Workshop on Privacy in the Electronic Society 2025

Privacy-Aware Visual Memorability in Traffic Surveillance

Yuxin Gao, **Arani Bhattacharya**, SouYoung Jin, Shinyoung Cho

Traffic Surveillance: A Boon for Urban Planners

Traffic Surveillance

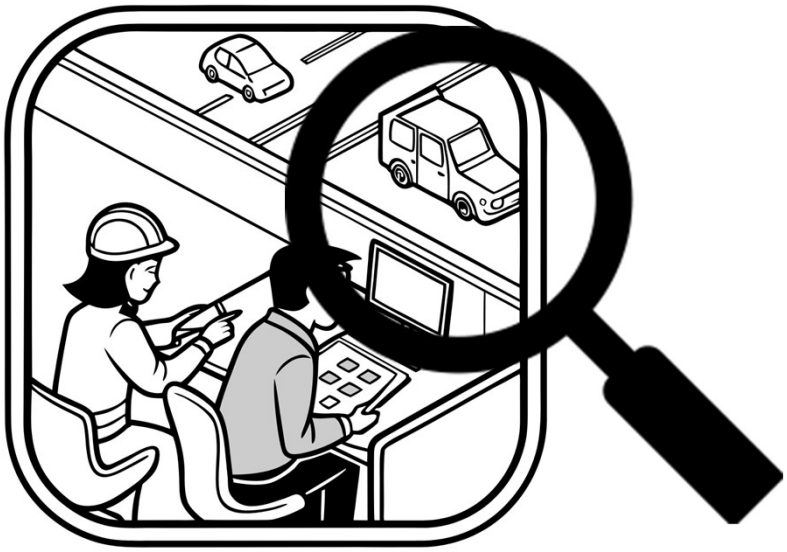
Traffic Surveillance: A Boon for Urban Planners

Traffic Surveillance

Useful for

Infrastructure Planning + Enforcement of Traffic Rules

Traffic Surveillance: A Boon for Urban Planners



Traffic Surveillance

Bumper stickers and/or political stickers often allow operators to uniquely identify objects

Traffic Surveillance: A Boon for Urban Planners

Traffic Surveillance

Bumper stickers and/or political stickers often allow operators to uniquely identify objects

MATT BURGESS | DHRUV MEHROTRA | SECURITY | OCT 3, 2024 6:30 AM

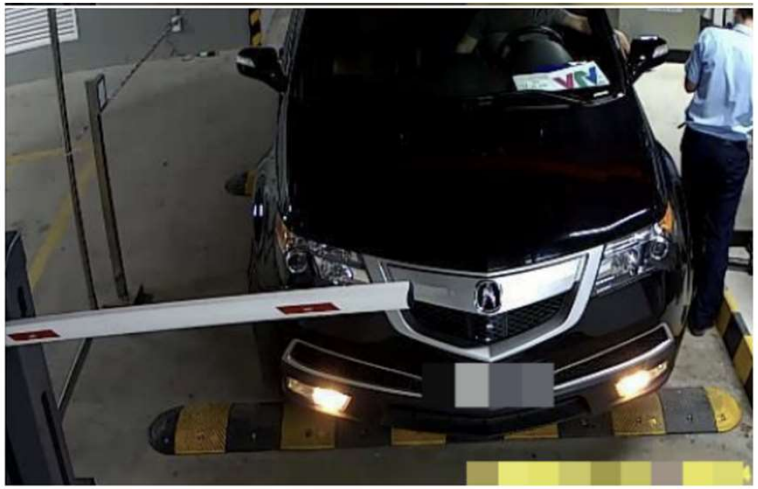
License Plate Readers Are Creating a US-Wide Database of More Than Just Cars

From Trump campaign signs to Planned Parenthood bumper stickers, license plate readers around the US are creating searchable databases that reveal Americans' political leanings and more.

… but carries significant privacy risks

Re-identification Problem

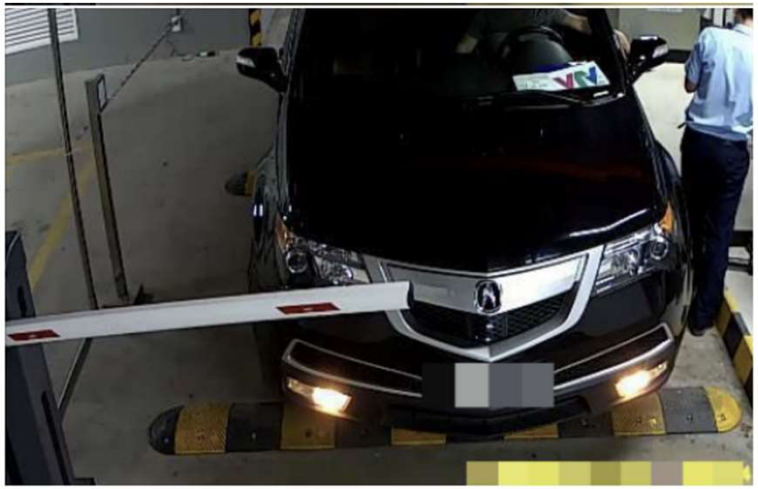
- Even with blurred faces or license plates,



@CS231

Re-identification Problem

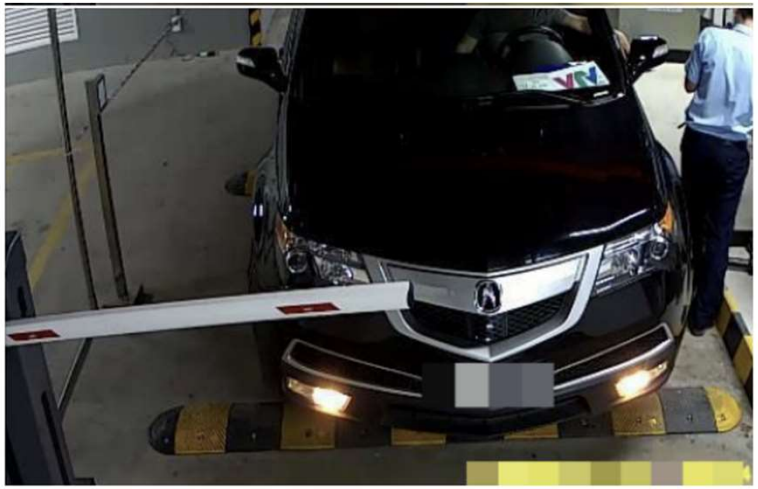
- Even with blurred faces or license plates,
  - **Vehicles can still be re-identified** through distinctive features like colors or bumper stickers



@CS231

Re-identification Problem

- Even with blurred faces or license plates,
  - **Vehicles can still be re-identified** through distinctive features like colors or bumper stickers
- Human operators may recall standout ones,
  - “the person with the vintage red convertible in the town”



@CS231

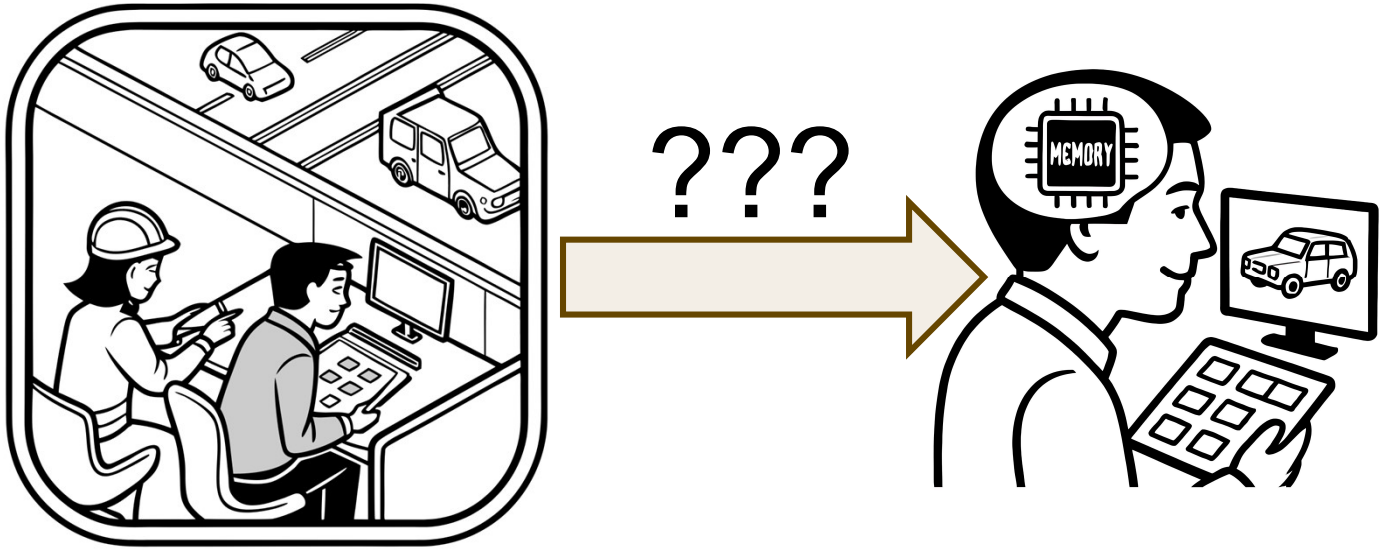
Prior Works

- Hiding private information (e.g., faces, license plates)
  - → Yet distinctive vehicles can still be re-identified

- Applying differential privacy to balance privacy and utility [Privid at NSDI 22, VideoDP at PETS 20]
  - → Protects against machine recognition, not human perception

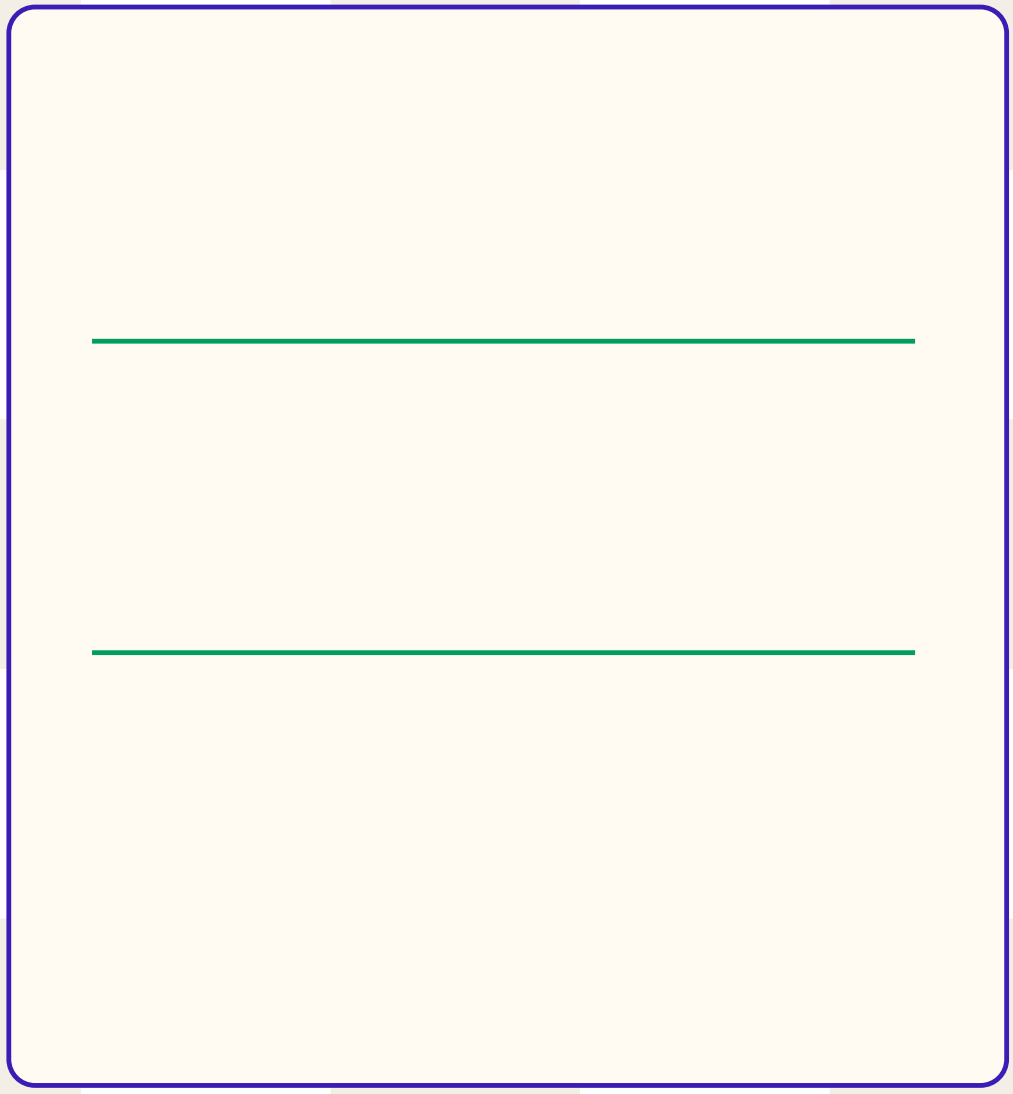
- Restricting access to unauthorized users [SCVS at ACM TiOT 22]
  - → Honest-but-curious observers learn identifiable patterns

Our Research Focus



What factors make certain vehicles more memorable than others in traffic surveillance videos?

Contributions



Contributions

Analyze why some vehicles are more memorable in traffic footage

Contributions

Analyze why some vehicles are more memorable in traffic footage

Develop a pipeline to estimate object-level memorability

Contributions

Analyze why some vehicles are more memorable in traffic footage

Develop a pipeline to estimate object-level memorability

Introduce visual memorability as a privacy-relevant factor

Our Threat Model

- Honest-but-curious human observers with legitimate video access

Our Threat Model

- Honest-but-curious human observers with legitimate video access
  - e.g., System operators
  - Reply on human perception and memory, not automated tracking

Our Threat Model

- Honest-but-curious human observers with legitimate video access
  - e.g., System operators
  - Reply on human perception and memory, not automated tracking
- Privacy Risk
  - Unique vehicles become easily remembered and re-identified
  - Leads to associations with specific people or routines
  - Existing methods guard against machines. not human observers

Memorability

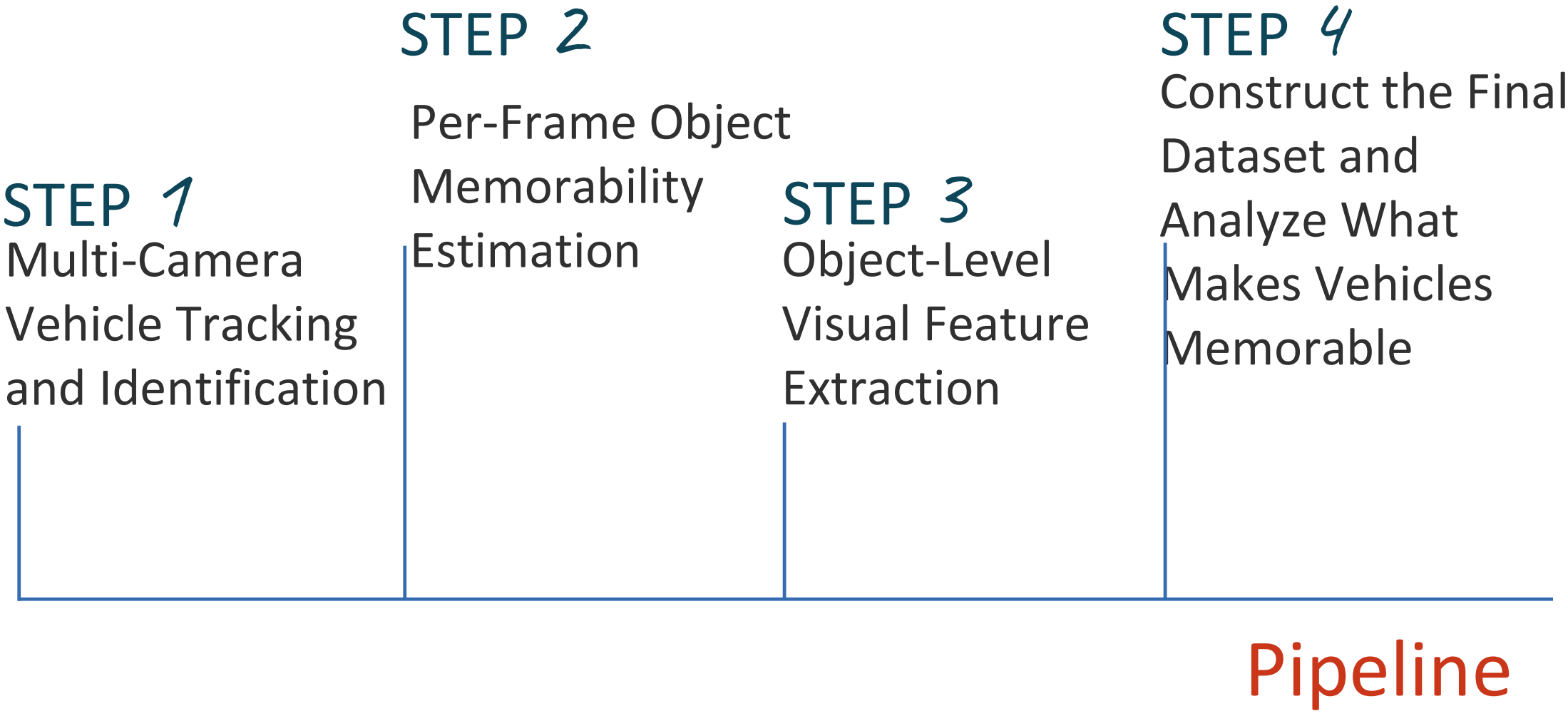
- Salient visual features capture attention and memory

- Some images are objectively more memorable even across different people

- **Memorability is a stable property of an image shared across viewers**
  (Isola et al., CVPR 2011)

a) Most memorable images (86%)

c) Least memorable images (34%)


STEP 1
Multi-Camera Vehicle Tracking and Identification
STEP 2
Per-Frame Object Memorability Estimation
STEP 3
Object-Level Visual Feature Extraction
STEP 4
Construct the Final Dataset and Analyze What Makes Vehicles Memorable
Pipeline

Step 1: Tracking Vehicles Across Cameras

- **Tracking Framework**: Multi Target Multi Camera Tracking (MTMC)
  1st place solution by Liu et al. in 2021 NVIDIA AI City Challenge
  - Vehicle detection with YOLO
  - ReID feature extraction during single-camera tracking
  - Cross-camera association

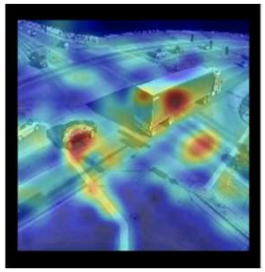
- **Integrates** detection, intra-camera tracking, cross-camera association
  - Generates standardized annotations: object ID, camera ID, frame ID, bounding box

Step 2: Estimate Object-Level Memorability

- Apply **AMNet** to generate spatial attention maps per frame
  - These maps highlight regions that contribute most to predicted memorability (a proxy for memorability)

- For each vehicle, align vehicle bounding boxes with attention maps; compute mean attention intensity as memorability score

- **Output**: Aggregate scores across frames to obtain object-level, time-indexed memorability



Step 3: Extract Object-Level Features

- For each vehicle object, we extract visual features including:
  - Color (predicted using image-based classifier)
  - Size (bounding box area)
  - Position (center coordinates)
- Match each feature to object's memorability scores across frames

Step 4: Integration and Analysis

- **Integrate** MTMC tracking data, memorability scores, and visual features into a unified dataset

- Each record includes tracking info, spatial features (area, position), color, and memorability score

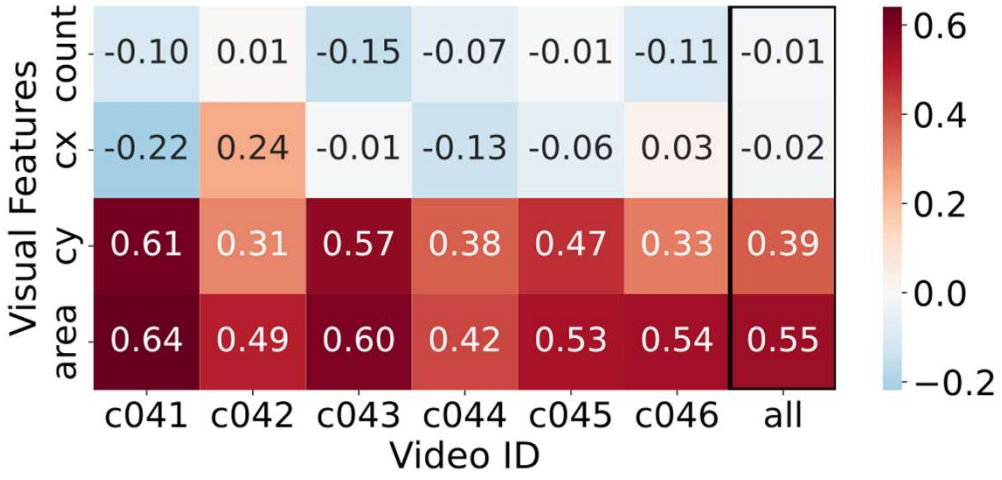
- Enables statistical analysis of visual attributes influencing vehicle memorability

Analysis: Geometric Feature Analysis

- **Spearman correlation** between visual features and vehicle memorability scores

- Area and vertical position (cy) show strong positive correlations

- Horizontal position (cx) shows little to no effect



- Suggests larger and lower-positioned vehicles are more memorable → Supports visual salience theory

Analysis: Color Distinctiveness

- Analyzed average memorability scores across vehicle colors
- Uncommon colors (yellow, brown, silver) → higher memorability
  - Common colors (black, white) → lower memorability
- Distinctiveness drives attention

- Limitation: color classifier may miss perceptual nuances (e.g., brightness, glossiness)

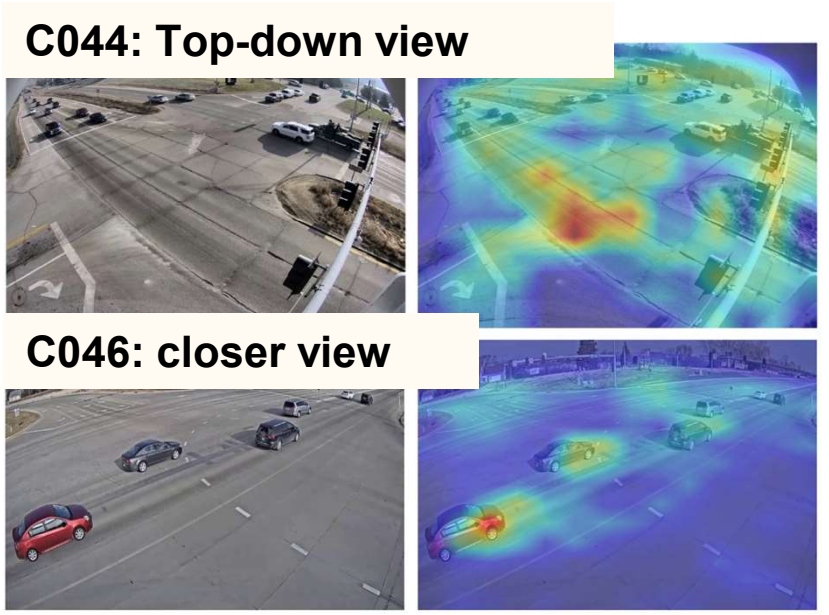
Analysis: Multivariate Memorability Modeling

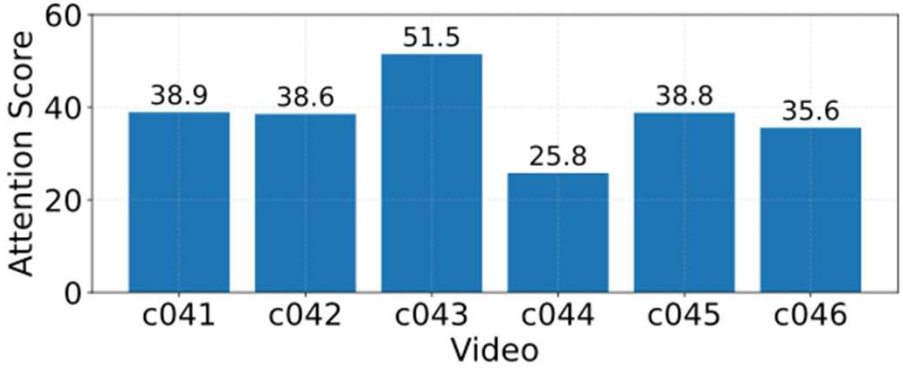
- Built hierarchical regression models adding visual feature groups step by step
- Adding visual features improves prediction accuracy
- Size x position interaction drives major gain
- Color improves fit, object count does not

Model	**Formula**	**Adj R^2**
Model 1	$area$	0.184
Model 2	$area + cx + cy$	0.202
Model 3	$area * cx * cy$	0.254
Model 4	$area * cx * cy + \mathrm{C}(color)$	**0.279**
Model 5	$area * cx * cy + \mathrm{C}(color) + objectCount$	**0.279**

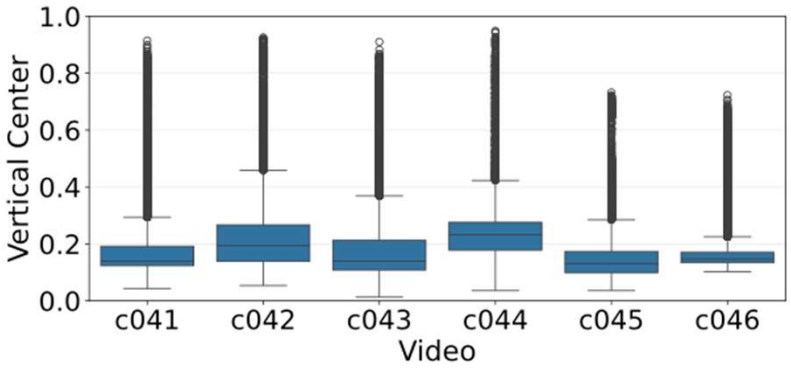
Analysis: Viewpoint Effects

- Lower/Frontal view → higher memorability
- Top-down views → lower memorability
- Camera angle & framing shape attention and privacy



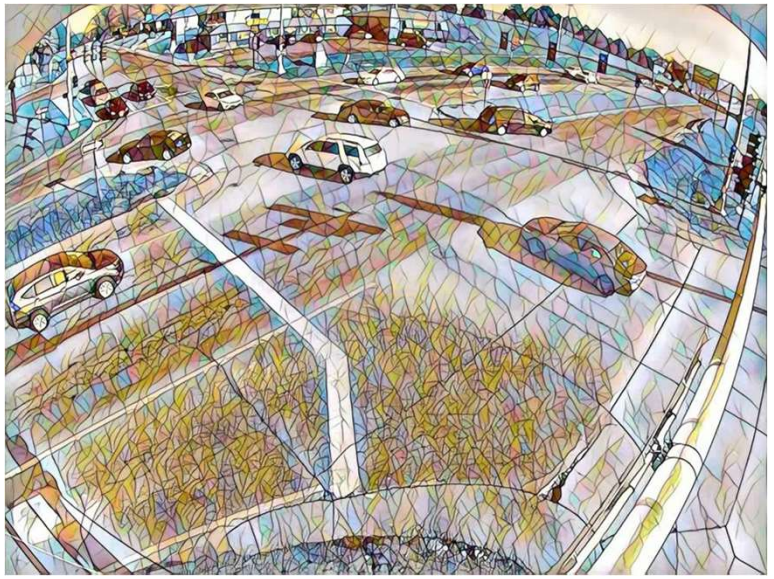


Analysis: Viewpoint Effects (cont'd)

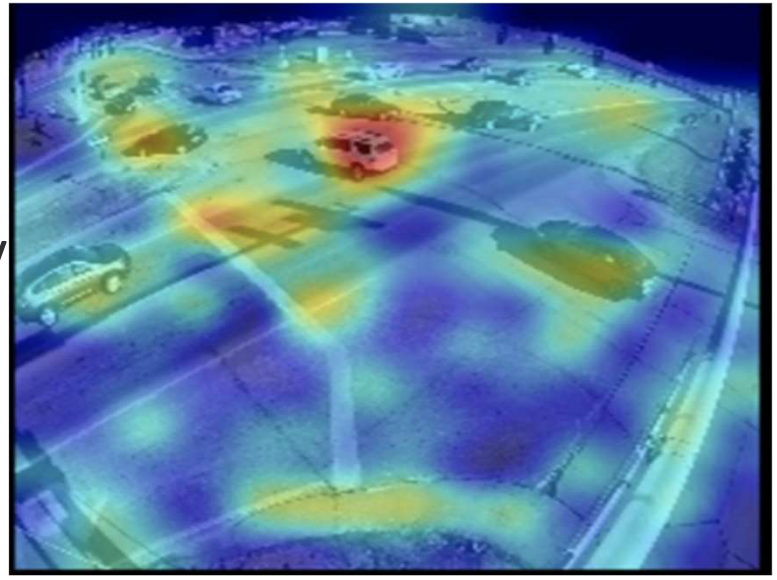


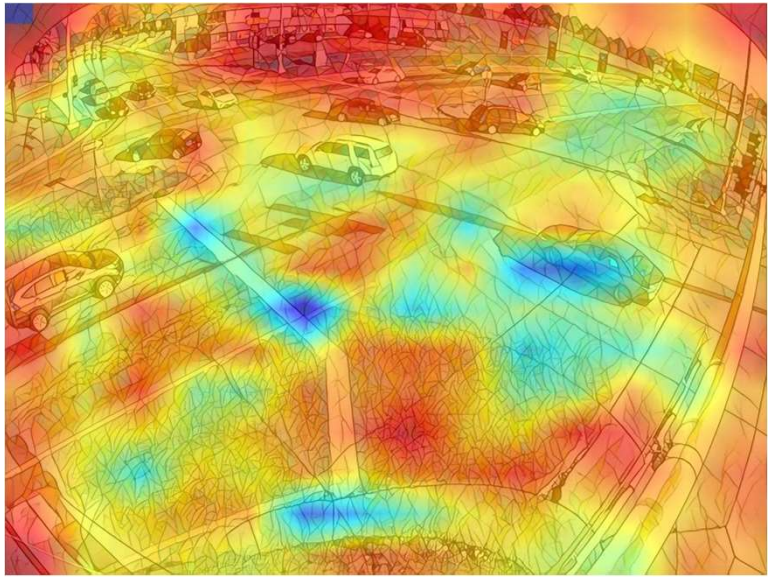
•

Style Transfer



Mosaic stylization diffuses visual attention across the frame





Suggests a potential privacy enhancement by lowering vehicle salience

Key Takeaways

Some vehicles are consistently more memorable than others

Simple visual features affect memorability

Visual transformations can alter object memorability and thus, help protect privacy

THANK YOU!