Real-Time Model Checking for Shill Detection in Live Online Auctions

Prof. Haiping Xu
Computer and Information Science Department
University of Massachusetts Dartmouth
Email: hxu@umassd.edu

Acknowledgement

- Graduate Student:
  - **Christopher K. Bates**
- Collaborator:
  - **Sol M. Shatz**, Professor, UIC
- Sponsor:
  - **National Science Foundation**

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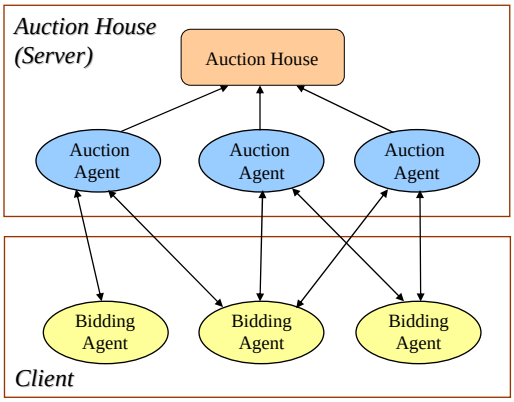
Online Auctions

- Different types of auctions
  - Increase-price auction (English auction)
  - Decrease-price auction (Dutch auction)
  - Second-price sealed-bid auction (Vickrey auction)
- English auction has become the most popular one in online auction houses (e.g., eBay).
- However, it is time-consuming for a human user to search and place bids on an auctioned item.
- There is a pressing need to introduce agent technology into online auction systems.

Agent-Based Online Auctions



- It consists of an auction house and a number of clients.
- It is designed as a multi-agent system.
- The auction house is managed by auction house administrator.
- Agents at the client side work on behalf of human users.

Bidding agents can place bids on behalf of human users, and they are typically running on different machines.

Shilling Behaviors

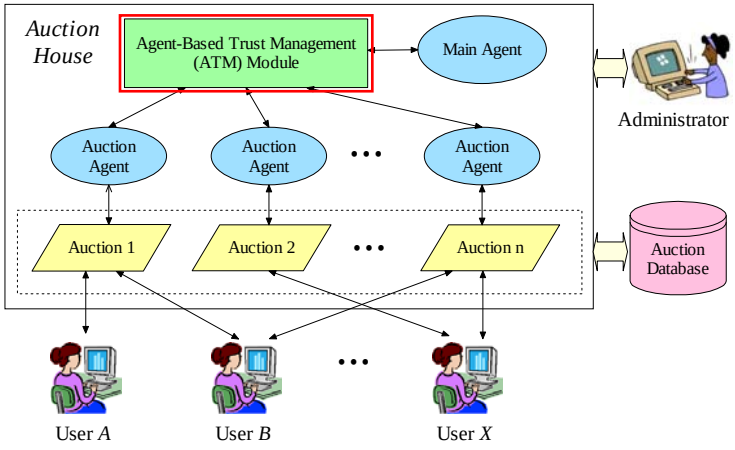
- A shill bidding is a deliberate activity of placing bids in order to artificially raise the price of an auctioned item.
- Although most of the online auction houses prohibit shilling behaviors, it is easy for malicious users to disguise themselves and put in shill bids in online auctions.
- In a recent research study at Carnegie Mellon University, dozens of probable fraudsters were detected at eBay using data mining techniques.
- It is vital to introduce a feasible trust management mechanism to prevent, detect and avoid trading frauds, such as shilling behaviors.

An Example

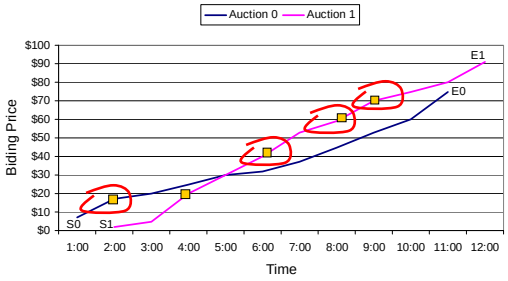
While two auctions with the same type of auctioned items are running concurrently, a shill bidder might put bids in the auction with higher bidding price rather than the one with lower bidding price in order to drive up the price in one auction.

- We call this type of shilling behavior *concurrent shilling.*
- Other types of shilling behaviors include: reserve price shilling, competitive shilling etc.
- Shilling behaviors become much more severe in an agent-based online auction system because
  - Automatic detection of shill bidders in agent-based online auctions can be much more difficult.
  - Malicious users may set up bidding strategies and automatically initiate shilling activities.

A Trustworthy Auction House



Model Checking Technology



S1: Start of *Auction 1*

E0: End of *Auction 0*

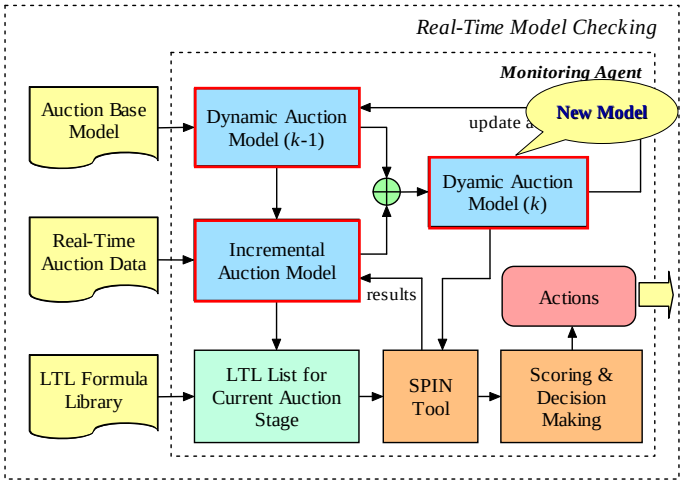
P: User *A* bids in *Auction 0* && Price is lower in *Auction 1*

S: User *A* bids in *Auction 1* && Price is lower in *Auction 0*

A Predicate for Concurrent Shilling: after "start of *Auction 1*" until "end of *Auction 0*", does "(User *A* bids in *Auction 0* && Price is lower in *Auction 1*) or (User *A* bids in *Auction 1* && Price is lower in *Auction 0*) become *true*?"

```
([](S1 && !E0 -> (!E0 U(P && !E0)))) || ([](S1 && !E0 ->
(!E0 U(S && !E0))))
```


Real-Time Model Checking



Three Stages of an Auction

- **Definition: Early Stage**. The early stage of an auction is defined as the first quarter of the auction duration. Typically there are only a few bids placed, but a shill bidder may be eager to drive up the price as early as possible.
- **Definition: Middle Stage**. Most of the bidding activities shall occur at the middle stage, which is defined as [0.25T, 0.9T), where T is the duration of an auction. Most of the shilling behaviors shall be detected at this stage.
- **Definition: Final Stage**. The final stage of an auction is defined as the last 10% of the auction time. In this stage, a shill only places bids occasionally and very carefully in order to avoid winning the auction.

Dynamic Auction Model (DAM)

DAM = CDAM ⊕ IAM

CDAM: Current Dynamic Auction Model
IAM: Incremental Auction Model

Current Dynamic Auction Model (CDAM)

```
/* type and variable declaration */
typedef Auction {
  int startTime = 0; int endTime = 172800;
  short estimatedPrice = 1500; short reservePrice = 1350;
  short minIncrement = 5;
} auc;
typedef Bid{
  short bidderID;  // bidder's identification
  short bidAmount; // bid amount in dollars
  int bidTime;     // time when bid is placed
} bids[100];
short numberOfBids;  // number of bids so far
short startingIndex; // for current stage
int middleStageStart;// middle stage start time
int finalStageStart; // final stage start time
...
short monitoredBidderID = 000001;
short monitoredBid;// bid amount in dollars
short monitoredInc // bid increment
bit bidFlag;       // == 1 if the current bid is monitored
```


Current Dynamic Auction Model (CDAM)

```
proctype SimulateBiddingProcess() {
  int index = startingIndex;
  ...
  do
  ::(index < numberOfBids) ->
    d_step {
      bidFlag = 0; // reset bid status
      ...
      if /* bid is monitored */
      ::(bids[index].bidderID == monitoredBidderID)->
        monitoredIncrement = bids[index].bidAmount-previousBid;
        monitoredBid=bids[index].bidAmount;
        bidFlag = 1; // == 1 if the current bid is monitored
      fi;
      ...
      index++;
    }
  od;
}
```

Incremental Auction Model (IAM)

```
typedef ShillingBehavior {
  bit detected;
  int timeDetected;
  int detectionCount;
}
/* shilling behaviors checked in the current auction stage */
ShillingBehavior BM1;
ShillingBehavior BM2;
ShillingBehavior BM3;
...
proctype CreateIncrementModel(){
  /* real time auction data */
  bids[26].bidID = 000003;
  bids[26].bidAmt = 885;
  bids[26].bidTime = 50424;
  ...
  numberOfBids = 30;   // number of bids so far
  startingIndex = 21;  // for the middle stage
  ...
}
```

real-time auction data

Examples of Shilling Behaviors

- **BE1:** Bidding time very close to the start of an auction

```
#define p (bidFlag == 1)
#define q (elapsedAuctionTime > 14400)
([]!q || (!q U (p && !q)))
```

- **BM1:** Bid close to the reserve price with no larger bids over the reserve price in the middle stage

```
#define p ((monitoredBid>(0.8*auc.reservePrice))
 &&(monitoredBid <= auc.reservePrice))
#define q (monitoredBid > auc.reservePrice)
#define r (elapsedAuctionTime>middleStageStart)
<>(r && (<>p && (!<>q)))
```

- **BF2:** BM1 detected, and bids with small bid increments over the reserve price in the final stage

```
#define p (monitoredInc < 10)
#define q (BM1.detected == 1)
#define r (monitoredBid > auc.reservePrice)
(<>q && ([](!(q && r)) || <>((q && r) && <>p)))
```

Algorithm: Real-Time Shill Detection

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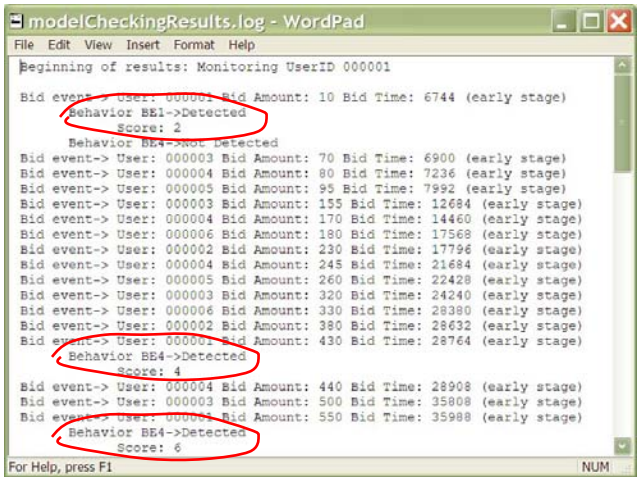
1. Create an initial auction model for each involved auction
2. Initialize total shilling score *tss* = 0 for monitored bidder *mb*
3. **while** (any involved auction *auc* is active)
4. **if** (*monitoredBidEvent* or *endOfStageEvent* occurs in *auc*)
5. generateIncrementalModel (*auc*)
6. DAM = CDAM ⊕ IAM
7. Select a list of LTL formulas for current stage of *auc*
8. **for each** LTL formula for shilling behavior *be*
9. Run SPIN model checker on DAM
10. **if** (*valid*)
11. *tss* += calculateShillingScore (*be*)
12. **if** (*tss* > *threshold*)
13. Give warning to bidder *mb*
14. Report to *security agent* for shill verification
15. Update CDAM with DAM for the next iteration
16. Save model checking results for IAM in next iteration
17. **else** *blocking*

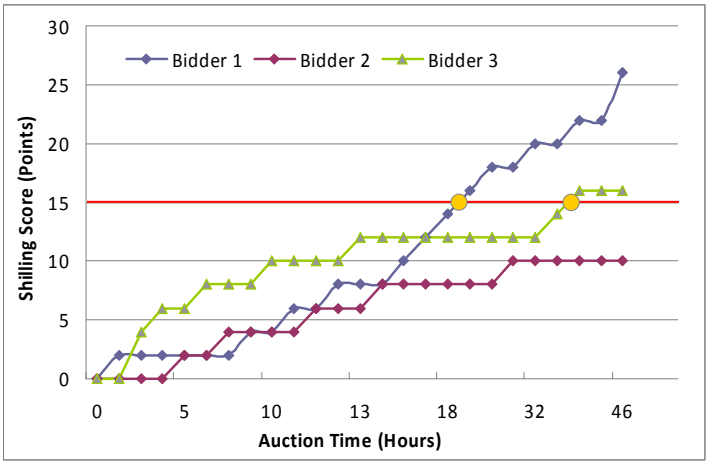
A Case Study

- Auctioned item: a bundle of NintendoWii, Playstation3, and XBox 360
  - Estimated price: $1,500; Reserve price: $1,350
  - Duration of the agent-based online auction: 48 hours
  - Six agent bidders involved, namely Bidder 1 to Bidder 6 (000001 ~ 000006)
  - Bidder 1 and Bidder 2 are specified with aggressive strategies that may involve shilling behaviors.
  - Bidder 3 to Bidder 6 are normal bidders specified with normal bidding strategies.

Model Checking Results for Bidder 1



Comparison of Shilling Scores



Conclusions and Future Work

- Provided a design of trustworthy agent-based online auction systems
- Proposed the real-time model checking approach for shill detection in online auctions
- The case study showed that our approach was efficient and effective to detect shills in real-time
- For our future work, we plan to summarize and formalize a more complete list of shill patterns
- Explore AI technique such as Dempster-Shafer theory of evidence to verify shill bidders
- Develop a prototype trustworthy agent-based online auction house for real-time shill detection.

Thank you for your attention!