Multiagent Systems

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Introduction

Distributed Sensors Example

Coalition Formation Example

Distributed Resource Allocation

Conclusion

Multiagent Systems

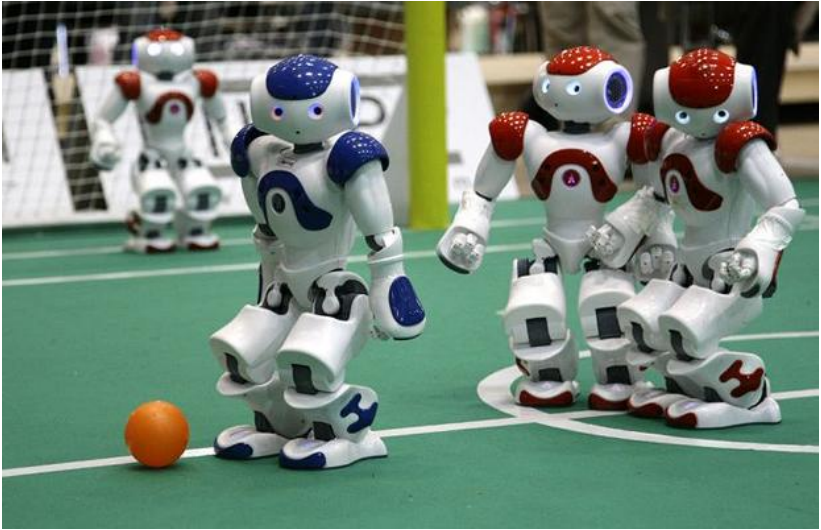
Engineer systems composed of autonomous and localized entities.

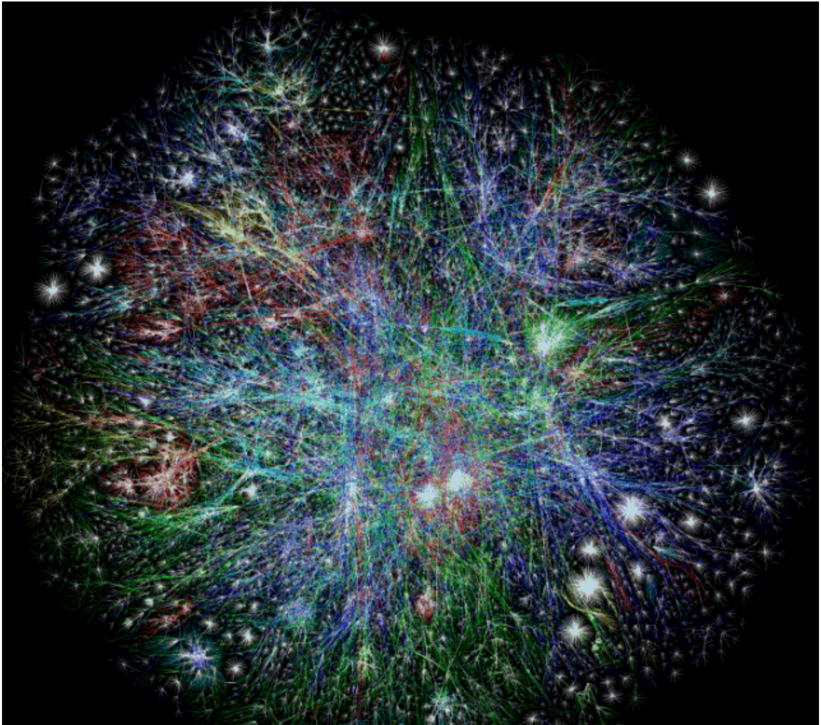
Ongoing Trends

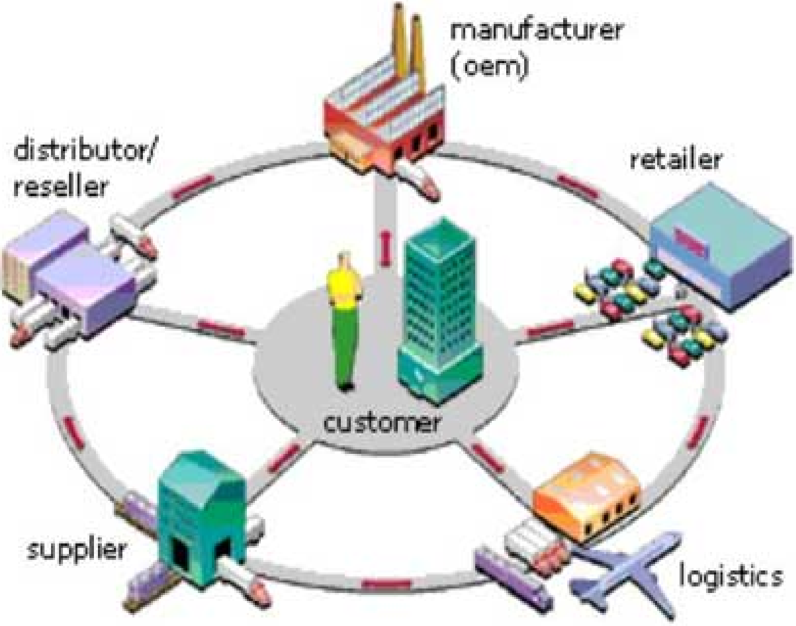
- Internet.
- Mobile. Ubiquity.
- Delegation. Automation. Online interactions.
- Agent intelligence.

Examples


ItemFetch™
OrderFetch™
CaseFetch™






manufacturer
(oem)
distributor/
reseller
retailer
customer
supplier
logistics

Tools

- AI, Algorithms
- Economics, Game Theory, Algorithmic Game Theory

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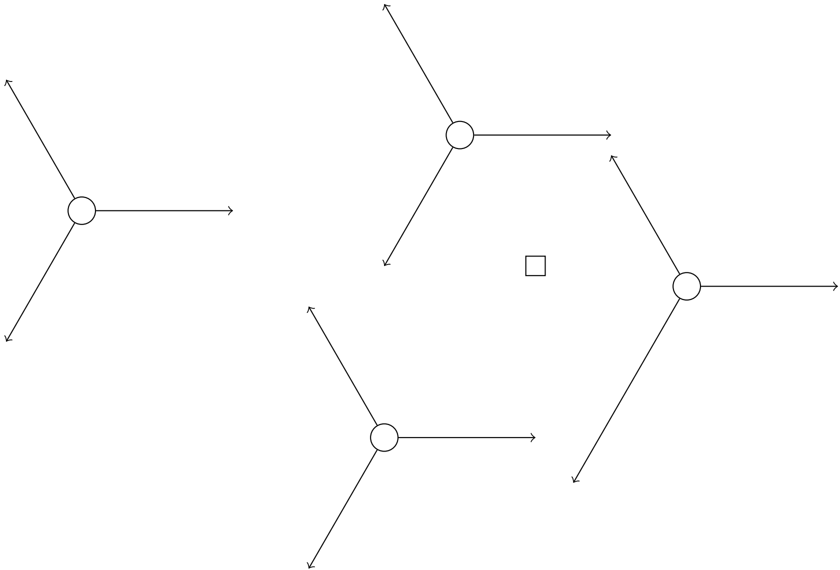
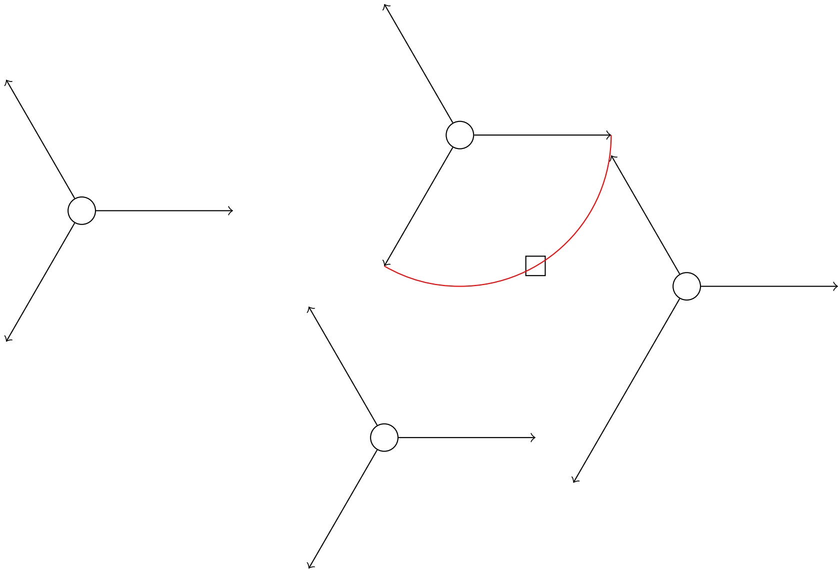
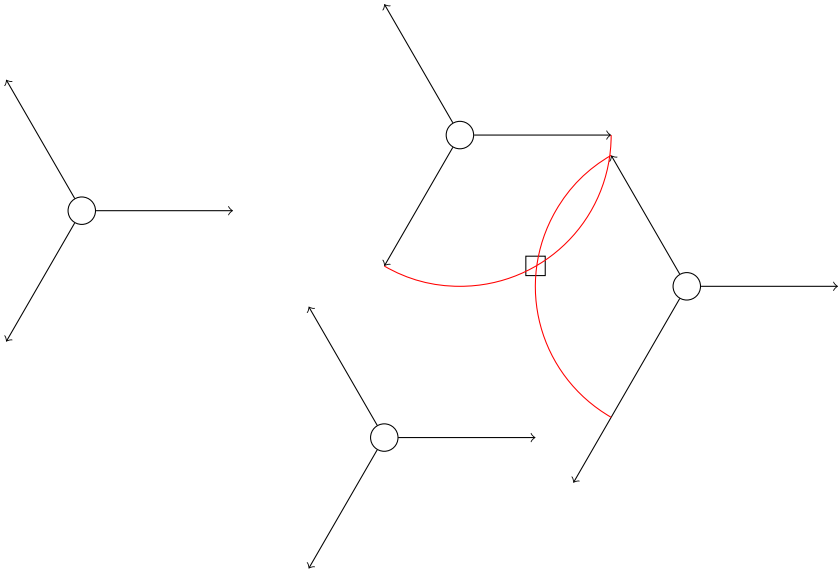
Distributed Sensor Network



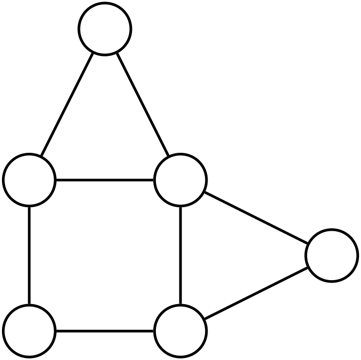
Distributed Sensor Network



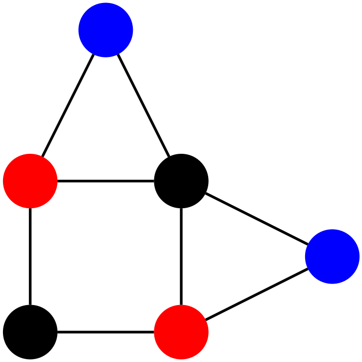
Distributed Sensor Network



Graph Coloring



Graph Coloring



Distributed Constraint Satisfaction Problem (DCSP)

Given variables $x_1, x_2, \ldots x_n$, each one controlled by a different agent, with domains $D_1, D_2, \ldots D_n$ and a set of boolean constraints P of the form $pk(x_{k1}, x_{k2}, \ldots, x_{kj}) \rightarrow \{0, 1\}$, find assignments for all the variables such that no constraints are violated.

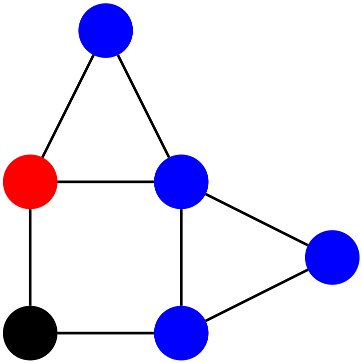
Algorithms

- Filtering algorithm
- Hyper-Resolution Based Consistency algorithm
- Aynchronous Backtracking
- Asynchronous Weak-Commitment Search
- Distributed Breakout

Algorithms

- Filtering algorithm NOT Complete
- Hyper-Resolution Based Consistency algorithm Complete
- Aynchronous Backtracking Complete
- Asynchronous Weak-Commitment Search Complete
- Distributed Breakout NOT Complete

Hill Climbing



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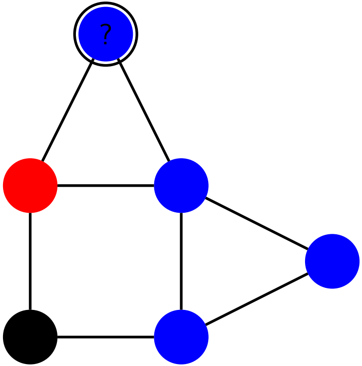

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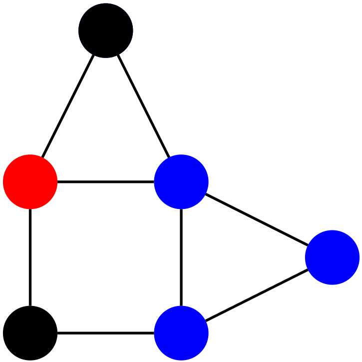

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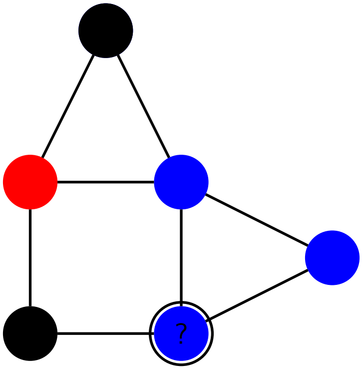

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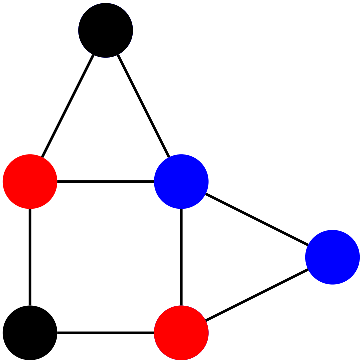

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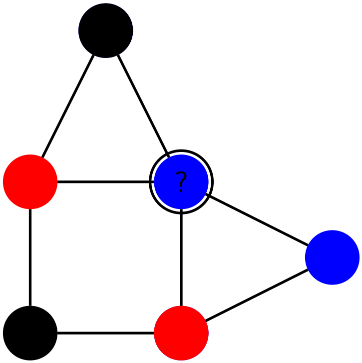

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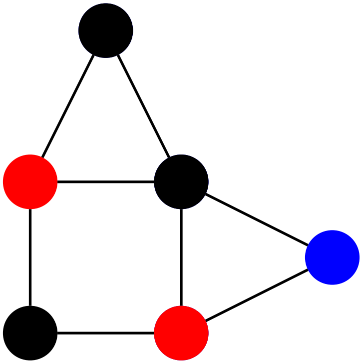
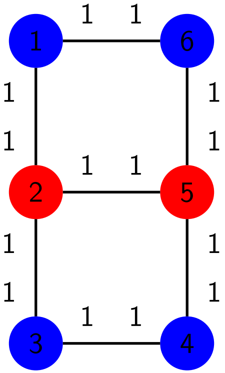


Distributed Breakout



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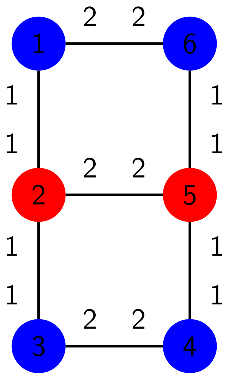

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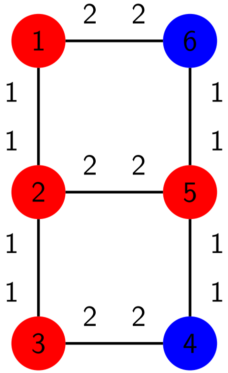
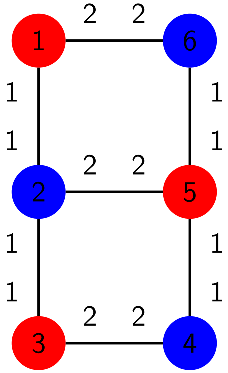


Distributed Breakout



Distributed Constraint Optimization Problem (DCOP)

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Algorithms

- Adopt
- OptAPO

Tradeoffs

Completeness vs Speed vs Distribution

Added Complications of Distributed Sensor Networks

- Noise
- Minimize communication
- Continuous problem

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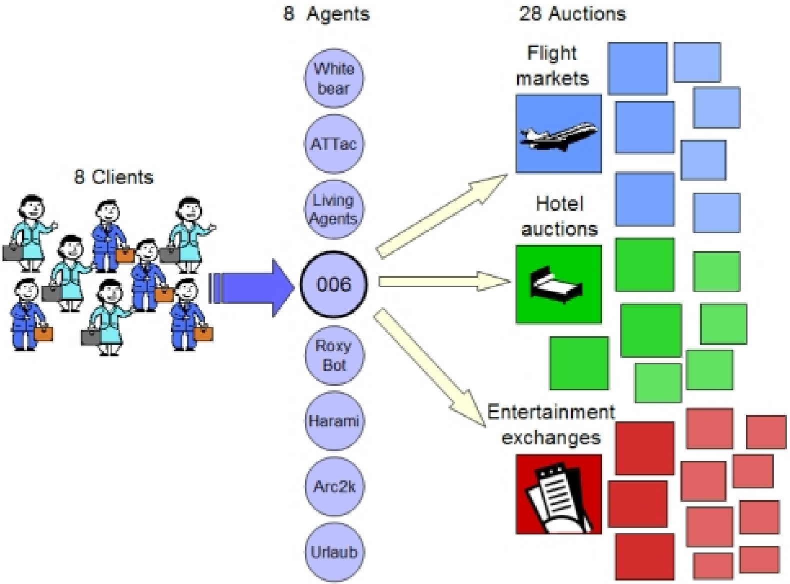
Travel Software Agents



Characteristic Form Game

S	$v(S)$
(a)	1
(b)	2
(c)	2
(ab)	4
(ac)	3
(bc)	4
(abc)	6

$(a)(b)(c)$
$1 + 2 + 2 = 5$

$(a)(bc)$
$1 + 4 = 5$

$(b)(ac)$
$2 + 3 = 5$

$(c)(ab)$
$2 + 4 = 6$

(abc)
6

The Core

Definition (Core)

An outcome $\mathbf{u}$ is in the *core* if

1. $$\forall_{S \subset A} : \sum_{i \in S} \mathbf{u}_i \geq v(S)$$
2. it is feasible.

Characteristic Form Game

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$\mathbf{u} = \{2, 3, 2\}$ in core?

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(abc)
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$\mathbf{u} = \{2, 3, 2\}$ in core? no, not feasible

Characteristic Form Game

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Characteristic Form Game

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(abc)
6

$\mathbf{u} = \{2, 2, 2\}$ in core? yes

How do we Distribute Value?

S	$v(S)$
()	0
(1)	1
(2)	3
(12)	6

- If they form (12), how much should each get paid?

Definition (Shapley Value)

Let $B(\pi, i)$ be the set of agents in the agent ordering π which appear before agent i. The *Shapley value* for agent i given A agents is given by

$$\phi(i, A) = \frac{1}{A!} \sum_{\pi \in \Pi_A} v(B(\pi, i) \cup i) - v(B(\pi, i)),$$

where Π_A is the set of all possible orderings of the set A.

How do we Distribute Value?

S	$v(S)$
()	0
(1)	1
(2)	3
(12)	6

- If they form (12), how much should each get paid?

$$\begin{aligned}
\phi(1,\{1,2\}) &= \frac{1}{2}\cdot(v(1)-v()+v(21)-v(2)) \\
&= \frac{1}{2}\cdot(1-0+6-3)=2 \\
\phi(2,\{1,2\}) &= \frac{1}{2}\cdot(v(12)-v(1)+v(2)-v()) \\
&= \frac{1}{2}\cdot(6-1+3-0)=4
\end{aligned}$$

Solutions

From Game Theory:

- Core
- Nucleolus
- Shapley value

From Sociology

- Equi-resistance
- Power-Dependence
- Expect Value

Solutions

From Game Theory:

- Core
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From Sociology

- Equi-resistance
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How to compute these? Distributedly.

Distributed Search

FIND-COALITION(i)

1 $L_i \leftarrow$ set of all coalitions that include i.
2 $S_i^* \leftarrow \arg\max_{S \in L_i} v_i(S)$
3 $w_i^* \leftarrow v_i(S_i^*)$
4 Broadcast (w_i^*, S_i^*) and wait for all other broadcasts.
  Put into W^*, S^* sets.
5 $w_{\max} = \max W^*$ and S_{max} is the corresponding coalition.
6 **if** $i \in S_{\max}$
7   **then** join $S_{\max}$
8 Delete $S_{\max}$ from L_i.
9 Delete all $S \in L_i$ which include agents from $S_{\max}$.
10 **if** L_i is not empty
11   **then** goto 2
12 **return**

Added Complications of Real-World Coalition Formation

- Uncertain knowledge
- Distributed incentive-compatible algorithms
- Speed! Approximation algorithms needed.

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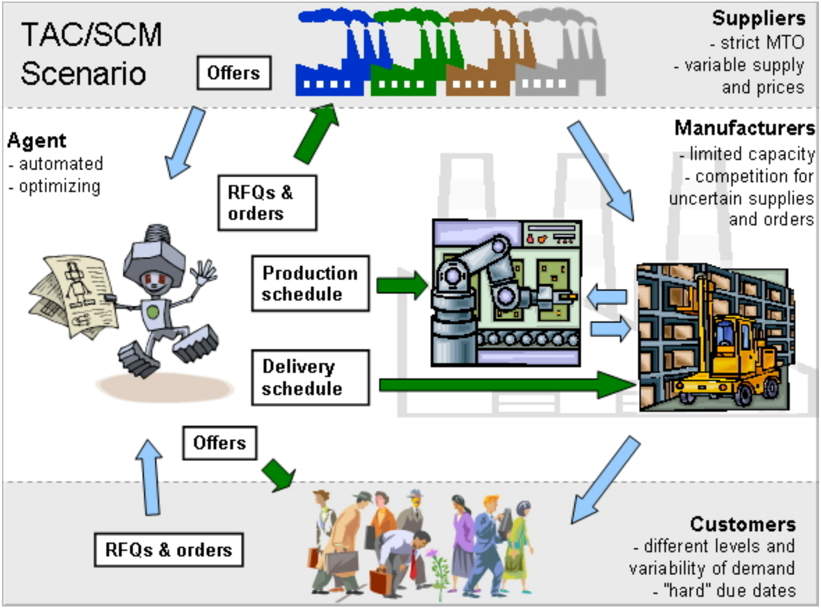

TAC/SCM
Scenario
Offers
Suppliers
- strict MTO
- variable supply
and prices
Agent
- automated
- optimizing
RFQs &
orders
Manufacturers
- limited capacity
- competition for
uncertain supplies
and orders
Production
schedule
Delivery
schedule
Offers
RFQs & orders
Customers
- different levels and
variability of demand
- "hard" due dates

Combinatorial Auction

Bid Price	Bid items
\$1	Beast Boy
\$3	Robin
\$5	Raven, Starfire
\$6	Cyborg, Robin
\$7	Cyborg, Beast Boy
\$8	Raven, Beast Boy

It is Hard

Theorem

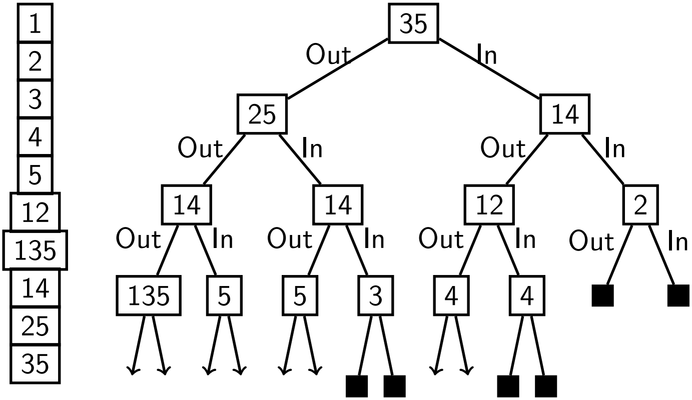
Winner Determination in Combinatorial Auction is NP-hard. That is, finding the X^* that maximizes revenue is NP-hard.

It is Really Hard

Theorem

The decision version of the winner determination problem in combinatorial auctions is NP-complete, even if we restrict it to instances where every bid has a value equal to 1, every bidder submits only one bid, and every item is contained in exactly two bids.

Branch on Bids Search Tree



Centralized Winner Determination Algorithms

- Results depend a lot on bid distribution and correlation.
- Thousands of bids doable in seconds.

- Newer algorithms use many different heuristics.
- Approximation algorithms are 1-2 orders faster but find only 99% of optimal solution.

PAUSE Auction

```
Have simultaneous open-cry auctions for each individual item.
For (k ← 2; k ≤ m; k ← k + 1)
        do Each bidder must place a complete bidset
            (using his bids or others' bids)
            where bids are all of size less than k.
```

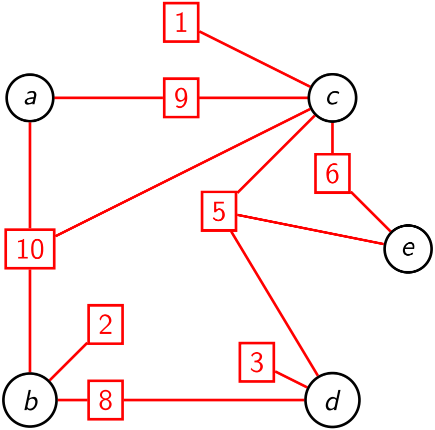
PAUSE Bidding

- PAUSEBID: myopically-optimal bidding algorithm.
- PAUSE+PAUSEBID $\rightarrow$ social welfare maximization, usually.

Distribute Over Sellers

- Each seller of an item negotiates with other sellers to clear a bid for himself.
- We then have a negotiation network.

Negotiation Network



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- AI + Algorithms + Economics + Game Theory (Algorithmic Game Theory)

GOALS:

- Engineer systems composed of autonomous and localized entities.