High-Quality Activity-Level Video Advertising

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\textsuperscript{2}Tencent Marketing Solution
• Introduction
  • Multimodal Content Embedding
  • Activity-Level Video Advertising
  • Evaluation
  • Conclusion
Introduction

Billion-Dollar Business
2020 Video Advertising Market Volume

Top 5

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Revenue (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>United States</td>
<td>10,857m</td>
</tr>
<tr>
<td>2.</td>
<td>China</td>
<td>5,897m</td>
</tr>
<tr>
<td>3.</td>
<td>Japan</td>
<td>2,153m</td>
</tr>
<tr>
<td>4.</td>
<td>United Kingdom</td>
<td>1,222m</td>
</tr>
<tr>
<td>5.</td>
<td>Germany</td>
<td>1,035m</td>
</tr>
</tbody>
</table>

https://www.statista.com/outlook/218/109/video-advertising/united-states#market-globalRevenue
Introduction

Video Advertising Formats

- Skippable In-Stream Ads
- Non-Skippable In-Stream Ads
- Video Discovery Ads
- Bumper Ads
- Out-Stream Ads
- Masthead Ads

https://support.google.com/google-ads/answer/2375464?hl=en
Introduction

Low CTR Compared with Traditional Ads

Youtube 0.38% << AdWords 3.17%

https://blog.adstage.io/youtube-benchmarks-cpc-cpm-and-ctr
https://www.wordstream.com/blog/ws/2016/02/29/google-adwords-industry-benchmarks
Content-Related Video Advertising

Will you marry me?

Diamond Rings
White Sapphire 58...
HK$3,928.00
Glamira HK

Matched Ads Demands

Jewelry Company

Tourism Product

Wedding Dress

LoveShackFancy
Irene Gown in Whi...
HK$9,262.70
revolve.com
Introduction

Content-Related Video Advertising

Will you marry me?

Matched Ads Demands
- Jewelry Company
- Tourism Product
- Wedding Dress
Introduction

Activity-Level Video Advertising

ActVA

Will you marry me?

Matched Ads Demands
- Jewelry Company
- Tourism Product
- Wedding Dress
Introduction

Activity-Level Video Advertising

Main Contributions

1. The first non-predefined activity-level video advertising system;
2. Effective algorithm for optimizing advertising service over content relevance, revenue and intrusiveness perception.
Introduction

Activity-Level Video Advertising
System Framework

Step#1: Find possible ads positions.
Step#2: Assign ads properly.
• Introduction

• Multimodal Content Embedding

• Activity-Level Video Advertising

• Evaluation

• Conclusion
Multimodal Content Embedding

Market Research @ Tencent

150 Content-Targeted Advertising Needs

Necessary Information for Ads Demands

- Celebrity Identity: 6%
- Object: 17%
- Scene: 10%
- Subtitle Keywords: 22%
- Human Behavior: 45%

Celebrity Identity
Object
Scene
Subtitle Keywords
Human Behavior
Both visual & textual information matter.

### Necessary Information for Ads Demands

- **Celebrity Identity**: 6%
- **Object**: 17%
- **Scene**: 10%
- **Subtitle Keywords**: 22%
- **Human Behavior**: 45%

Both visual & textual information matter.

**Market Research @ Tencent**

**150 Content-Targeted Advertising Demands**
Multimodal Content Embedding

Key Frame Detection

Color-Histogram based Shot Detection

Visual Shot — Textual Shot

S1 — S2 — S3 — S4 — S5 — S6

Activity-Level Video Advertising

Activity Similarity

Assigning Algorithm

A1 — A2 — A3 — A4
Multimodal Content Embedding

Key Frame Detection

- Video
- Subtitle
- Advertising Query
- Key Frame Detection
- Atom Feature Extraction
- Activity Graph
- Activity-Level Video Advertising
  - Activity Similarity
  - Assigning Algorithm

Start-End Timestamps in Subtitles

Visual Shot
Textual Shot

S1  S2  S3  S4  S5  S6
Multimodal Content Embedding

Key Frame Detection

Multimodal Content Embedding

Video
Subtitle
Advertising Query

Key Frame Detection

Atom Feature Extraction
Activity Graph

Activity-Level Video Advertising
Activity Similarity
Assigning Algorithm

Semantic Shots
uniformly k-sampling in each shot
Multimodal Content Embedding

Atom Feature Extraction

- Video
- Subtitle
- Advertising Query

Multimodal Content Embedding

- Key Frame Detection
- Atom Feature Extraction
- Activity Graph

Activity-Level Video Advertising
- Activity Similarity
- Assigning Algorithm

- Face Detection and Encoding
- Object Detection
- Scene Classification
- Human Pose Encoding
- Keyword Extraction

$F \in \mathbb{R}^{128}$

$O \in \mathbb{R}^{80}$

$S \in \mathbb{R}^{365}$

$P \in (\mathbb{R}\times\mathbb{R})^{17}$

$K$: BoW model
Multimodal Content Embedding

Activity Graph Representation

Vertices

\[ F \in \mathbb{R}^{128} \]
\[ O \in \mathbb{R}^{80} \]
\[ S \in \mathbb{R}^{365} \]
\[ P \in (\mathbb{R} \times \mathbb{R})^{17} \]

\( K: \text{BoW model} \)
**Multimodal Content Embedding**

**Activity Graph Representation**

Edges

- **Pose-Pose Interaction**
  \[ R_{pp} : P \times P \to \mathbb{N} \]

- **Pose-Object Interaction**
  \[ R_{po} : P \times O \to \mathbb{N} \]

- **Pose-Face Matching**
  \[ R_{pf} : P \times F \to \mathbb{N} \]

- **Pose-Scene Correlation**
  \[ R_{ps} : P \times S \to \mathbb{R} \]

(b) Interaction samples.

Will you marry me?
Multimodal Content Embedding

Activity Graph Representation

Multimodal Content Embedding

Video
Subtitle
Advertising Query

Key Frame Detection
Atom Feature
Activity Graph

Activity-Level Video Advertising

Activity Similarity
Assigning Algorithm

matched Ads
 Demands

Jewelry Company
Tourism Product
Wedding Dress

Will you marry me?

marry, travel, jewelry, ...
• Introduction
• Multimodal Content Embedding
• **Activity-Level Video Advertising**
• Evaluation
• Conclusion
Activity-Level Video Advertising

Activity Similarity

Atom-Feature / Vertex Similarity

Interaction / Edge Similarity

Face / Human Pose

\[ x = (\text{encoding}, \text{confidence}) \]

\[
\begin{align*}
    s_1(x_1, x_2) &= 1 - \frac{1}{|\text{enc}_1|} \sum_{c_i \in \text{enc}_1} \min_{c_j \in \text{enc}_2} \frac{\theta_1 ||e_i - e_j||_2}{(1 + \min(c_i, c_j))}
\end{align*}
\]
Activity-Level Video Advertising

Activity Similarity

Atom-Feature / Vertex Similarity

Face / Human Pose
\[ x = (\text{encoding}, \text{confidence}) \]

Object / Scene / Keyword
\[ x = (\text{category}, \text{confidence}) \]

Interaction / Edge Similarity

\[
\begin{align*}
    s_1(x_1, x_2) &= 1 - \frac{1}{|\text{enc}_1|} \sum_{e_i \in \text{enc}_1, e_j \in \text{enc}_2} \min_{e_i \in \text{conf}_{f_1}, e_j \in \text{conf}_{f_2}} \theta_1 ||e_i - e_j||_2 \\
    s_2(x_1, x_2) &= \frac{1}{|\text{cls}_1|} \sum_{e_i \in \text{cls}_1, e_j \in \text{cls}_2} \max_{e_i \in \text{conf}_{f_1}, e_j \in \text{conf}_{f_2}} (\theta_2 \min(c_i, c_j) \rho(e_i, e_j))
\end{align*}
\]
Activity-Level Video Advertising

Activity Similarity

Multimodal Content Embedding
- Video
- Subtitle
- Advertising Query

Key Frame Detection → Atom Feature Extraction → Activity Graph

Activity Similarity

Assigning Algorithm

1. Face / Human Pose
   \[ x = (\text{encoding, confidence}) \]
   \[ s_1(x_1, x_2) = 1 - \frac{1}{|\text{enc}_1|} \sum_{\substack{e_i \in \text{enc}_1 \cap \text{enc}_2 \cap \text{conf}_1 \cap \text{conf}_2 \cap \text{f}_1 \cap \text{f}_2 \cap \text{f}_3}} \min_{e_j \in \text{enc}_2} \frac{\theta_1 ||e_i - e_j||_2}{(1 + \min(c_i, c_j))} \]

2. Object / Scene / Keyword
   \[ x = (\text{category, confidence}) \]
   \[ s_2(x_1, x_2) = \frac{1}{|\text{cls}_1|} \sum_{\substack{e_i \in \text{cls}_1 \cap \text{cls}_2 \cap \text{conf}_1 \cap \text{conf}_2 \cap \text{f}_1 \cap \text{f}_2 \cap \text{f}_3}} \max_{e_j \in \text{cls}_2} (\theta_2 \min(c_i, c_j) \rho(e_i, e_j)) \]

3. Pose-Scene
   \[ s_3(e_i, e_j) = \begin{cases} 1 - ||e_i - e_j||_2, & \text{numerical} \\ \rho(e_i, e_j), & \text{categorical} \end{cases} \]

Atom-Feature / Vertex Similarity

Interaction / Edge Similarity
Activity-Level Video Advertising

Activity Similarity

Multimodal Content Embedding

- Video
- Subtitle
- Advertising Query

Key Frame Detection → Atom Feature Extraction → Activity Graph

Atom-Feature / Vertex Similarity

Face / Human Pose
\[ x = (\text{encoding, confidence}) \]

Object / Scene / Keyword
\[ x = (\text{category, confidence}) \]

Interaction / Edge Similarity

Pose-Scene
numerical

Pose-Pose / Pose-Object / Pose-Face
categorical

Assigning Algorithm

Activity Similarity

\[ s_1(x_1, x_2) = 1 - \frac{1}{|\text{enc}_1|} \sum_{e_i \in \text{enc}_1, e_j \in \text{enc}_2} \min_{e_i \in \text{con}_f_1, e_j \in \text{con}_f_2} \theta_1 ||e_i - e_j||_2 (1 + \min(c_i, c_j)) \]

\[ s_2(x_1, x_2) = \frac{1}{|\text{cls}_1|} \sum_{e_i \in \text{cls}_1, e_j \in \text{cls}_2} \max_{e_i \in \text{con}_f_1, e_j \in \text{con}_f_2} (\theta_2 \min(c_i, c_j) \rho(e_i, e_j)) \]

\[ s_3(e_i, e_j) = \begin{cases} 1 - ||e_i - e_j||_2, & \text{numerical} \\ \rho(e_i, e_j), & \text{categorical} \end{cases} \]
Activity-Level Video Advertising

Activity Similarity

\[ S(g_1, g_2) = \sum w_i s_i(g_1, g_2) \]

- **Face / Human Pose**
  \[ x = (\text{encoding}, \text{confidence}) \]

- **Object / Scene / Keyword**

- **Interaction / Edge Similarity**

- **Pose-Pose / Pose-Object / Pose-Face**
  - numerical
  \[ s_1(x_1, x_2) = 1 - \frac{1}{|\text{enc}_1|} \sum_{e_i \in \text{enc}_1, e_j \in \text{enc}_2} \min_{c_i \in \text{con}_{f_1}, c_j \in \text{con}_{f_2}} \frac{\theta_1 ||e_i - e_j||_2}{(1 + \min(c_i, c_j))} \]

  - categorical
  \[ s_3(e_i, e_j) = \begin{cases} 
    1 - ||e_i - e_j||_2, & \text{numerical} \\
    \rho(e_i, e_j), & \text{categorical}
  \end{cases} \]
Activity-Level Video Advertising

Activity Similarity

Multimodal Content Embedding

Video → Key Frame Detection → Atom Feature Extraction → Activity Graph

Activity-LEVEL Video Advertising

Activity Similarity

Assigning Algorithm

Ad1, Ad2, Ad3, Ad4
Activity-Level Video Advertising

Activity Similarity

Scene: Airport
Activity-Level Video Advertising

Ads Assignment

- Video
- Subtitle
- Advertising Query

Multimodal Content Embedding
- Key Frame Detection
- Atom Feature Extraction
- Activity Graph

Activity-Level Video Advertising
- Activity Similarity
- Assigning Algorithm

Ads Revenue vs. User Experience
Activity-Level Video Advertising

Ads Assignment: Ads Revenue

\[ f(S) = \sum_{(x_i, y_j) \in S} r_j s(x_i, y_j) \]

The subset of selected ads assignments.
Activity-Level Video Advertising

Ads Assignment: Ads Revenue

An assignment is a pair of key frame and ad query.

\[ f(S) = \sum_{(x_i, y_j) \in S} r_j s(x_i, y_j) \]
Activity-Level Video Advertising

Ads Assignment: Ads Revenue

\[ f(S) = \sum_{(x_i, y_j) \in S} r_{j} s(x_i, y_j) \]

Activity similarity between the key frame and ad query.
Activity-Level Video Advertising

Ads Assignment: Ads Revenue

\[ f(S) = \sum_{(x_i, y_j) \in S} r_{ij} s(x_i, y_j) \]

Query-j revenue.
Activity-Level Video Advertising

Ads Assignment: Intrusiveness Perception

Intrusiveness Distribution Function

\[ g(t|S') = 0, \quad 0 \leq t \leq t_1 \]

The intrusiveness of ads is the function over viewing time given an assigning output.

User Experience

[Diagram showing user experience attributes such as valuable, useful, accessible, usable, desirable, findable, credible]
Activity-Level Video Advertising

Ads Assignment: Intrusiveness Perception

Intrusiveness Distribution Function

\[ g(t|S) = 0, \quad 0 \leq t \leq t_1 \]

Before the first ad, the intrusiveness is 0.

User Experience
Intrusiveness Distribution Function

\[ g(t|S) = 0 \quad , 0 \leq t \leq t_1 \]

\[ g(t|S) = g(t_i) + \frac{\alpha}{s(p_i)} \quad , t_i < t \leq t_{i+1} \]

The incremental intrusiveness of a new ad is inversely proportional to the content similarity.
Activity-Level Video Advertising

Ads Assignment: Intrusiveness Perception

Intrusiveness Distribution Function

\[
g(t|S) = 0, \quad 0 \leq t \leq t_1
\]

\[
g(t|S) = g(t_i) + \frac{\alpha}{s(p_i)}, \quad t_i < t \leq t_{i+1}
\]

\[
g(t|S) = g(t_i) + \frac{\alpha}{s(p_i)} - \gamma(t - t_i - \frac{\beta}{s(p_i)})
\]

The duration of high intrusive perception is also inversely proportional to the similarity score.
Ads Assignment: Intrusiveness Perception

Intrusiveness Distribution Function

$$g(t|S) = 0 \quad , 0 \leq t \leq t_1$$

$$g(t|S) = g(t_i) + \frac{\alpha}{s(p_i)} \quad , t_i < t \leq t_{i+1}$$

$$g(t|S) = g(t_i) + \frac{\alpha}{s(p_i)} - \gamma(t - t_i - \frac{\beta}{s(p_i)})$$

As the time goes on, the intrusiveness will decline and $\gamma$ controls the descent speed.
Activity-Level Video Advertising

Ads Assignment: Trade-Off Model

Trade-Off Model: Revenue Optimization under Intrusiveness Constraint

\[
\max_{S \subseteq P} f(S) + \delta E(S)
\]

s.t. \[ \int_0^{t_{\text{max}}} g(t|S)dt \leq B \]
Activity-Level Video Advertising

Ads Assignment: Trade-Off Model

Trade-Off Model: Revenue Optimization under Intrusiveness Constraint

\[ \max_{S \subseteq P} f(S) + \delta E(S) \]
\[ \text{s.t. } \int_0^{t_{\text{max}}} g(t|S) \, dt \leq B \]

\[ E(S) = \sum_{(x_i, y_j) \in S} p_{y_j} \log_2 \left( \frac{p_{y_j}}{N_y} \right) \]

E(S) is an entropy-like function that measures balance of served ad queries distribution.

User Experience

Valuable  Useful  Usable

Accessible  Desirable  Credible

Findable
Activity-Level Video Advertising

Ads Assignment: NMS-Greedy Algorithm

Algorithm 1 NMS-Greedy algorithm for Equation 9.

Require: key frame set $X$, ad set $Y$, intrusiveness budget $B$

Ensure: assignments $S$

1: Initialize the value matrix $M_{N_y \times N_x}$, where $m_{ij} = r_i s(x_j, y_i)$.
2: Apply the kernel $K_{11 \times N_x}$ to $M$.
3: Apply the kernel $K_{2N_y \times N_k}$ to $M$.
4: Greedily select assignments with $\arg\max m_{ij}$ into $S$ until $\int_0^{t_{max}} g(t|S)dt$ exceeds the intrusiveness budget $B$.
5: return $S$

Trade-Off Model: Revenue Optimization under Intrusiveness Constraint

$$\max_{S \subseteq P} \int_0^{t_{max}} g(t|S)dt \leq B$$

$$\max_{S \subseteq P} f(S) + \delta E(S)$$
Algorithm 1 NMS-Greedy algorithm for Equation 9.

Require: key frame set $X$, ad set $Y$, intrusiveness budget $B$

Ensure: assignments $S$

1: Initialize the value matrix $M_{N_y \times N_x}$, where $m_{ij} = r_i s(x_j, y_i)$.
2: Apply the kernel $K_{11 \times N_y}$ to $M$.
3: Apply the kernel $K_{2N_y \times N_x}$ to $M$.
4: Greedily select assignments with $\arg \max m_{ij}$ into $S$ until $\int_0^{t_{max}} g(t|S)dt$ exceeds the intrusiveness budget $B$.
5: return $S$

Calculating the pairwise similarity to construct the value matrix.
Algorithm 1 NMS-Greedy algorithm for Equation 9.

Require: key frame set $X$, ad set $Y$, intrusiveness budget $B$
Ensure: assignments $S$
1: Initialize the value matrix $M_{Ny \times Nz}$, where $m_{ij} = r_i s(x_j, y_i)$.
2: Apply the kernel $K_{11 \times Nz}$ to $M$.
3: Apply the kernel $K_{2Ny \times N_k}$ to $M$.
4: Greedily select assignments with $\arg \max m_{ij}$ into $S$ until $\int_0^{t_{max}} g(t|S)dt$ exceeds the intrusiveness budget $B$.
5: return $S$

K1: Balancing the assignments for each ad.
Algorithm 1 NMS-Greedy algorithm for Equation 9.

Require: key frame set $X$, ad set $Y$, intrusiveness budget $B$

Ensure: assignments $S$

1: Initialize the value matrix $M_{N_y \times N_x}$, where $m_{ij} = r_i s(x_j, y_i)$.
2: Apply the kernel $K_{11 \times N_y}$ to $M$.
3: Apply the kernel $K_{2N_x \times N_y}$ to $M$.
4: Greedily select assignments with $\arg \max m_{ij}$ into $S$ until $\int_0^{t_{max}} g(t|S)dt$ exceeds the intrusiveness budget $B$.
5: return $S$

K2: Avoiding successive ads within short interval.
Activity-Level Video Advertising

Ads Assignment: NMS-Greedy Algorithm

Algorithm 1 NMS-Greedy algorithm for Equation 9.

Require: key frame set $X$, ad set $Y$, intrusiveness budget $B$
Ensure: assignments $S$

1. Initialize the value matrix $M_{N_y \times N_z}$, where $m_{ij} = r_t s_s(x_j, y_i)$.
2. Apply the kernel $K_{1 \times N_y}$ to $M$.
3. Apply the kernel $K_{2 \times N_z}$ to $M$.
4. Greedily select assignments with $\arg \max m_{ij}$ into $S$ until $\int_0^{\tau_{max}} g(t|S)dt$ exceeds the intrusiveness budget $B$.
5. return $S$

Greedy assigning ads until reaching intrusiveness budget.
Activity-Level Video Advertising

ActVA: Extensibility

Multimodal Content Embedding

- Video
- Subtitle
- Advertising Query

Key Frame Detection
Atom Feature Extraction
Activity Graph

Activity-Level Video Advertising

- Activity Similarity
- Assigning Algorithm

No need for activity-level labelled training data.

Video Data

Ads Query

Will you marry me?

Activity Graph Representation

Diamond Ring
White Sapphire
HK$5,228.00
Utama HK

Love Shack Fancy
Irene Gown in White
HK$9,262.70
revolve.com
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Evaluation

Experiment Setup

140 Videos

100X

10X

30X

150 Real Ads Needs

Vehicle

Electronic

Food and Beverage

Clothing

Estate

Household

Jewelry

Gaming

Cosmetic

Medicine
Evaluation

Semantic-Shot Key Frame Detection

(a) Keyword# CDF. (b) Keyword# distribution.

Richer Textual Information

Query

Top-3 Results

High Accuracy with >10k FPS retrieval speed
Evaluation

Advertising Position Retrieval

(a) Keyword# CDF. (b) Keyword# distribution.

Richer Textual Information

High Accuracy with >10k FPS retrieval speed
Evaluation

NMS-Greedy Ads Assignment

(a) Average Assignment Value V.S. Intrusiveness Budget

(b) Average Time Cost

(c) Subject Intrusiveness Evaluation

Highest Value

Low Cost

User Friendly
Evaluation

NMS-Greedy Ads Assignment

(a) Average Assignment Value V.S. Intrusiveness Budget

Highest Value

(b) Average Time Cost

Low Cost

(c) Subject Intrusiveness Evaluation

User Friendly
Outline

• Introduction
• Multimodal Content Embedding
• Activity-Level Video Advertising
• Evaluation

• Conclusion
Based on atom features and activity-graph representation, we can implement an efficient and scalable activity-level video advertising system.
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