# Multi-attribute Regret-based Dynamic Pricing

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# Outline

- Problem: Multi-attribute dynamic pricing
- Solution:
  - Preference elicitation using minimax regret
  - Dynamic pricing using minimax regret
- Experimental validation
  - while varying system parameters
  - comparison with other dynamic pricing approaches

# Problem

- Online market with buyers and sellers
- Simplification: Only one type of product or item is sold/purchased
- Each product is differentiated along a finite set of attributes

# Sellers

- Each seller has multiple, infinite number of items in its inventory
- Each seller has a production cost (min threshold) and each buyer has a reservation cost (max threshold)

# Buyer Attribute Preference Model

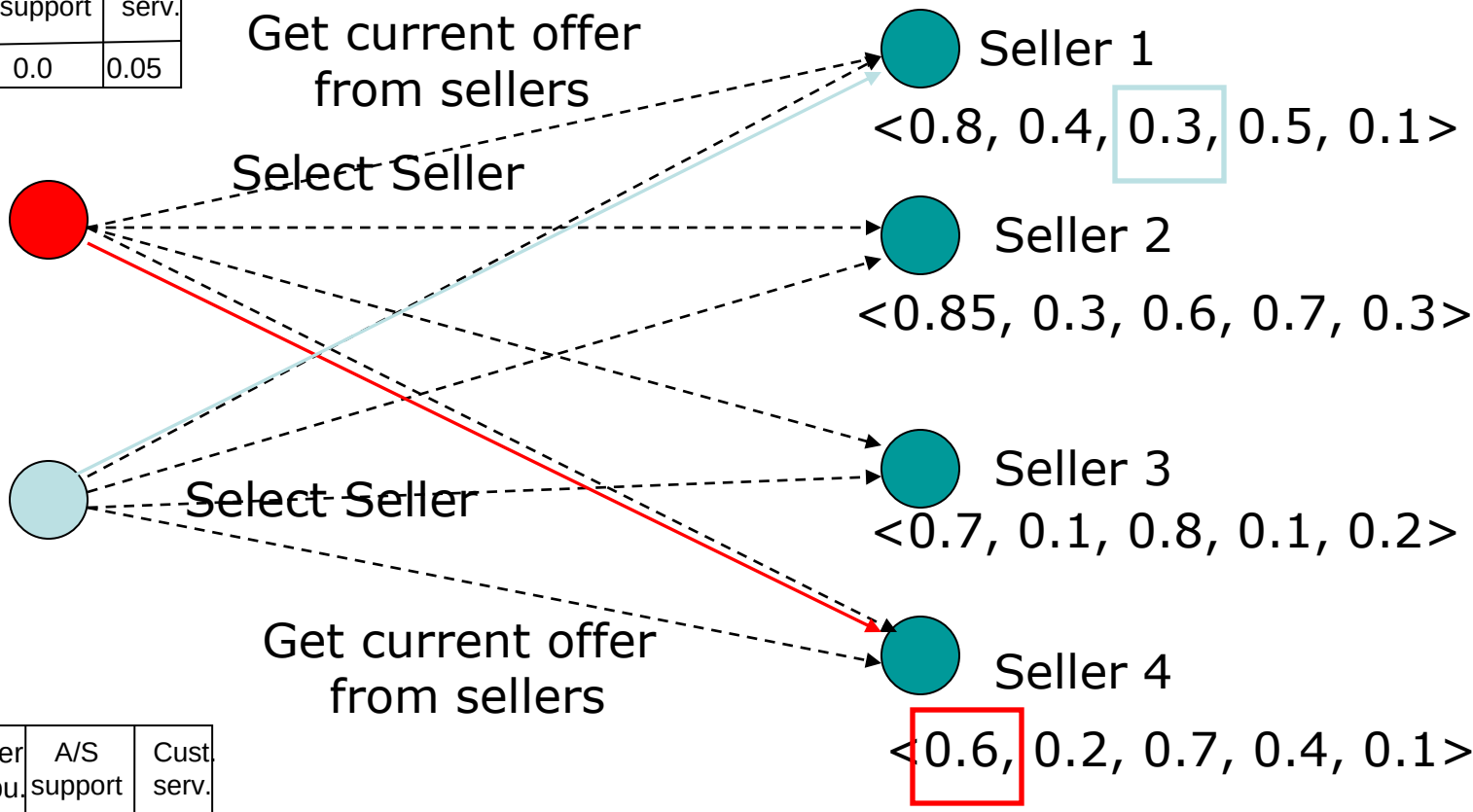
| | A1 | A2 | A3 | A4 | A5 |
|---|---|---|---|---|---|
| Item | 0.2 | 0.15 | 0.6 | 0.0 | 0.05 |

| | Time | Insur-ance | Seller Repu. | A/S support | Cust. serv. |
|---|---|---|---|---|---|
| Item | 0.2 | 0.15 | 0.6 | 0.0 | 0.05 |

- Each buyer differentiates a product along different attributes using a preference vector of probabilities
- Set of preference vectors is finite
- Buyers can be of different types (finite set of types)
  - each type corresponds to one preference vector

# Market Operation

| | Time | Insur-ance | Seller Repu. | A/S support | Cust. serv. |
|---|---|---|---|---|---|
| Item | 0.7 | 0.15 | 0.1 | 0.0 | 0.05 |




| | Time | Insur-ance | Seller Repu. | A/S support | Cust. serv. |
|---|---|---|---|---|---|
| Item | 0.2 | 0.15 | 0.6 | 0.0 | 0.05 |

<p1, p2, p3, p4, p5> represents seller prices along different product attributes

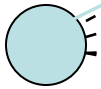
# Market Operation: Over Time

| | Time | Insur-ance | Seller Repu. | A/S support | Cust. serv. |
|---|---|---|---|---|---|
| Item | 0.2 | 0.65 | 0.1 | 0.0 | 0.05 |

Buyer 1: Preferred attribute $a_2$

Get current offer from sellers

Select Seller



Buyer 2: Preferred attribute $a_3$

Select Seller

Get current offer from sellers

Seller 1

<0.8, 0.4, 0.3, 0.5, 0.1>

Seller 2

<0.85, 0.3, 0.6, 0.7, 0.3>

Seller 3

<0.7, 0.1, 0.8, 0.1, 0.2>

Seller 4

<0.6, 0.2, 0.7, 0.4, 0.1>

| | Time | Insur-ance | Seller Repu. | A/S support | Cust. serv. |
|---|---|---|---|---|---|
| Item | 0.2 | 0.15 | 0.6 | 0.0 | 0.05 |

<p1, p2, p3, p4, p5> represents seller prices along different product attributes

# Sellers' Knowledge

| | Time | Insur-ance | Seller Repu. | A/S support | Cust. serv. |
|---|---|---|---|---|---|
| Item | 0.7 | 0.15 | 0.1 | 0.0 | 0.05 |

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Buyer 1: Preferred attribute $a_2$

Buyer 2: Preferred attribute $a_3$

| | Time | Insur-ance | Seller Repu. | A/S support | Cust. serv. |
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Seller 1 <0.8, 0.4, 0.3, 0.5, 0.1>

Seller 2 <0.85, 0.3, 0.6, 0.7, 0.3>

Seller 3 <0.7, 0.1, 0.8, 0.1, 0.2>

Seller 4 <0.6, 0.2, 0.7, 0.4, 0.1>

<p1, p2, p3, p4, p5> represents seller prices along different product attributes

# Sellers' Knowledge

- A seller knows
  - Set of product attributes
  - Purchase decision of buyer
- A seller does not know
  - How many other sellers are there?
  - What prices other sellers are charging?
  - How many buyers are there?
  - What is the preference distribution of buyers?

# Research Question

- How can a seller adjust the prices it charges along different product attributes over time to respond to temporal changes in
  - Buyer demand (Preferences of buyers over different attributes)
  - Competitors' strategies (Prices charged by competing sellers)

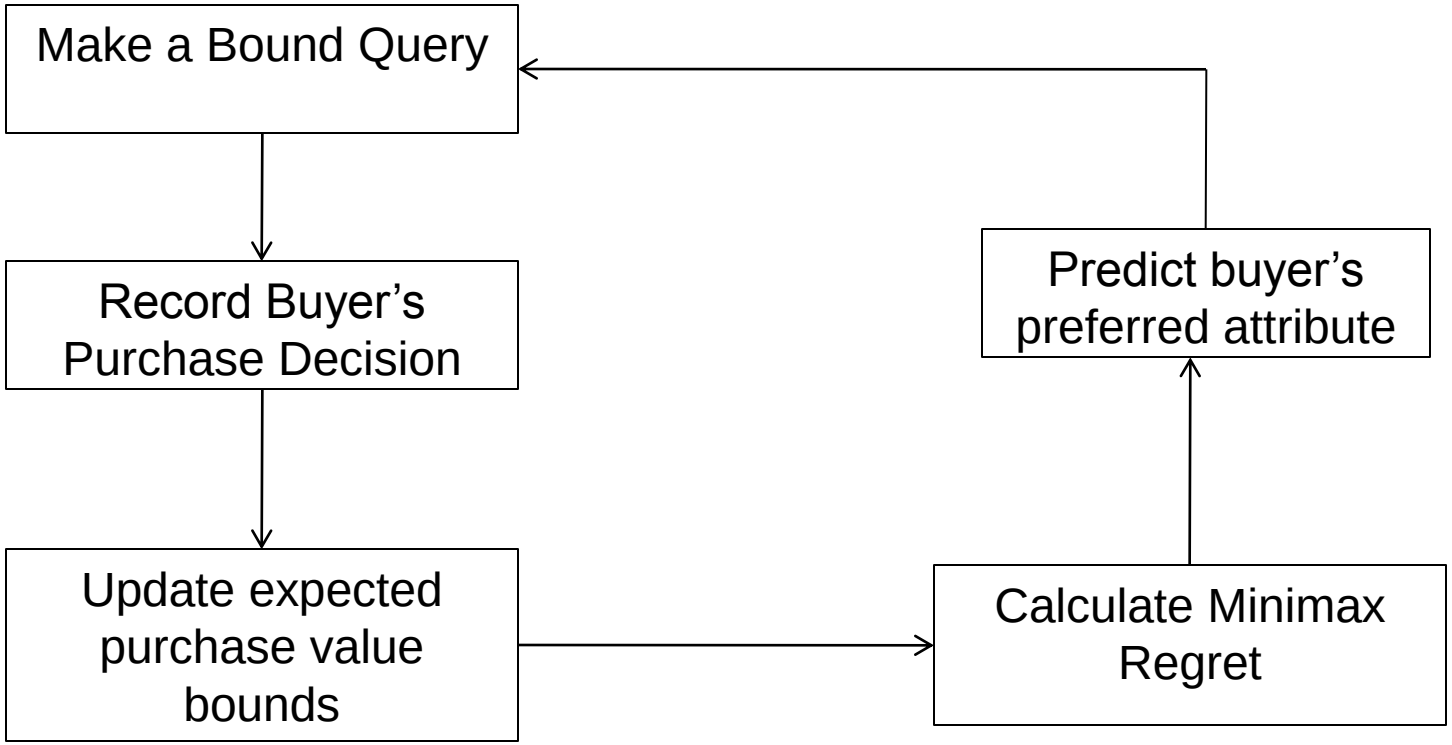
# Minimax Regret-based Attribute Prediction

- Estimate buyer preferences from the buyer's purchase decision
- Minimax regret technique of preference elicitation is used
- Seller makes a decision it would regret the least
  - Which attribute to predict for each buyer

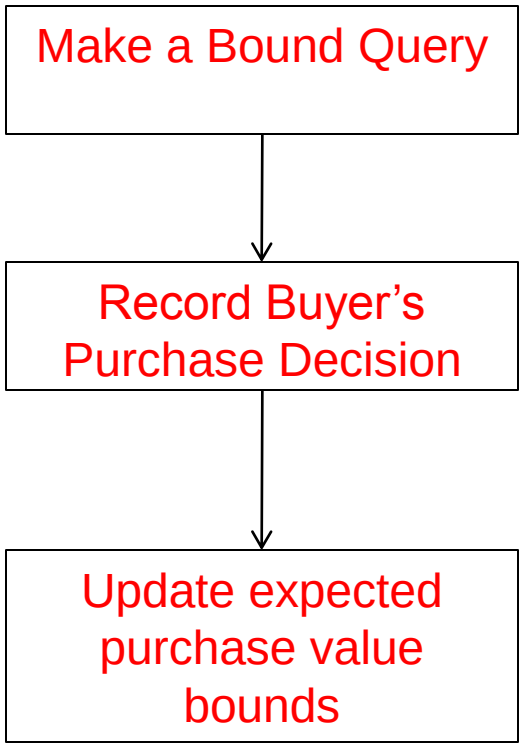
# Minimax Regret-based Attribute Prediction

- Sellers keep an upper and lower bounds of each buyer's expected purchase value for each attribute
- Consider buyer-seller interaction as a querying process
- Sellers make an attribute prediction decision at the end of each interval

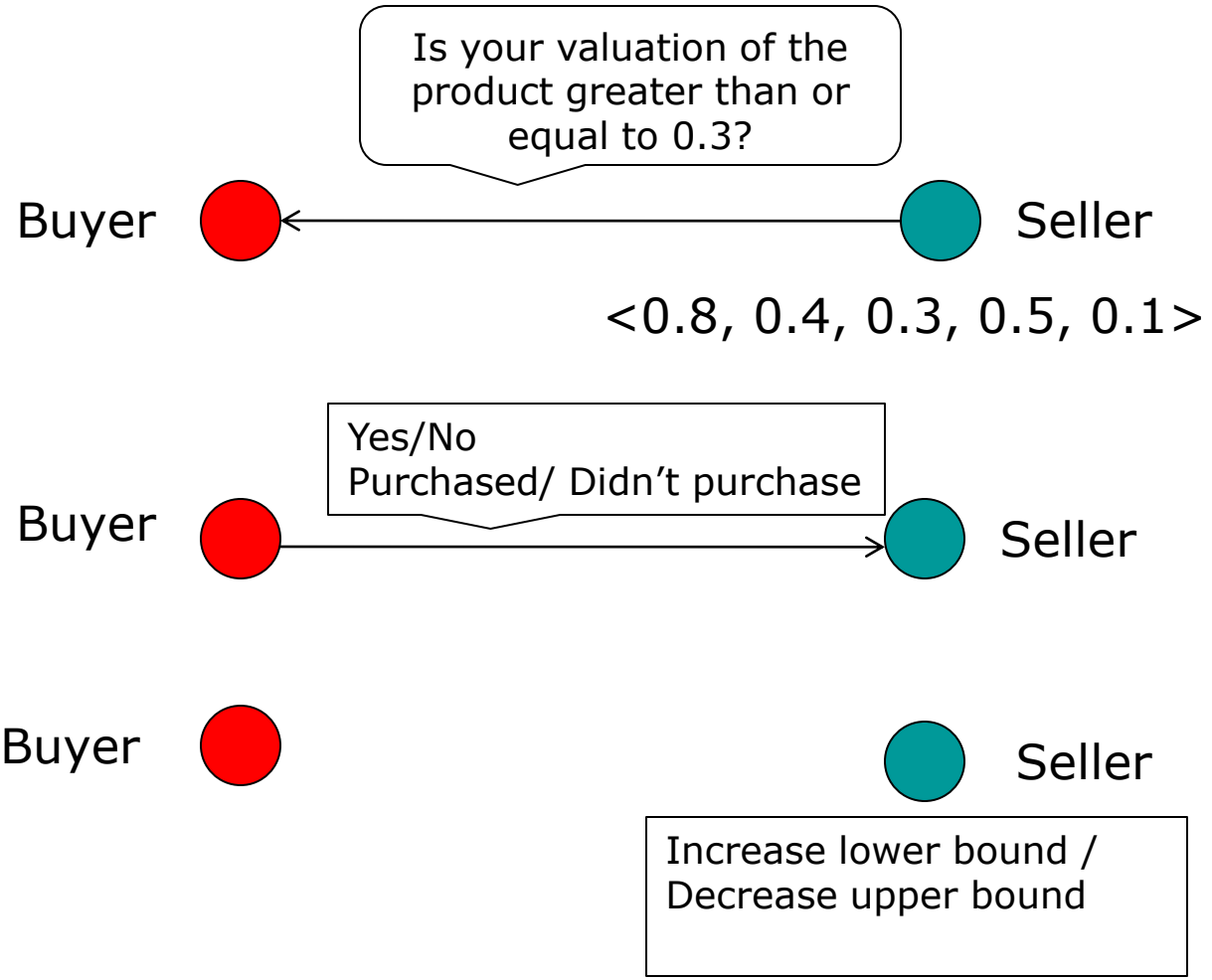
# Attribute Prediction Process



# Attribute Prediction Process

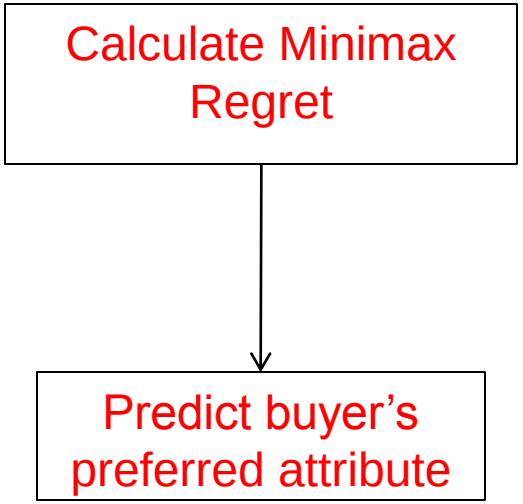



Assume seller predicted attribute $a_3$



# Attribute Prediction Process

Seller




1) Calculate pairwise regret for every attribute

$R(a_i,a_{-i}) = ub_{a-i} - lb_{ai}$

$R(a_i,a_i) = 0$

2) Find maximum for each attribute

$MR_{ai} = \max R(a_i,a_{-i})$

3) Choose attribute giving minimum regret

$a^* = arg_{ai} \min MR\ a_i$

# Regret-based Dynamic Pricing

- After attribute prediction, sellers calculate profit-maximizing price using:
  - Historical weighted average price
  - Past profits
  - Average bounds on the purchase values across all buyers
  - Normalized number of buyers with preferred attribute $a_i$ from attribute prediction part

# Regret-based Dynamic Pricin

1) Calculate historical weighted over past *h* intervals average price, $p^*_{ai}$

2) Calculate average regret-based price

$$p_{ai}` = n_{ai} \cdot ub_{ai} + (1- n_{ai}) \cdot lb_{ai}$$

3) If the direction of the price movement is the same as the direction of the profit change

$$p_{ai} = \alpha_1 \cdot p_{ai}` + (1- \alpha_1) \cdot p^*_{ai} \text{ , with } \alpha_1 > 0.5$$

Otherwise

$$p_{ai} = past\_p_{ai} + sign \cdot \varepsilon$$ , where *sign* is the sign of the profit difference in the last two intervals

# Simulations

- Number of buyers: 500 or 1000
- Number of sellers: 3 or 5
- Number of product attributes: 5
- Unit production cost: 0.1
- Interval for price updates: 40 quote requests
- Entry price: U[0.1, 1]

# Attribute Prediction

- Buyers randomly select a preference vector upon the entrance to the market
- Buyers change the selected preference vector at different random times

- Collaborative Filtering – for comparison
  - Attribute is predicted based on purchase history

# Pricing Comparison Strategies

- Fixed Pricing
  - Price is randomly selected U[0.1,1] and is fixed
- Derivative-Follower Pricing
  - Price is determined based on the profits obtained
- Goal-Directed Pricing
  - Price is determined based on the actual and expected number of products sold