A Practical Framework of Conversion Rate Prediction for Online Display Advertising

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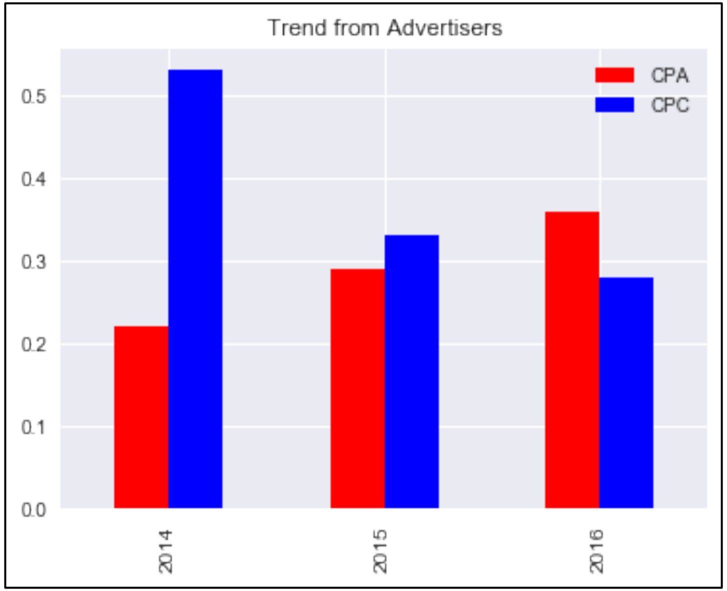
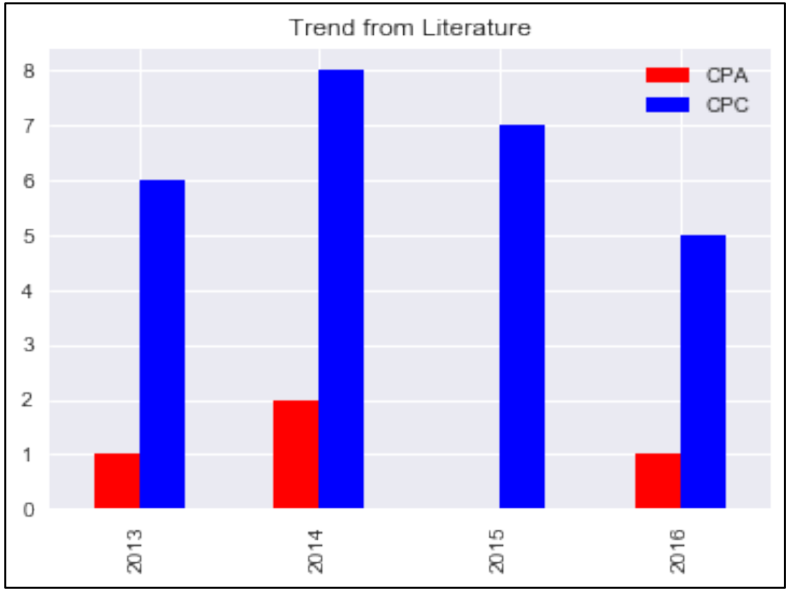
CPA vs CPC Trend



Percentage of campaigns with each goal type



Number of publications at each year

Challenges for CPA Predictions

Rarity

Extremely low conversion rate. Typically in 10E-5 to 10E-6 range.

Attribution

There is no 100% causal relationship between the events and following conversions

Heterogeneity

Learning across different advertisers is not allowed.

Delayed Feedback

Days or weeks delay before getting the response.

Different types

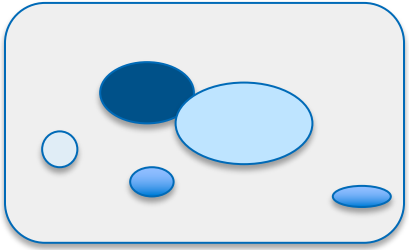
Post-click-action and post-view-action are naturally different in modeling.

Challenges of Conversion Predictions Due to Conversion Rarity

- Worse performance
- Low delivery
- Costly exploration

CVR Safe Prediction Framework

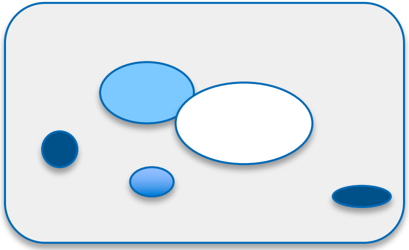
1



Initial stage

Exploration regions are derived from the trained GBDT models. Each region may have different CVR priors.

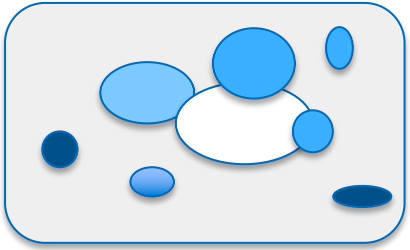
2



Evolution stage

Each region’s predicted CVR is converted to its own empirical mean. So, some regions’ outputs automatically fade out.

3



Growing stage

New exploration regions are added based on the cross region conversions to provide continuously explorations.

Performance Comparison

Campaign	Machine-Learning Tree			Machine-Learning + Data-Driven Tree			CVR lift	eCPA drop	imps lift
	CVR	eCPA	imps	CVR	eCPA	imps			
Campaign1	6.96E-06	63.5419	1,174,131	7.06E-06	61.9564	1,293,526	1.52%	-2.50%	10.17%
Campaign2	5.38E-06	130.2857	1,300,893	9.66E-06	83.8571	1,448,639	79.60%	-35.64%	11.36%
Campaign3	1.49E-03	0.8359	576,431	2.13E-03	0.5987	678,384	42.78%	-28.37%	17.69%

Table 1: Online test results from 3 campaigns. It shows performance and delivery improvements after adding data-driven trees on top of machine-learning trees.

Conversion Adjustment for Delayed Feedbacks

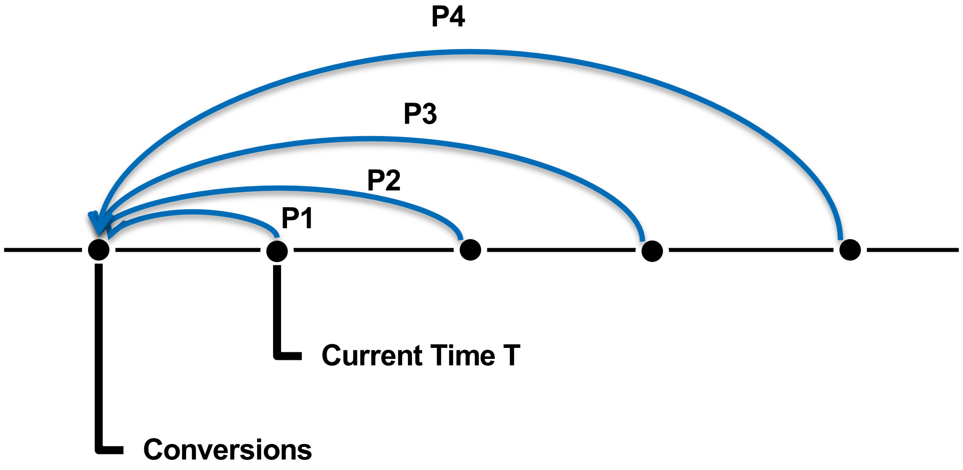
- Trade-off of including new data with compensating empirical estimation.
- Formulate and solve as the following linear programming problem.

$$\min \sum_{j=T+1}^{n} \left[\sum_{i=j-T}^{j} \left(\sum_{j'=i}^{i+T} C_{i,j'} \right) \cdot P_{j-i,D(i)} - \sum_{i=j-T}^{j} C_{i,j} \right]^2$$

$$s.t.$$

$$\sum_{k=0}^{T} P_d(k) = 1 \text{ for } d = 0, 1, \ldots, 6,$$

$$0 \leq P_d(k) \leq 1 \text{ for } k = 0, 1, \ldots, T.$$



Adjusted Conversions at T-1 = N1 / P1

Bid Price Adjustment for Last-Win-All Attribution

- For post-view-conversion campaign, impression value decreases when user has been shown the same impression before.
- The discounted value positively correlates to the elapsed time between the last shown impression at the same user
- The key is to conduct noise reduction and do fast approximation of the integration value online

Algorithm 1 Value Adjustment Factor Estimation

Input: time related parameters:

t_0 : time the previous impression was shown;

t : the current time to bid for a new impression;

T : length of attribution window (in hours);

W : length of conversion window (in hours).

Input: n hours of historical data.

1: For $i, j \in \{1, 2, 3 \ldots, n\}$, find counts $C_{i,j}$, the number of conversions from hour j that are attributed to impressions shown at hour i.

2: Calculate the probability mass of $\kappa(x)$ at hour $h \leq W$:

$$\hat{\kappa}(h) = \frac{\sum^{n}_{\substack{j=T+1 \\ \text{hod}(j)=\text{hod}(h)}} \sum_{i=1}^{j} C_{i,j}}{\sum_{j=T+1}^{n} \sum_{i=1}^{j} C_{i,j}} \Big/ \left|\{h' \leq W : \text{hod}(h') = \text{hod}(h)\}\right|,$$

and we set $\hat{\kappa}(h) = 0$ for $h > W$. Note that we excluded the first T hours of conversions since their attributed impressions may be incomplete.

3: Calculate the probability mass of $q(x - t_0)$ at hour h:

$$\hat{q}(h - t_0) = \frac{\sum^{n}_{\substack{j=T+1 \\ j>h-t_0}} C_{j-(h-t_0),j}}{\sum_{j=T+1}^{n} \sum_{i=1}^{j} C_{i,j}}.$$

4: Calculate attribution probabilities:

$$\hat{f}_{t_0}(t) = \sum_{h=t}^{t_0+T} \hat{q}(h - t_0) \cdot \hat{\kappa}(h), \text{ and } \hat{f}_t(t) = \sum_{h=t}^{t+T} \hat{q}(h - t_0) \cdot \hat{\kappa}(h).$$

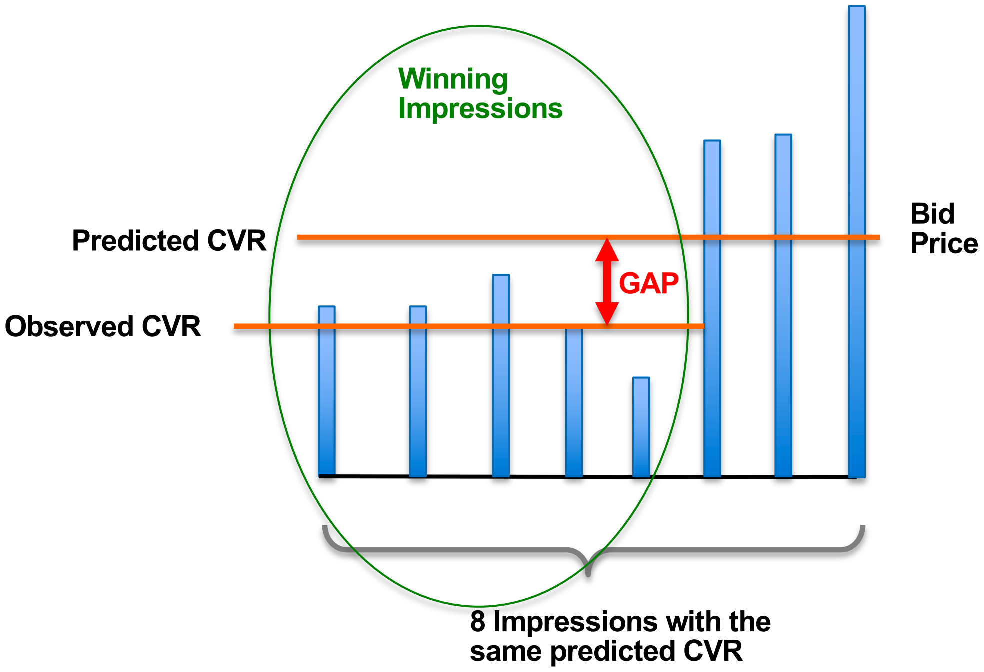
Output: estimated value adjustment factor

$$1 - \frac{\hat{f}_{t_0}(t)}{\hat{f}_t(t)} = 1 - \frac{\sum_{h=t}^{t_0+T} \hat{q}(h - t_0) \cdot \hat{\kappa}(h)}{\sum_{h=t}^{t+T} \hat{q}(h - t_0) \cdot \hat{\kappa}(h)}.$$

Over-prediction Gap Brought by RTB

- Gaps between observations and predictions could be partially introduced by real-time bidding.

- For CPA remarketing impressions, this phenomenon is more obvious due to sharing common information



Problems are not stop signs, they are guidelines

- Robert H. Schuller