes sometimes (light related)

  - Each point: 96 + 24 bits or 15 bytes

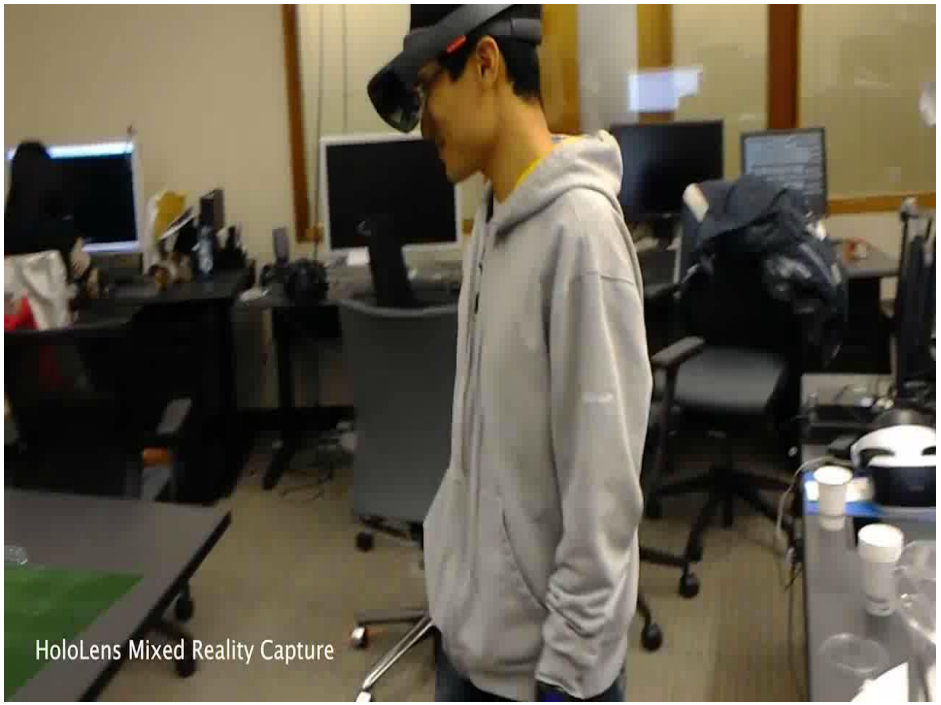
- Typically, a point cloud has thousands to millions of points – guess the data rate numbers

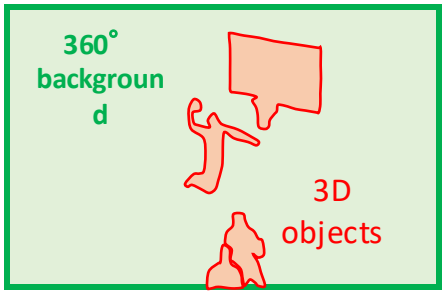
Point Cloud Streaming

Sample data numbers

	queen	longdress	loot	redandblack	soldier
Average number of points (in 300 frames)	1,005,000	834,000	794,000	727,000	1,076,000
Bitrates for transmitting uncompressed video (Mbytes/s)	514.47	542.22	490.61	448.21	681.96

Streaming Applications





1-3 Gbps per object

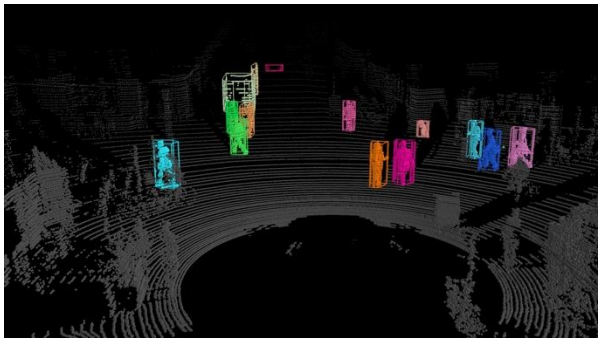
Key Challenges of Point Cloud Streaming

- Extremely data intensive – millions if not billions of points (each point 15 Bytes)
- Real-time processing requirements

- Streaming Trade-offs: Balance user experience (or downstream tasks metrics e.g., accuracy for ML apps) and available resources (e.g., network bandwidth, CPU/GPU, battery, memory)

Point Cloud Streaming

- Input: Point cloud sequence (compressed bitstreams) – Draco, MPEG GPCC or VPCC or ML based
- Output: 3D Playback
- Constraints: Compute and Network Resources
- Objective: User QoE or Machine tasks (e.g., point cloud segmentation)

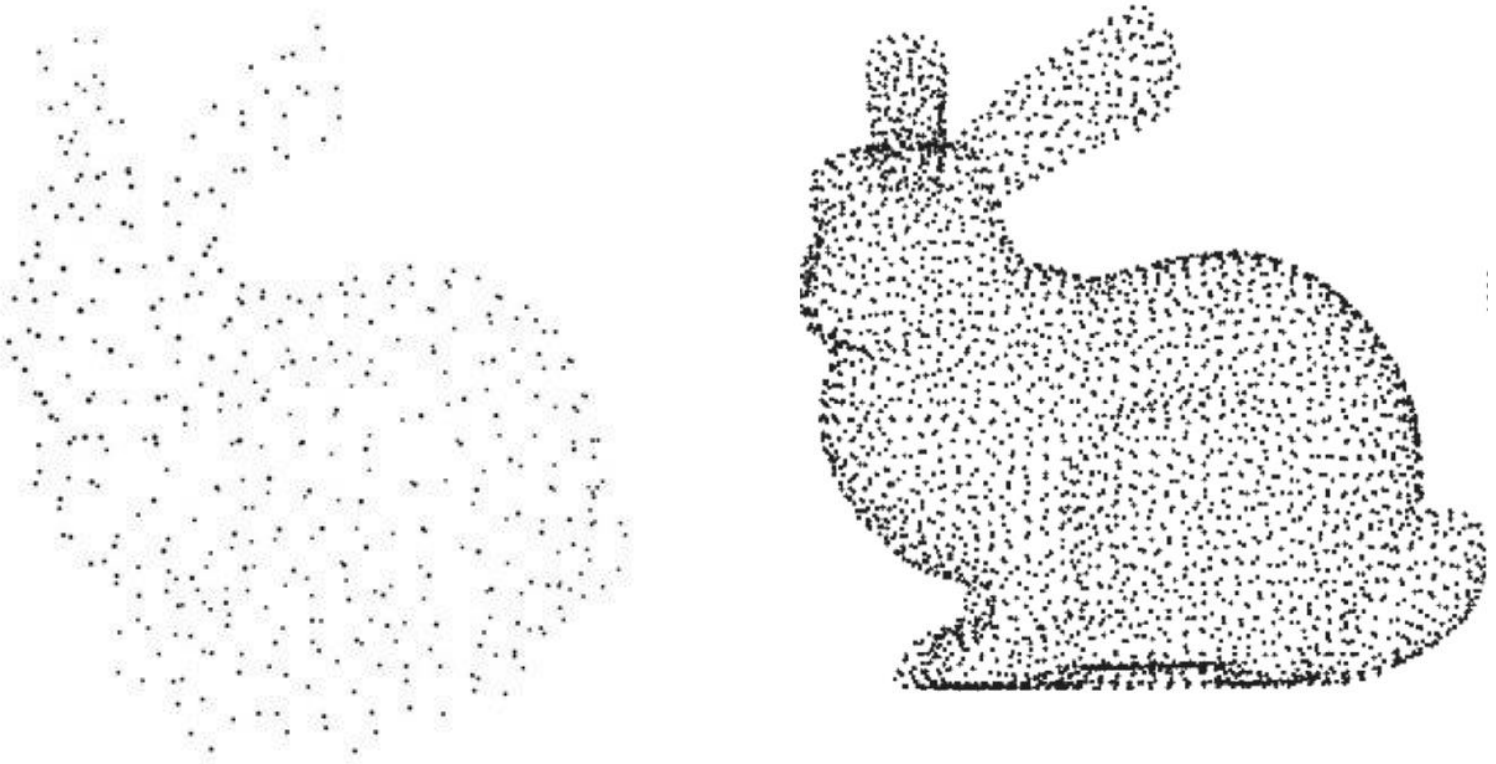


Point Cloud Streaming

- Point Cloud QoE Metrics
  - Rendered visual quality
  - Point density
  - Point size (i.e., Volume it represents)??
  - Latency
  - Frames per second
  - Distance and size of the point cloud
  - Additional metrics similar to standard videos (that we discussed in the last lecture)

Point Cloud Streaming

- Point Density



Point Cloud Streaming

- Distance and size of the object

Distance: 5m
Density: 30%

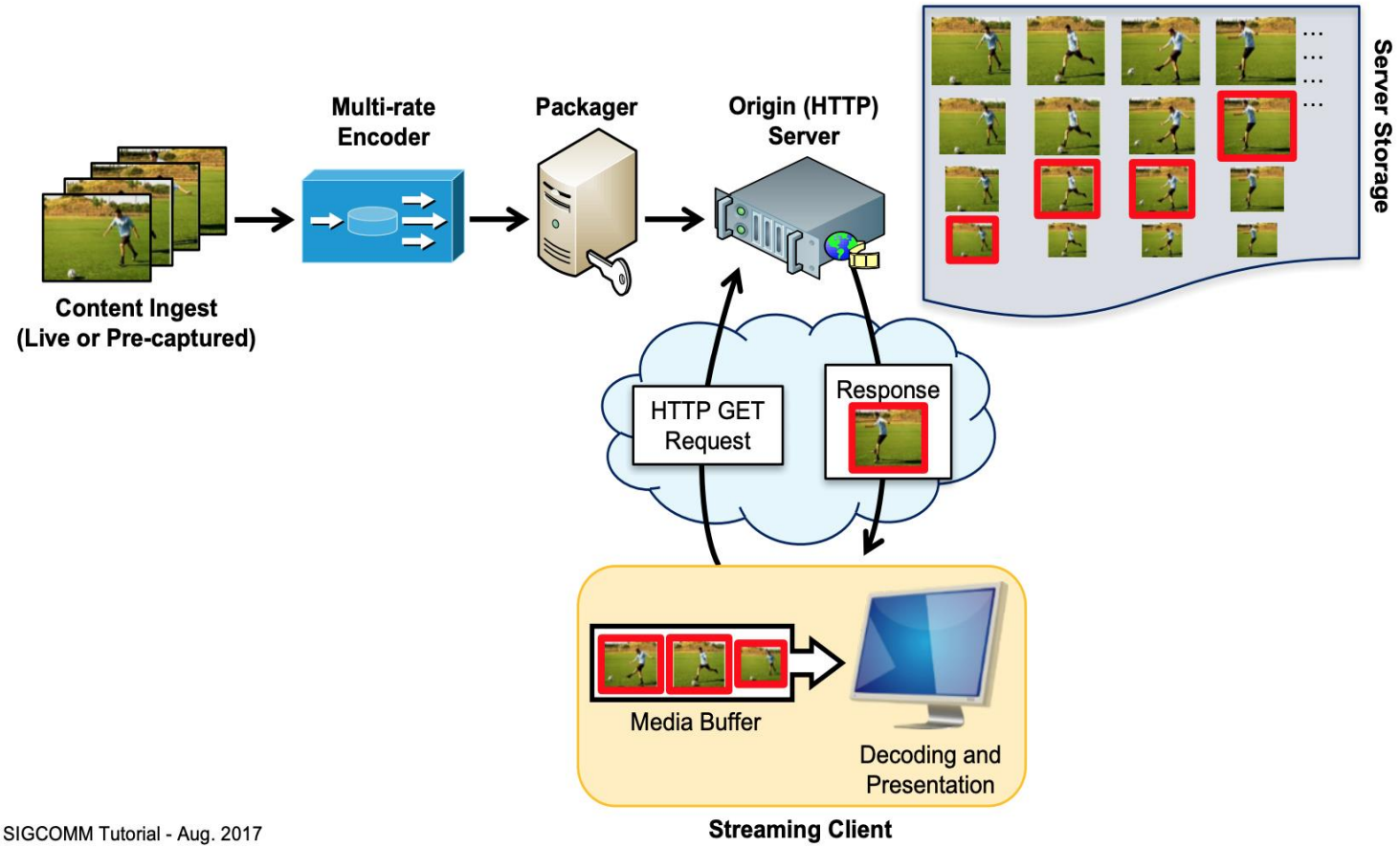
Distance: 3m
Density: 60%

Distance: 1m
Density: 90%

Point Cloud Streaming

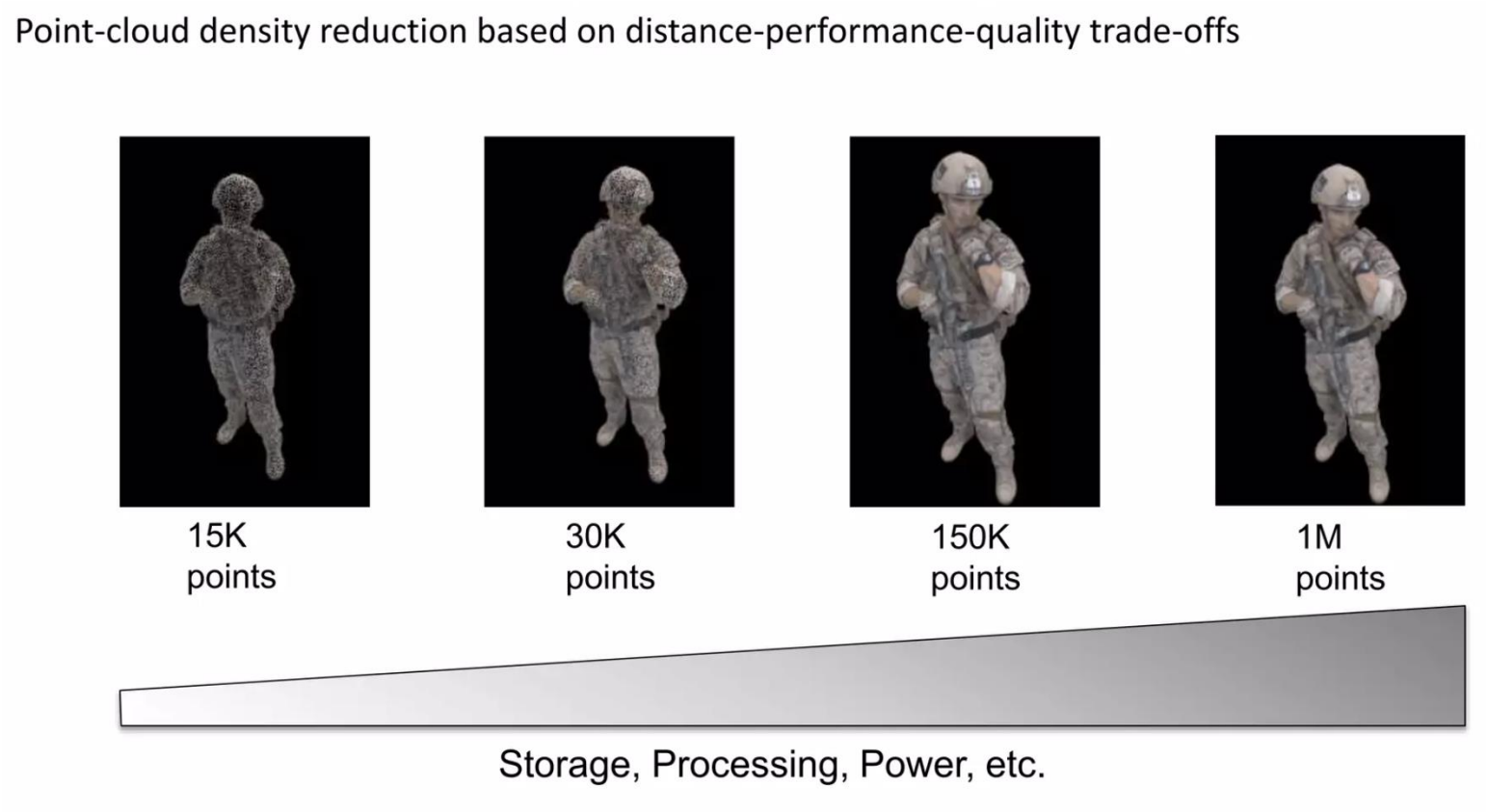
- Can we use standard video streaming protocols?
  - Remember DASH ABR Algorithms?

Point Cloud Streaming



Point Cloud Streaming

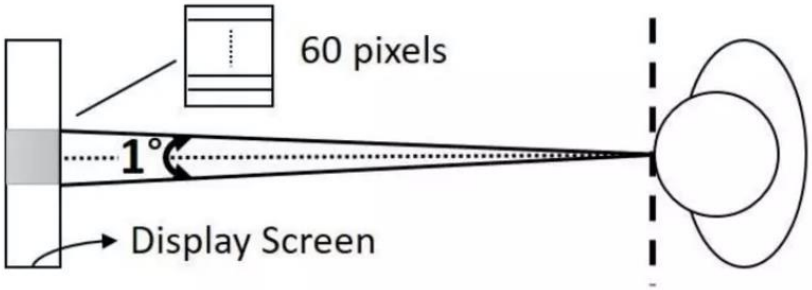
- DASH for point cloud streaming



Hosseini et.al

Point Cloud Streaming

- Quality adaptation based on distance
- Human Visual Acuity!
  - 60 Pixel per degree for adults



Hosseini et.al

$$PPI = \frac{1}{2 \times D \times tan(\frac{1}{2} \times \frac{1}{60} \times \frac{\Pi}{180})}$$

D … distance of a user from the display screen
S … scale factor of a point cloud object
D' … distance of the camera position from the centroid of the object's bounding box

Point Cloud Streaming

Figure 6: Visual view of scaled point cloud models. (left) 15K sub-sampled, (middle) 15K scaled by a ratio of $2x$, (right) 1M scaled by a ratio of $2x$.

Hosseini et.al

$$PPI = \frac{S}{2 \times (D + D') \times tan(\frac{1}{2} \times \frac{1}{60} \times \frac{pi}{180})}$$

D … distance of a user from the display screen
S … scale factor of a point cloud object
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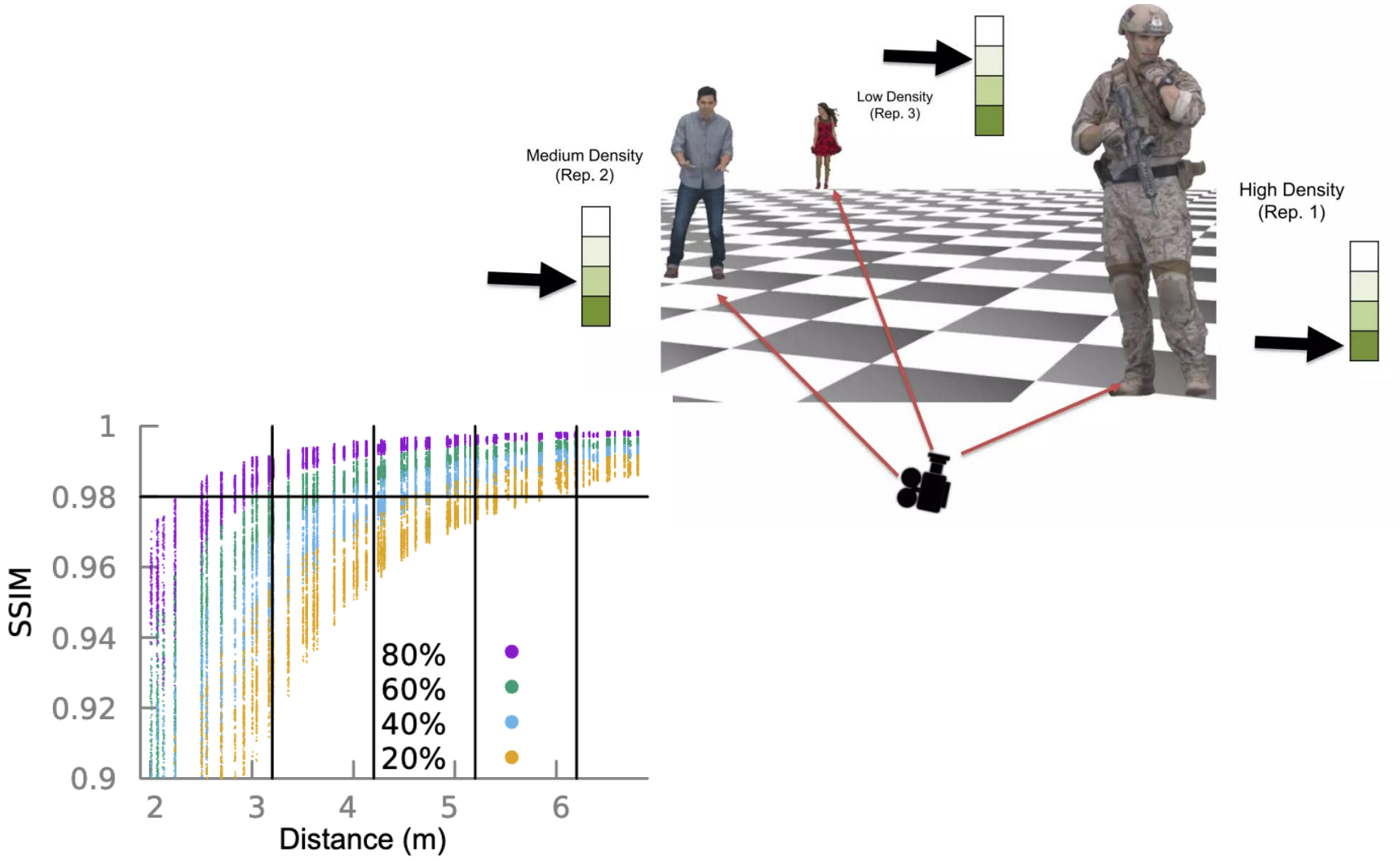
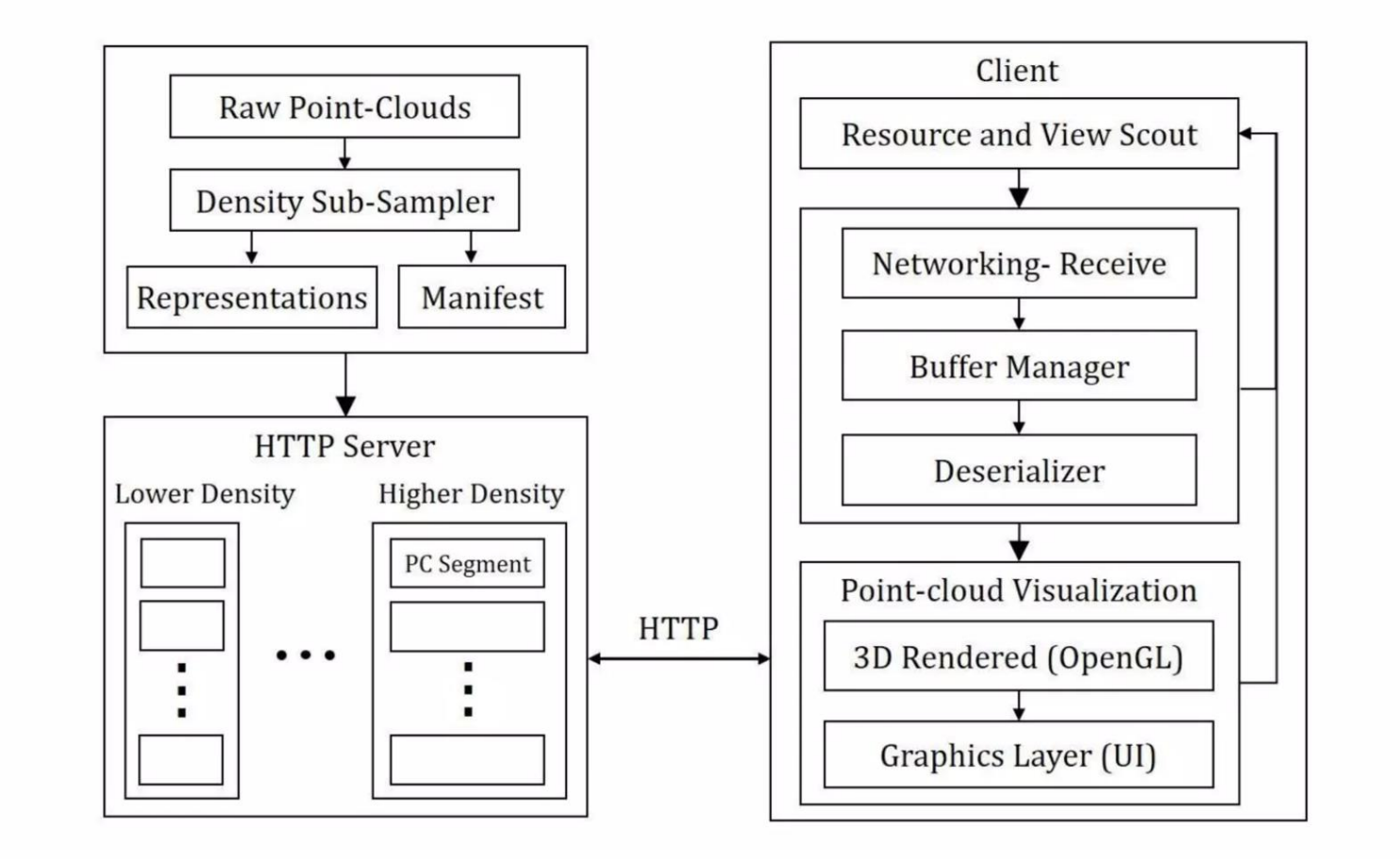
Point Cloud Streaming



Point Cloud Streaming



Point Cloud Streaming

- Similar to DASH, the adaptation feature of DASH-PC is described by an XML-formatted manifest containing metadata
- Hierarchical manifest, divided into separate PC frames. Each frame including a variety of adaptation sets:
  - Multiple quality alternatives
  - Index of each frame
  - The frame's HTTP location
  - Level of Density (LoD) representations

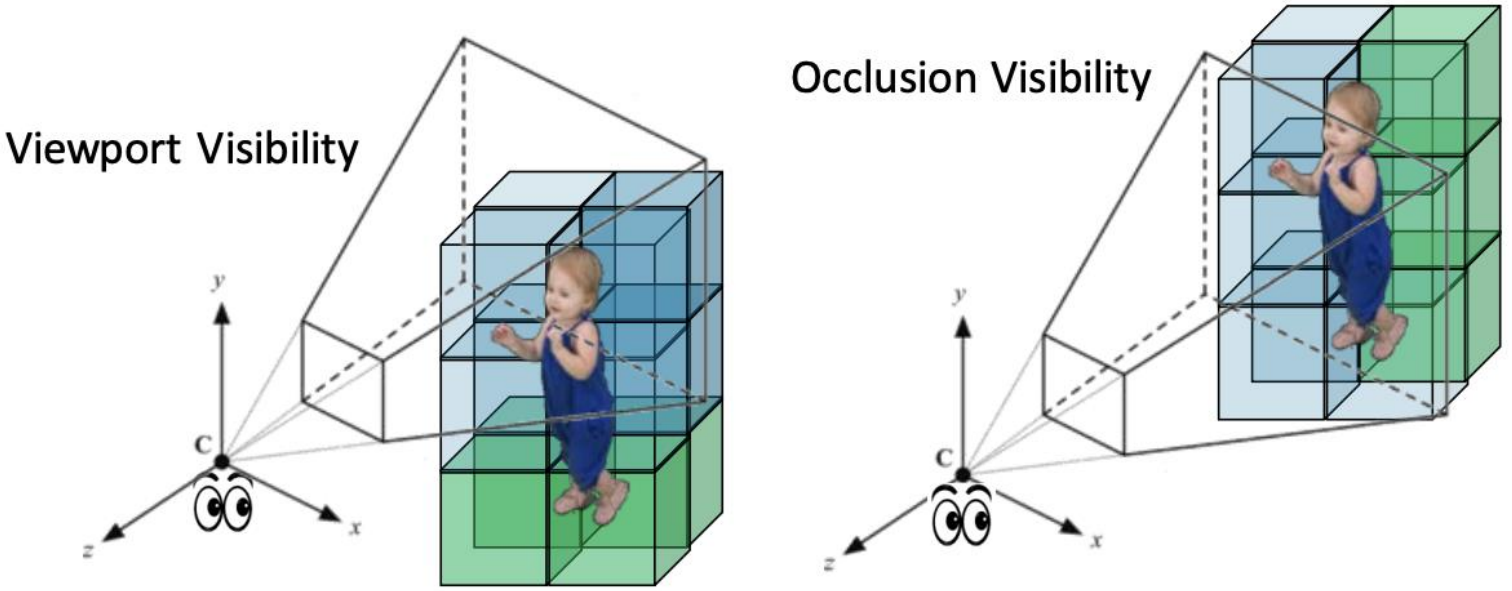
Point Cloud Streaming

- An example manifest

```
<?xml version='1.0' encoding='UTF-8'?>
<MPD format="pointcloud/ply" type="static" encoding="ASCII" frames="2" >
  <!--Created for DASH-PC, VERSION=1.0 Alpha-->
  <BaseURL>https://sra.samsung.com/dashpc/soldier/</BaseURL>
    <Frame id="0" >
        <AdaptationSet>
        <!--Point cloud-->
            <Representation density="1060000" size="22.3M" id="0">
                <BaseURL>$frameID$/$repID$.ply</BaseURL>
            </Representation>
            <Representation density="150000" size="3.92M" id="1">
                <BaseURL>$frameID$/$repID$.ply</BaseURL>
            </Representation>
            <Representation density="33000" size="872K" id="2">
                <BaseURL>$frameID$/$repID$.ply</BaseURL>
            </Representation>
        </AdaptationSet>
    </Frame>
    <Frame id="1" >
        <AdaptationSet>
        <!--Point cloud-->
            <Representation density="1200000" size="25M" id="0">
                <BaseURL>$frameID$/$repID$.ply</BaseURL>
            </Representation>
            <Representation density="165000" size="4.6M" id="1">
                <BaseURL>$frameID$/$repID$.ply</BaseURL>
            </Representation>
            <Representation density="30000" size="990K"  id="2">
                <BaseURL>$frameID$/$repID$.ply</BaseURL>
            </Representation>
        </AdaptationSet>
    </Frame>
</MPD>
```

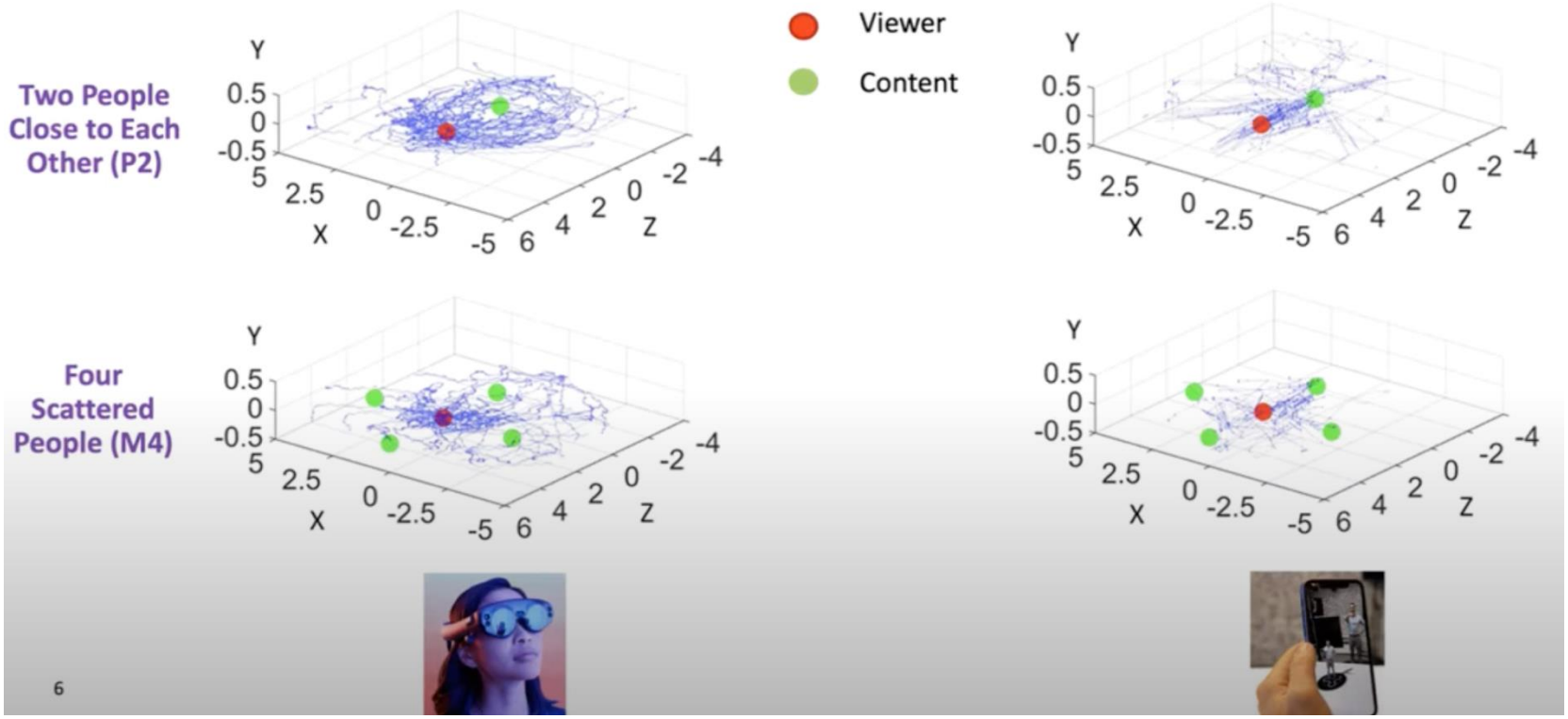
Point Cloud Streaming

- Problems with DASH-PC (above algorithm)
  - Bandwidth waste – streaming the entire PC
  - Discounts occlusion & View direction



Recall viewport adaptive 360^{o} video streaming

Point Cloud Streaming

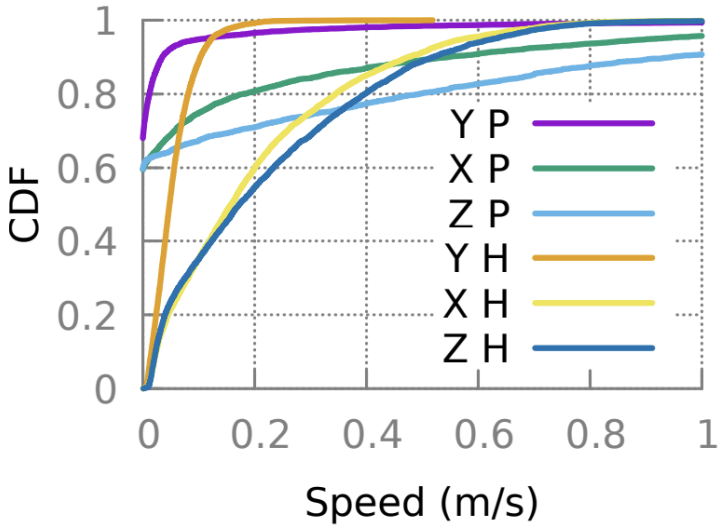


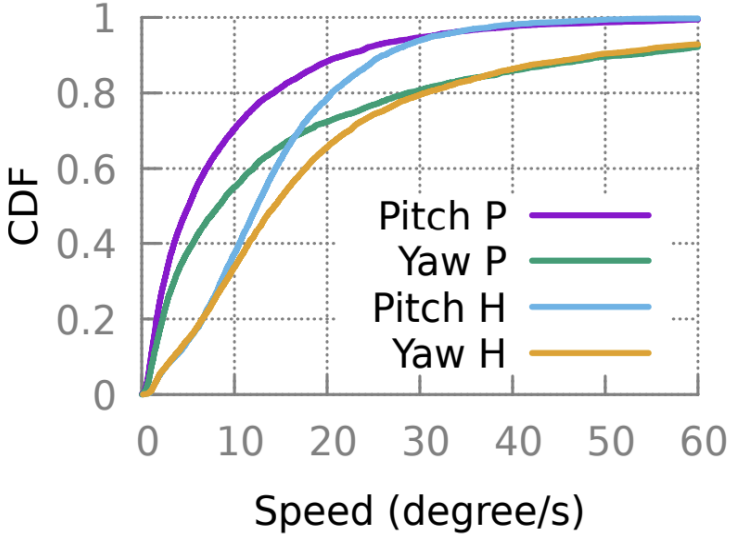
Diverse viewing angles and distances

ViVo, Mobicom'20

Point Cloud Streaming

- Translation and Rotation speeds



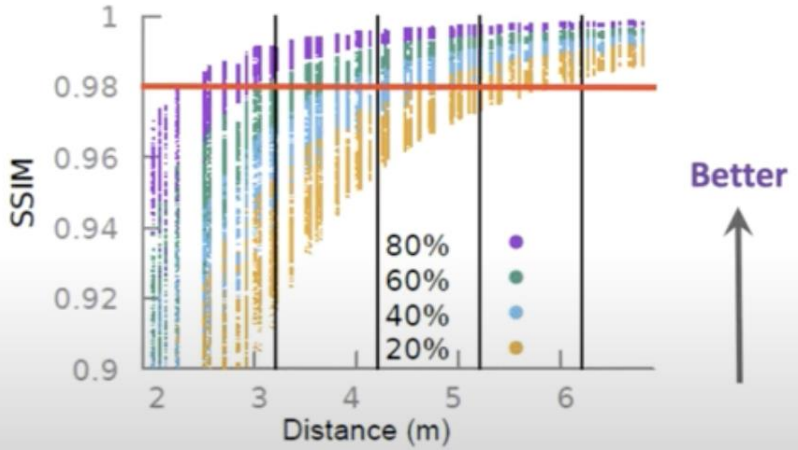


Point Cloud Streaming

- Goal: content to stream based on how, what and where viewer perceives
- Challenge: **inaccurate** prediction of future viewport
- Solution: dynamically adjusting **point density** for optimizing data traffic

Point Cloud Streaming

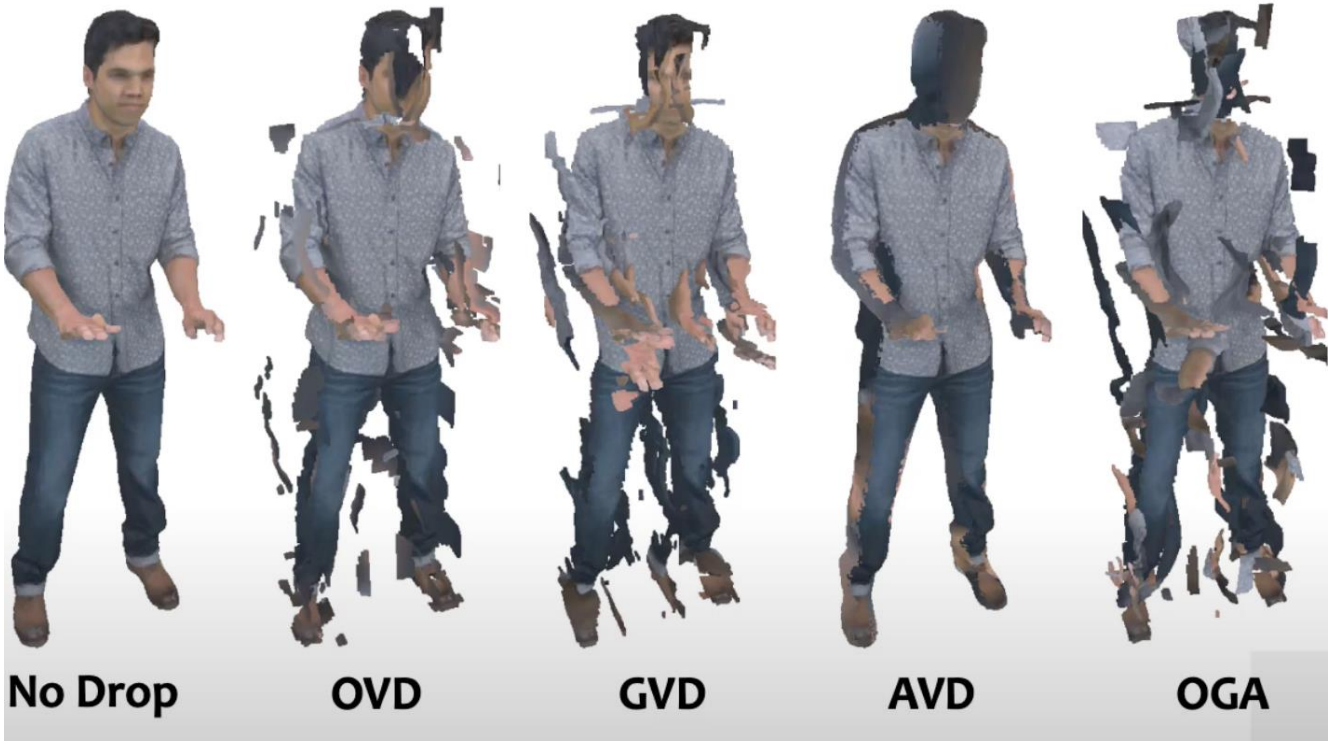
Distance Visibility



SSIM (Structural SIMilarity) for Point Clouds at Different Viewing Distances

Point Cloud Streaming

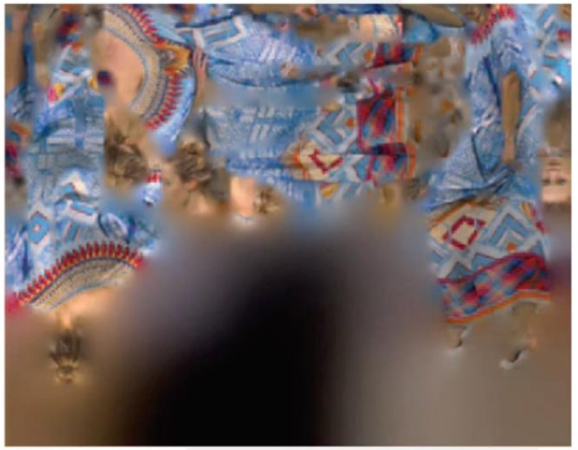
- Impact of packet loss – Error Concealment



Occupancy, Geometry, Attributes

Wu et.al, MMSYS'21

Point Cloud Streaming



Geometry: Each 3D point cloud is projected into a near and a far geometry map

Occupancy: A reduced resolution occupancy map is used to speed up the decoding process

Attribute: Multiple patches are packed into two attribute images; but their arrangements may change across point cloud frames

Wu et.al, MMSYS'21

Point Cloud Streaming

Error Concealment

- **Cause:** Copying previous image frame over may make no sense because of the (different) patch arrangements! ← in 2D space
- **Idea:** Interpolate each (missing) point with the corresponding points in the previous and next point cloud frames ← in 3D space
- **Challenge:** There is **no** info that relates a point in the previous frame to another point in the next frame → in fact, it's tricky to find the actual *physical* point
- **Solution:** Matching points using both attributes (RGB colors) and position (XYZ coord.)

Wu et.al, MMSYS'21

Point Cloud Streaming

Error Concealment

Summary of the Lecture

- Point cloud streaming
  - DASH for adaptive streaming
  - Adaptive Point Cloud Resolutions
  - Packet Loss Resiliency

Next up: Mesh Streaming