Autonomous Bidding

in the

Trading Agent Competition

Amy Greenwald

Brown University

with

Justin Boyan

ITA Software

Federal Communications Commission

Computing Research Association

Digital Fellows Program

May 7, 2002

Key TAC Features

Simultaneous Auctions

Combinatorial Valuations

- Complements
  - $v(X\bar{Y}) + v(\bar{X}Y) \leq v(XY)$
  - camera, flash, and tripod
- Substitutes
  - $v(X\bar{Y}) + v(\bar{X}Y) \geq v(XY)$
  - Canon AE-1 and Canon A-1

Examples

FCC auctions

`eBay` auctions

- proxy bidding agents
- bid up to the value of good x

v(Camera + Flash)

- autonomous bidding agents
- bid up to the marginal value of good x

Bid Determination

Allocation

- given the set of goods I hold, what is the maximum valuation I can attain?

Acquisition

- given the set of goods I hold, and given ask prices in any open auctions, on what set of additional goods should I bid to maximize valuation less costs?

Requisition

- given the set of goods I hold, and given bid prices in any open auctions, on what set of goods should I place asks to maximize valuation plus profits?

Completion

- given the set of goods I hold, and given ask and bid prices in any open auctions, on what set of goods should I place bids or asks to maximize my valuation less costs plus profits?

Overview

- TAC Market Game
- TAC Agent Architecture
- RoxyBot Agent Architecture

TAC Market Game

Score = Valuation − Costs + Profits

Supply

- Flights Inbound and Outbound
- Hotels Grand Hotel and Le FleaBag Inn
- Entertainment Red Sox, Symphony, Phantom

Auctions

- Flights infinite supply, prices follow random walk, clear continuously, no resale permitted
- Hotels ascending, multi-unit, 16th price auctions, transactions clear and random auction closes once per minute, no resale permitted
- Entertainment continuous double auctions, initial endowment, resale is permitted

TAC Market Game

Demand

Client	IAD	IDD	HV	RV	SV	TV
1	1	3	99	134	118	65
2	1	4	131	170	47	49
3	1	2	147	13	55	49
4	3	4	145	130	60	85
5	1	4	82	136	68	87
6	2	4	53	94	51	105
7	1	3	54	156	126	71
8	1	5	113	119	187	143

Feasible Packages

- arrival date prior to departure date
- same hotel on all intermediate nights
- at most one entertainment event per night
- at most one of each type of entertainment

TAC Market Game

Valuation

$$1000 - \text{travelPenalty} + \text{hotelBonus} + \text{funBonus}$$

$$\begin{aligned}
\text{travelPenalty} &= 100(|\text{IAD} - \text{AD}| + |\text{IDD} - \text{DD}|) \\
\text{hotelBonus} &= \begin{cases} \text{HV} & \text{if H} = \text{G} \\ 0 & \text{otherwise} \end{cases} \\
\text{funBonus} &= \text{entertainment values}
\end{aligned}$$

Allocation

Client	AD	DD	H	Ticket	Valuation
1	1	3	G	SV1, RV2	1351
2	1	3	G	RV1	1201
3	1	2	G	—	1147
4	3	4	G	RV3	1275
5	1	3	F	RV1, TV2	1123
6	3	4	G	TV3	1058
7	1	3	F	SV1, RV2	1282
8	1	5	G	TV1, SV3, RV4	1562

TAC Agent Architecture

REPEAT

1. how many copies of each good do i want?

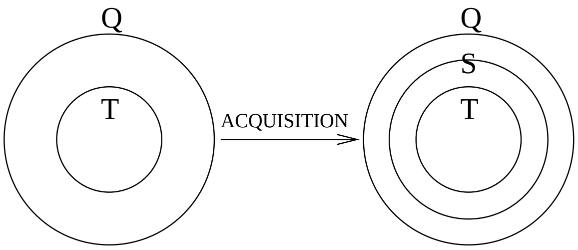
2. on the goods i want, should i bid now or later?

3. for the goods i want now, what am i willing to pay?

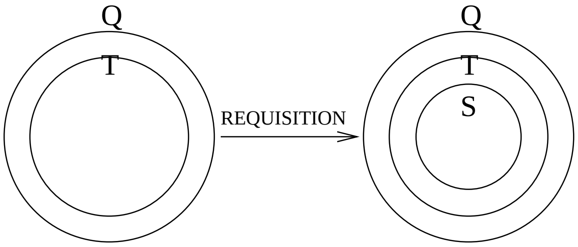
UNTIL game over

Bid Determination

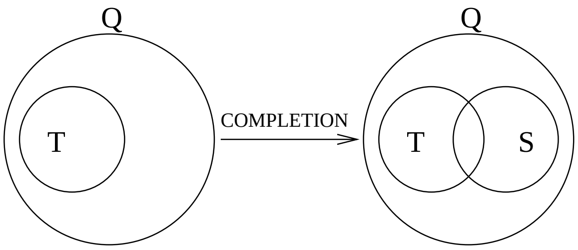
Bid on $S \setminus T$



Ask for $T \setminus S$



Bid on $S \setminus T$
Ask for $T \setminus S$



Observations

WD $\cong$ Allocation

- WD: auctioneer seeks the set of combinatorial bids that maximizes profits, given feasibility constraints

WDR $\cong$ Acquisition

- WDR (WD with reserve prices): auctioneer seeks the set of combinatorial bids that maximizes the difference between profits and reserve prices

BD problems in simultaneous auctions $\cong$
WD problems in combinatorial auctions

Pricelines

Buying Priceline

$\vec{p}_g = \langle 0, 0, 0, 0, 20, 30, \infty, \infty, \ldots \rangle$

$$
\begin{aligned}
\forall g, \quad n\mathsf{Buy}(S, g) &= \sum_{\vec{q} \in S} q_g \\
\forall g, \quad \mathsf{Cost}_g(S, P) &= \sum_{n=1}^{n\mathsf{Buy}(S,g)} p_{gn} \\
\mathsf{Cost}(S, P) &= \sum_{g \in G} \mathsf{Cost}_g(S, P)
\end{aligned}
$$

Selling Priceline

$\vec{\pi}_g = \langle 10, 5, 2, 1, 0, 0, 0, 0, -\infty, -\infty, \ldots \rangle$

$$
\begin{aligned}
\forall g, \quad n\mathsf{Sell}(S, g) &= \sum_{\vec{q} \notin S} q_g \\
\forall g, \quad \mathsf{Profit}_g(S, \Pi) &= \sum_{n=1}^{n\mathsf{Sell}(S,g,\Pi)} \pi_{gn} \\
\mathsf{Profit}(S, \Pi) &= \sum_{g \in G} \mathsf{Profit}_g(S, \Pi)
\end{aligned}
$$

Formalization

Acquisition

Inputs: set of packages Q

set of buying pricelines P

valuation function $v : Q \to \mathbb{R}^+$

Output: $S^* \in \arg\max_{S \subseteq Q}(\text{Valuation}(S, v) - \text{Cost}(S, P))$

Requisition

Inputs: set of packages Q

set of selling pricelines Π

valuation function $v : Q \to \mathbb{R}^+$

Output: $S^* \in \arg\max_{S \subseteq Q}(\text{Valuation}(S, v) + \text{Profit}(S, \Pi))$

Completion

Inputs: set of packages Q

set of buying pricelines P

set of selling pricelines Π

valuation function $v : Q \to \mathbb{R}^+$

Output: $S^* \in \arg\max_{S \subseteq Q}(\text{Val}(S, v) - \text{Cost}(S, P) + \text{Profit}(S, \Pi))$

Formalization

Acquisition

Inputs: set of packages Q

set of buying pricelines P

valuation function $v : Q \to \mathbb{R}^+$

Output: $S^* \in \arg\max_{S \subseteq Q}(\text{Valuation}(S, v) - \text{Cost}(S, P))$

Requisition

Inputs: set of packages Q

set of selling pricelines Π

valuation function $v : Q \to \mathbb{R}^+$

Output: $T^* \in \arg\max_{T \subseteq Q}(\text{Valuation}(T, v) + \text{Profit}(T, \Pi))$

Completion

Inputs: set of packages Q

set of buying pricelines P

set of selling pricelines Π

valuation function $v : Q \to \mathbb{R}^+$

Output: $$S^*, T^* \in \arg\max_{S,T \subseteq Q}(\text{Valuation}(S, v) - \text{Cost}(S, P) + \text{Profit}(T, \Pi) - \text{Cost}(T, P))$$

Completion $\longmapsto$ Acquisition

Buying Priceline
$\vec{p}_g = \langle 0, 0, 0, 0, 20, 30, \infty, \infty, \ldots \rangle$

Selling Priceline
$\vec{\pi}_g = \langle 10, 5, 2, 1, 0, 0, 0, 0, -\infty, -\infty, \ldots \rangle$

1st Reduction

- add reverse of selling pricelines to buying pricelines:
  $\vec{p}_g + \text{reverse}(\vec{\pi}_g) = \langle 1, 2, 5, 10, 20, 30, \infty, \infty, \ldots \rangle$

2nd Reduction

- extend package input set with singleton packages, one for each copy of each good in selling pricelines; assign selling prices as dummy package valuations:
  $\vec{\pi}_g \longmapsto$ 4 new packages with valuations 10, 5, 2, 1

Bid Determination in double-sided auctions $\longmapsto$
Bid Determination in single-sided auctions

Utility

Acquisition

Inputs: set of packages Q

set of buying pricelines P

valuation function $v : Q \to \mathbb{R}^+$

Output: $S^* \in \arg\max_{S \subseteq Q}(\text{Valuation}(S, v) - \text{Cost}(S, P))$

$u(S^*) = \max_{S \subseteq Q}(\text{Valuation}(S, v) - \text{Cost}(S, P))$

Example

valuations

$v(XYZ) = v(XY) = v(YZ) = 500$

$v(X) = v(Y) = v(Z) = v(XZ) = 0$

pricelines

$p(X) = p(Y) = p(Z) = 100$

utilities

$u(XY) = u(YZ) = 300$

Marginal Utility

for the goods i want now, what am i willing to pay?

Acquisition

Inputs: set of packages Q

set of buying pricelines P

valuation function $v : Q \to \mathbb{R}^+$

Output: $S^* \in \arg\max_{S \subseteq Q}(\text{Valuation}(S, v) - \text{Cost}(S, P))$

$u(S^*) = \max_{S \subseteq Q}(\text{Valuation}(S, v) - \text{Cost}(S, P))$

Answer

$u(x) = u(A \cup \{x\}) - u(A)$, with $p(x) = 0$ & $p(x) = \infty$

Example

$u(X) = u(XYZ) - u(YZ) = 400 - 300 = 100$

$u(Y) = u(XYZ) - u(XZ) = 400 - 0 = 400$

$u(Z) = u(XYZ) - u(XY) = 400 - 300 = 100$

Bids

$b(Y) = 300$, $b(X) = b(Z) = 100$

$v(Y) - p(Y) = 200$

RoxyBot

how many copies of each good do i want?

Acquisition

Inputs: set of packages Q

set of buying pricelines P

valuation function $v : Q \to \mathbb{R}^+$

Output: $S^* \in \arg\max_{S \subseteq Q}(\text{Valuation}(S, v) - \text{Cost}(S, P))$

$u(S^*) = \max_{S \subseteq Q}(\text{Valuation}(S, v) - \text{Cost}(S, P))$

Answer

$n\text{Buy}(S^*, g) = \sum_{\vec{q} \in S^*} q_g$

Example

$n\text{Buy}(\{XY\}, X) = 1$

$n\text{Buy}(\{XY\}, Y) = 1$

$n\text{Buy}(\{XY\}, Z) = 0$

XOR

$n\text{Buy}(\{YZ\}, X) = 0$

$n\text{Buy}(\{YZ\}, Y) = 1$

$n\text{Buy}(\{YZ\}, Z) = 1$

Marginal Utility, Revisited

for the goods i want now, what am i willing to pay?

Acquisition

Inputs: subset of packages Q

set of buying pricelines P

valuation function $v : Q \to \mathbb{R}^+$

Output: $S^* \in \arg\max_{S \subseteq Q}(\text{Valuation}(S, v) - \text{Cost}(S, P))$

$u(S^*) = \max_{S \subseteq Q}(\text{Valuation}(S, v) - \text{Cost}(S, P))$

Answer

$u(x) = u(A \cup \{x\}) - u(A)$, with $p(x) = 0$ & $p(x) = \infty$

Example

$u(X) = u(XY) - u(Y) = 400 - 0 = 400$

$u(Y) = u(XY) - u(X) = 400 - 0 = 400$

Bids

$b(X) = b(Y) = 400$, $b(Z) = 0$

$v(XY) - p(X) - p(Y) = 300$

RoxyBot 2000 Architecture

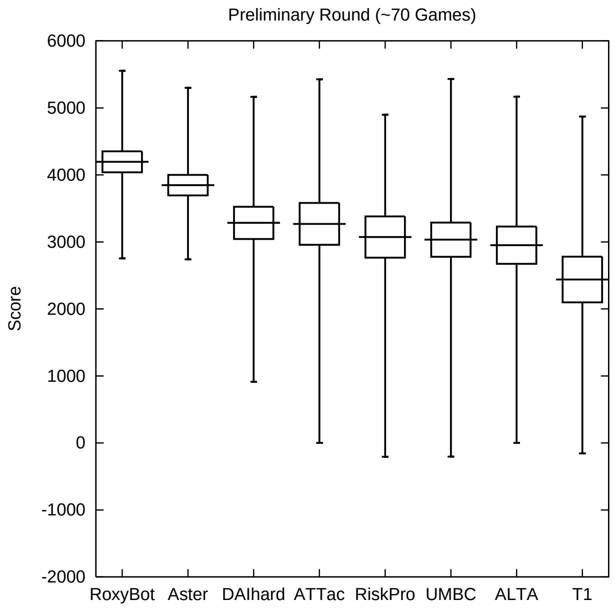
(A) REPEAT

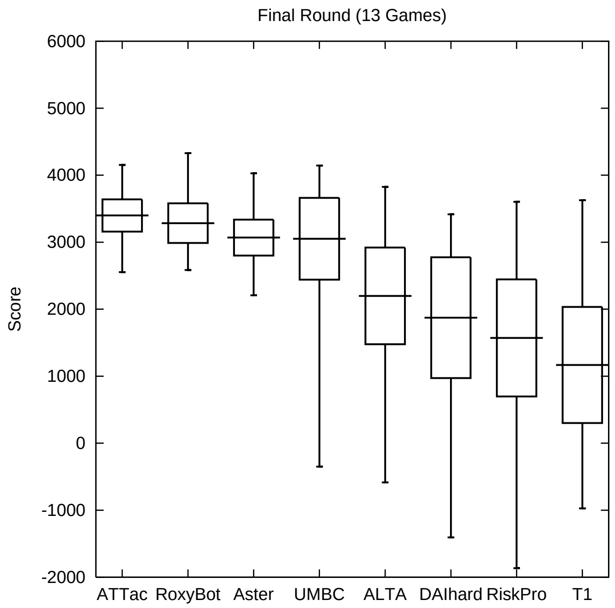
1. Ping server to update current prices and holdings
2. Estimate clearing prices and build buy/sell pricelines
3. Run completer to find optimal buy/sell quantities
4. Bid/ask marginal valuations

   UNTIL game over

(B) Run allocator

TAC 2000 Statistics





Price Uncertainty

for the goods i want now, what am i willing to pay?

Example

$p(x) = 0$, with probability $\frac{1}{2}$, and

$p(x) = 200$, with probability $\frac{1}{2}$,

for all $x \in \{X, Y, Z\}$

Answer

average marginal utility

Bidding Policy

X	Y	Z	$u(X)$	$u(Y)$	$u(Z)$
0	0	0	0	500	0
200	0	0	0	500	200
0	200	0	0	500	0
0	0	200	200	500	0
200	200	0	0	500	200
200	0	200	200	300	200
0	200	200	200	500	0
200	200	200	200	300	200
Bids			100	450	100

RoxyBot Under Uncertainty

how many copies of each good do i want?

Answer

sound and complete set of packages

Example

$n\text{Buy}(\{XY\}, X) = 1$

$n\text{Buy}(\{XY\}, Y) = 1$

$n\text{Buy}(\{XY\}, Z) = 0$

Bidding Policy

X	Y	$u(X)$	$u(Y)$
0	0	500	500
200	0	500	300
0	200	300	500
200	200	300	300
Bids		400	400

Bidding Under Uncertainty

X	Y	Z	ATTac	RoxyBot
0	0	0	500	500
200	0	0	500	300
0	200	0	300	300
0	0	200	500	500
200	200	0	300	100
200	0	200	0	300
0	200	200	300	300
200	200	200	−200	100
Scores			275	300

RoxyBot 2001 Architecture

INPUTS
Truncation Parameter $t_0 \in [0.5, 1.0]$
Schedule by which to Decay t_0

(A) REPEAT

1. Updates prices and winnings
2. Estimate clearing price distributions
3. Initialize $d = 0$, $s = 8$, $n = 0$, and $t = t_0$
4. REPEAT
   - (a) Sample clearing price distributions
   - (b) Compute optimal completion D_n
   - (c) Store D_n in completion list
   - (d) Increment n
   - (e) Tally results
     - i. for all items i
       - ◦ initialize $\#i = 0$
       - ◦ for all completions D_n
         - – if $i \in D_n$, increment $\#i$
       - ◦ if $\#i/n > t$
         - – increment d
         - – add i to D
       - ◦ if $\#i/n < 1 - t$
         - – decrement s
         - – delete i from S
   - (f) Discard from list inconsistent completions
   - (g) Set n equal to length of completion list
   - (h) Decay t

   UNTIL $d = s$ or TIME OUT

(B) Run allocator

Future Work

Empirical Testing

- Completion vs. No Completion
- Sampling vs. No Sampling
- ILP vs. LP Relaxation

Theoretical Study

- timing—optimal stopping problem
- estimate joint price distributions