Budget Balance in Social Choice

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Overview

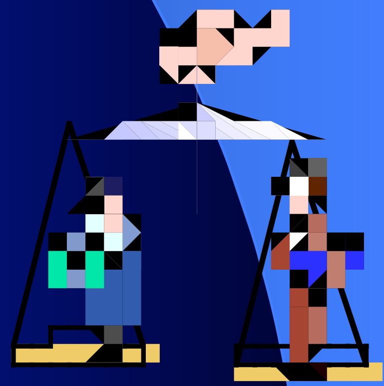
- Social choice
- Need for budget balance
- Ideas for achieving budget balance
- Budget balance in MDPOP

Social Choice

Choose an outcome o ∈ {o1,…} that a set of agents $A_1,..,A_k$ agree on

Examples:

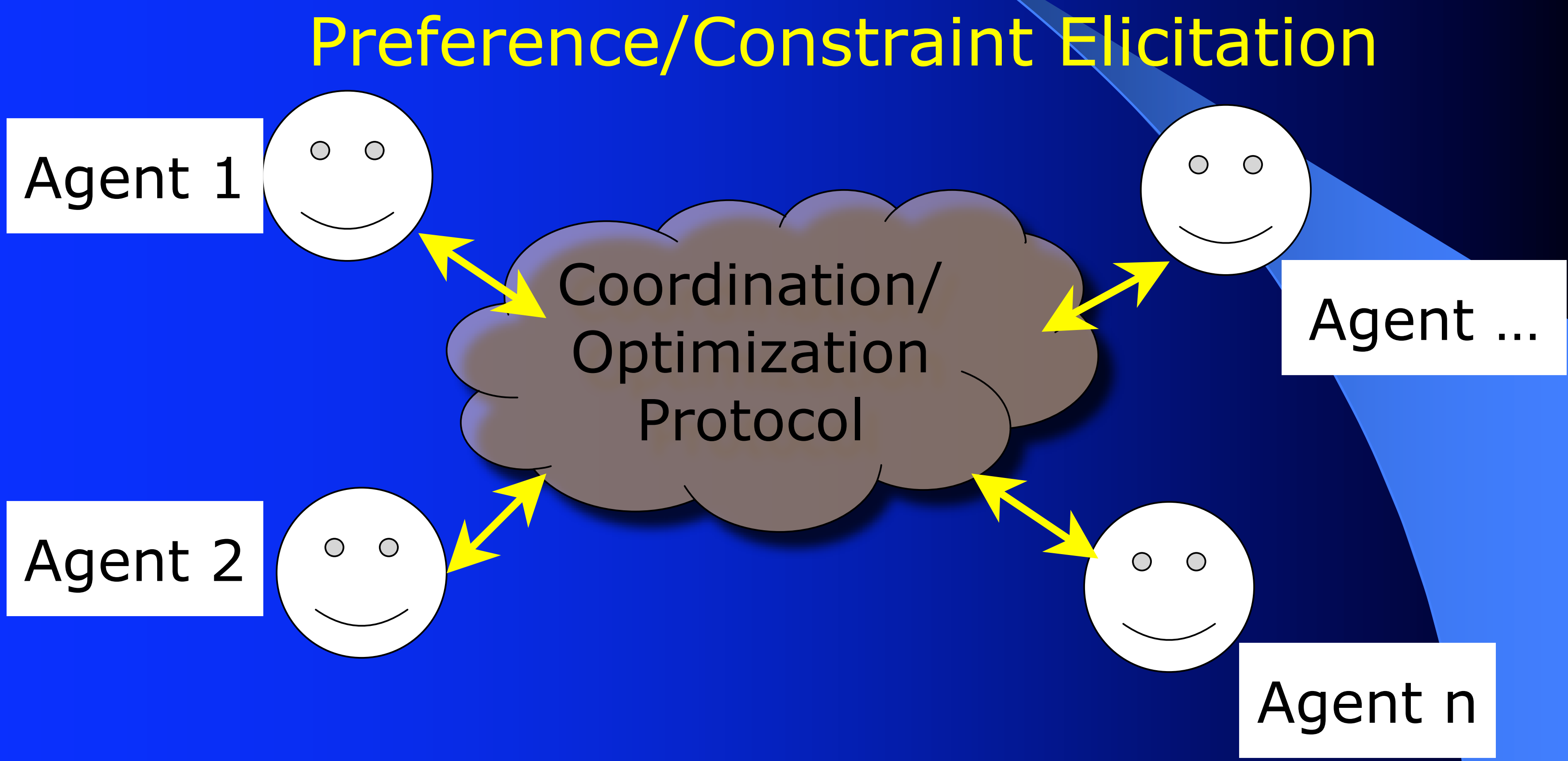
- How to share airspace, radio spectrum, power lines, etc.
- Public policy decisions
- Dividing an inheritance
- …



Example: Slot Allocation

- Airport runway can take only 1 plane/minute: 1 slot/minute
- Allocation:
  - what slot requests are granted?
- Coordination constraints:
  - flight needs takeoff and landing slot at different airports
  - flights need to be in sequence (rotation)

Agent-based Social Choice (Coordination)



EPFL results...

Distributed Constraint Satisfaction:

- AAS + successors [Silaghi,2000]
- Breakout [Eisenberg,Petcu,2003]
- DPOP [Petcu,2005-2006]

Preference/Constraint Elicitation:

- Open Constraint Programming [Macho-Gonzalez,2002-2005]
- Example-critiquing [Pu,Torrens,Chen,Viappiani,1997-2006]

Example

- Airport has 2 slots
- 4 airlines A_1-A_4 want to use a slot
- They value its utility as follows:

A_1	A_2	A_3	A_4
10	8	3	1

Choosing a solution

Maximize sum of values:

- A_1 and A_2 get the slots

=> A_3, A_4 would exaggerate their utilities!

=> coordination and optimization make no sense!

Incentive-compatibility

Agents have conflicting incentives
=> do not cooperate for best solution

Social choice mechanism should make incentives *compatible*
=> Achieve by side payments

Auctions

- Charge a variable fee for each slot
- English auction: increase fee until demand = supply

A_1	A_2	A_3	A_4
10	8	3	1

$\Rightarrow A_1$, A_2 can fly; each pays \$3($+\varepsilon$)

Give revenue (\$6) to airport

Incentive-compatibility

IC mechanism makes equivalent:

- optimizing agent's own utility
- optimizing combined utility

Auction achieves IC for airlines:

only agents with highest valuations have interest in winning auction

Incentives

If a runway is "closed for maintenance":

- only A_1 gets a slot
- how much does it pay?

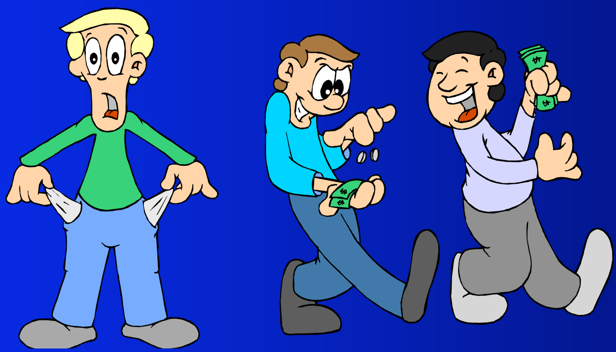
A_1	A_2	A_3	A_4
10	8	3	1

\$8(+ε) > \$6: airport revenue increases!

=> bad service is rewarded

Incentive-compatibility

- Auction is incentive-compatible for airlines, but not for airports!



- Right incentive: airport has no revenue from auction, but only from fees

An Impossible Objective?

Game theory:

impossible to simultaneously have:

- Budget-balance (no revenue/loss)
- Incentive compatibility
- Individual rationality
- Efficiency (optimality)

Proposals

- Return approximate refunds:
  - DaGVA [d'Aspremont & Gerard-Varet, 1979]
  - Primal refund [Bailey,1997]
  - Optimal redistribution [Cavallo 2006]
- Automated mechanism design: design a mechanism for a specific situation [Sandholm, 2003]
- Approximate IC [Parkes et al., 2001]

Redistribution (1)

- Primary refund to N agents [Bailey,1997] :
- Refund(agent i)= (total tax due in an economy without agent i)/N
- Total tax goes to 0 as $1/N^2$
- But can generate budget deficit

Redistribution (2)

- Redistribution mechanism for auctions [Cavallo 2006] [Bailey,1997] :
- Let V_i be the i-th highest valuation
- Refund to 2 highest bidders: V_3/N
- Refund to others: V_2/N
- No deficit
- Surplus goes to zero as $1/N^2$

RM example

- 1 item, 4 interested agents:

	V_i	Tax_i	R_i
1	10	8	5/4
2	8	0	5/4
3	5	0	2
4	4	0	2
Σ		8	6.5

Optimality

- Single/multiple item auction: can do better than RM (Conitzer, forthcoming)
- General case: VCG is already optimally balanced ([Cavallo 2006])

Revenue-free Auctions

Solution: give up optimality

- choose one agent to be excluded
- auction slots among remaining agents
- give revenue to excluded agent
- excluded agent chosen independently of declarations (random, round-robin, etc.)

Example

A_1 excluded => valuations:

A_1	A_2	A_3	A_4
10	8	3	1

$\Rightarrow A_2$, A_3 get a slot; each pays \$1(+ε)

give revenue (\$2) to A_1

Variant: random choice of excluded agent

Example (2)

Left out	Winners	Payment
A_1	A_2,A_3	2*$1
A_2	A_1,A_3	2*$1
A_3	A_1,A_2	2*$1
A_4	A_1,A_2	2*$3

Expected Outcomes

Airline	P(slot)	E[Payment]
A_1	¾	$ ¾
A_2	¾	$ ¾
A_3	½	0
A_4	0	- 2*$ ¾

Assumption: each agent left out with p=1/4

Properties

- Incentive-compatible for airlines:
  - A excluded: declarations do not matter
  - A included: equal to auction
- Individually rational for airlines:
  - A excluded: receives payment
  - A included: equal to auction
- Incentive-compatible for airport:
  - Best service optimizes income

Properties (2)

- Solution is suboptimal:
  - E[Utility] = 15 instead of 18
- But auctions not optimal either:
  - Total airline utility = 18-6 = 12
- Utility almost always better than auctions!

Formalizing Social Choice

Constraint optimization problem (COP) <X,D,C,R>:

- X = set of n variables (choices)
- D = set of n domains (options)
- C = set of m constraints (restrictions)
- R = set of p relations (valuations)
- Relations belong to agents $A_1,..,A_k$: $R_i = R(A_i)$, $R = \cup R_i$

Efficient Solution

$V^{*}_{R}(X)$ = assignment to X that

- satisfies all constraints
- maximizes sum of utilities in R

Incentive-compatibility…

- "Auction" mechanism => VCG tax:
  $Pay(A_i) = \sum_{j \neq i} R_j(V^*_{R \setminus R_i}) - R_j(V^*_R)$
  ("damage" to others)
- Incentive-compatible: agents best off to declare their true relations
- Tax decomposes by relations:
  $Pay_r(A_i) = r(V^*_{R \setminus R_i}) - r(V^*_R)$

Revenue-free VCG Tax

As in revenue-free auction:

- Choose excluded agent A_e
- Others optimize outcome
- Pay VCG tax to excluded agent:

  $Pay(A_i \to A_e) =$

$$\sum_{j \neq i,e} R_j(V^*_{R \setminus (R_i \cup R_e)}) - R_j(V^*_{R \setminus R_e})$$

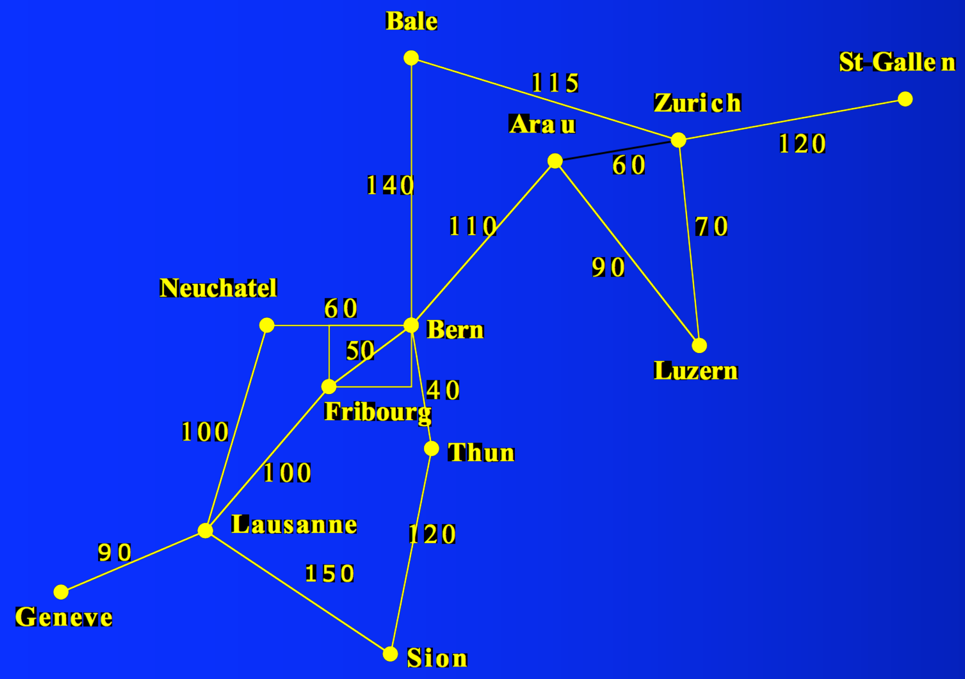
Suboptimal solution, but how bad?

Evaluating Mechanisms

Methodology: evaluate average performance on randomly generated problem instances

- Structured: model a real-world scenario
- Unstructured: completely random

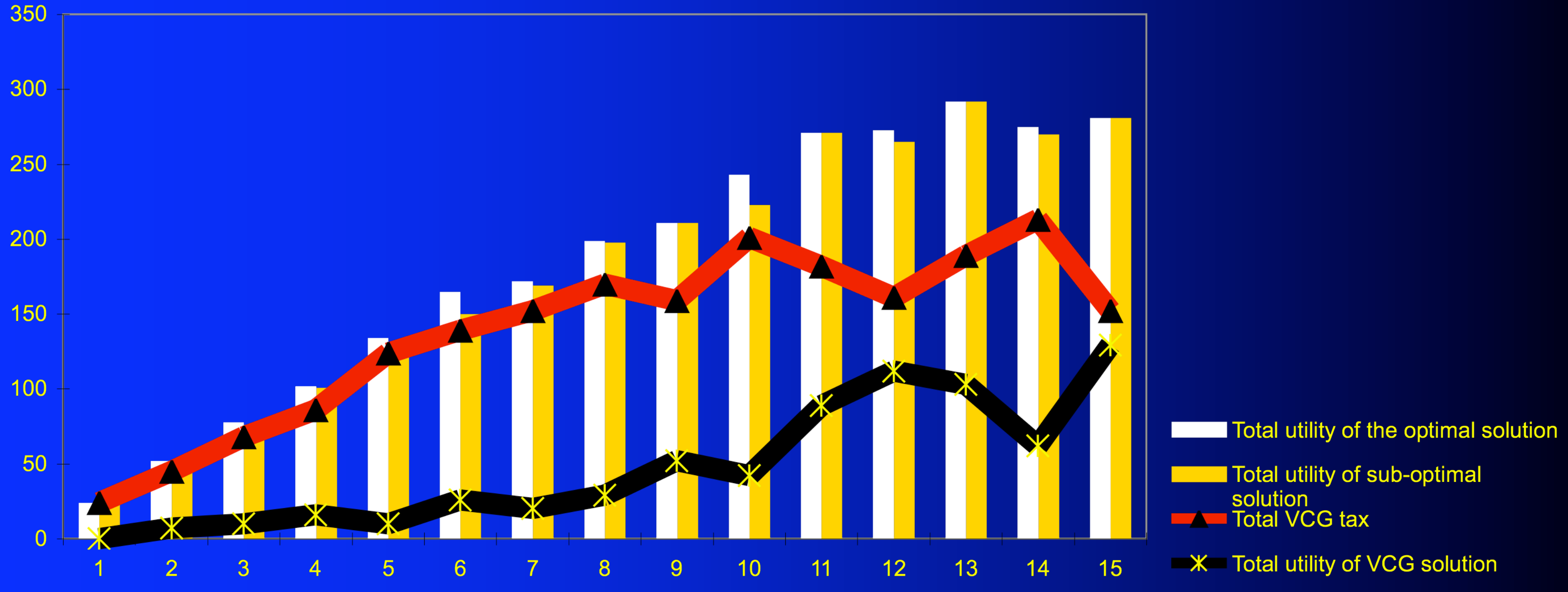
Resource allocation in networks



- Agents have different tasks and utilities
- Task = connect 2 nodes in graph
- Each link can only be used for one task

=> Allocate tasks to maximize revenue

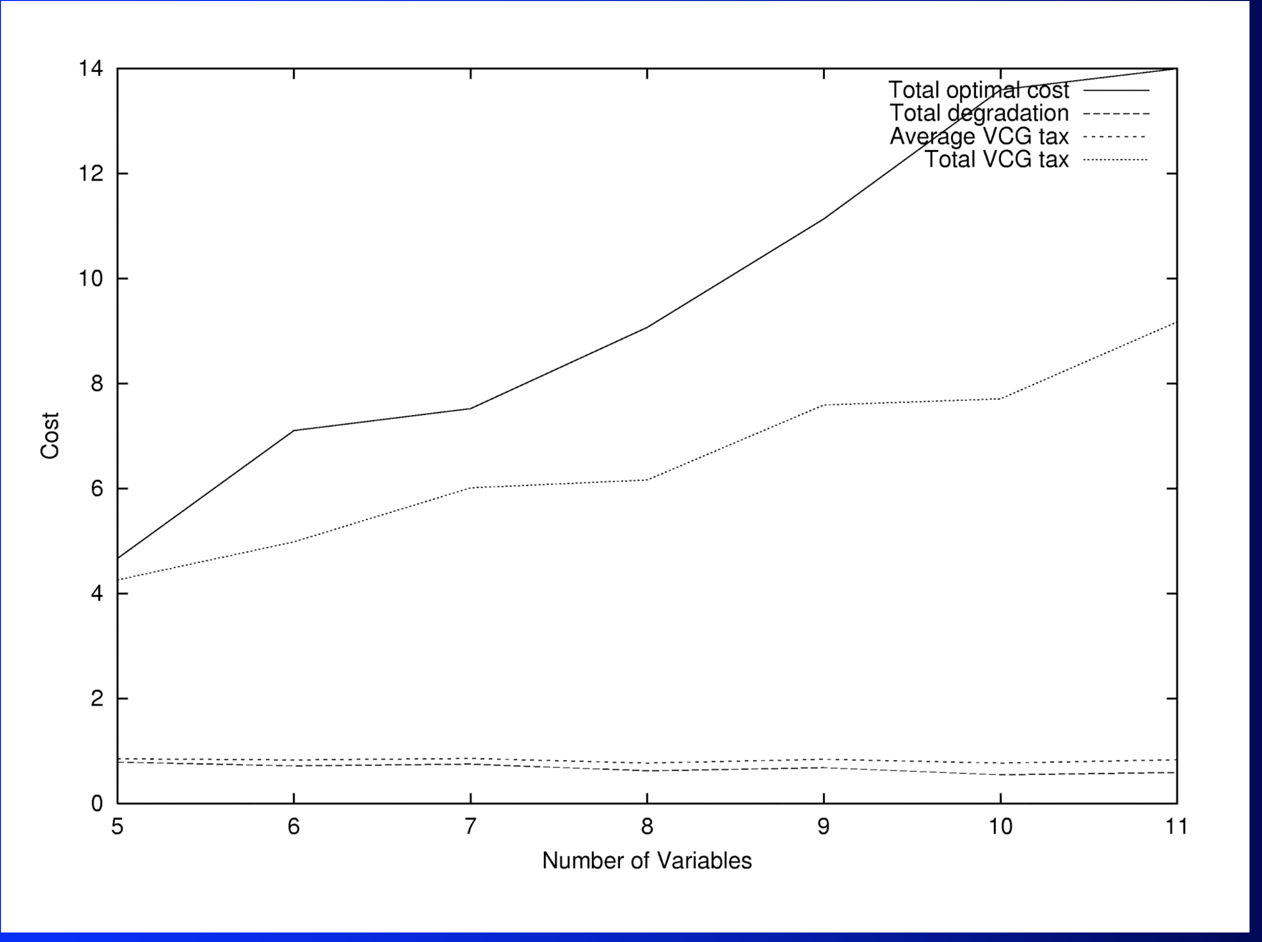
Network resource allocation



Unstructured problems

- Randomly generate set of variables, choices and constraints
- Relations = random value for each combination, uniformly distributed in [0..1], model cost
- Each agent seeks to minimize sum of its relations

Random Problems



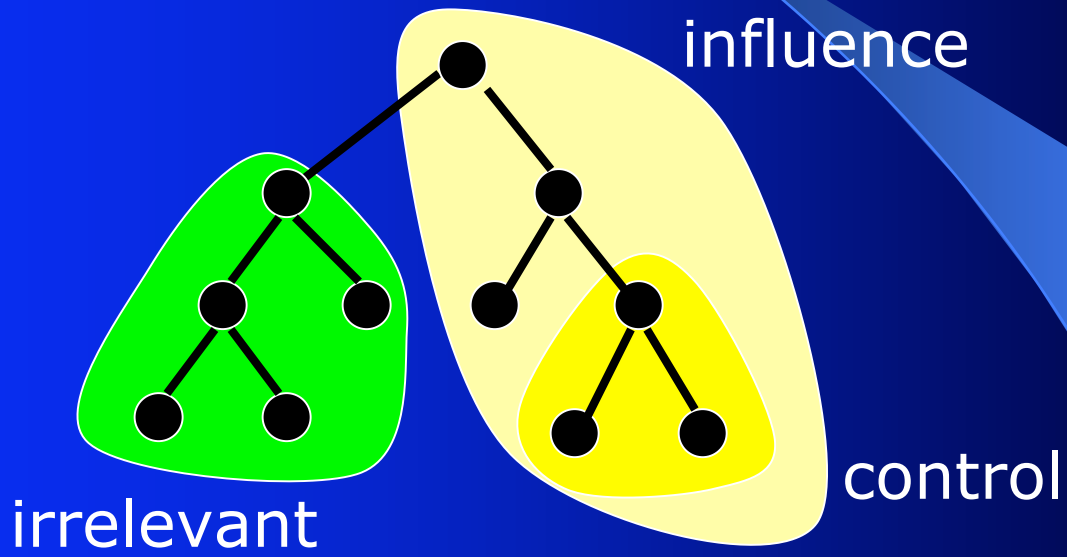
A problem…

One agent excluded everywhere

=> one airline gets no slots…

- Solution: use problem structure to exclude different agents in different parts of the problem

Spheres of Influence



- Consider influence of agent Ai
- Ai can receive tax from decisions where it is irrelevant

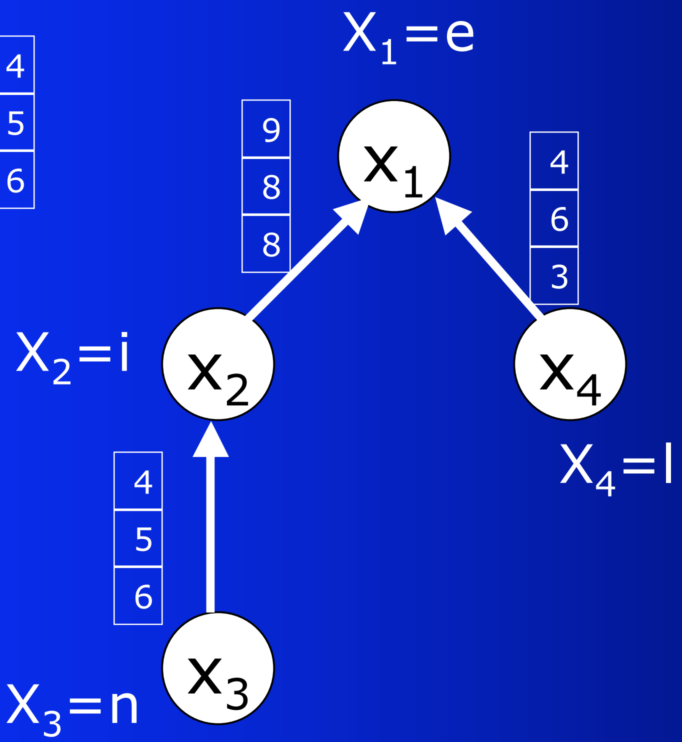
DPOP [Petcu & Faltings, 2005]

	x_1: d	e	f
x_2: g	[illegible]	[illegible]	[illegible]
h	8	[illegible]	8
i	9	8	[illegible]

+

4
5
6

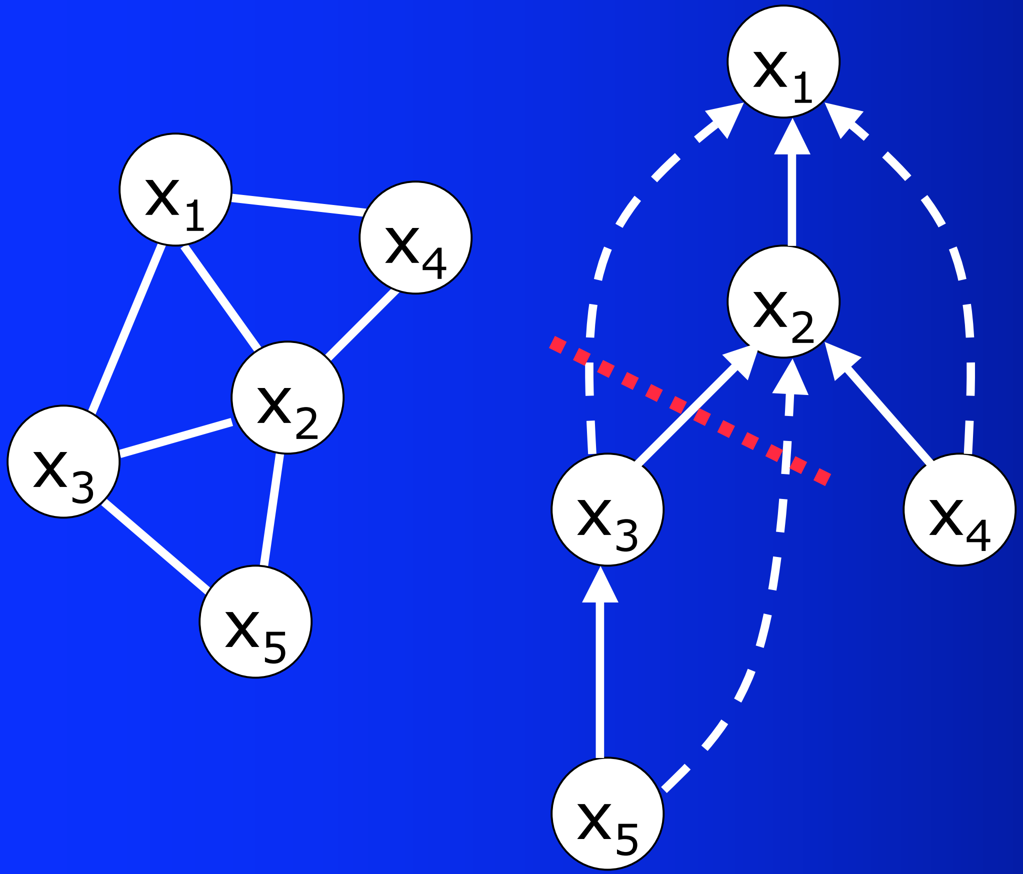
	x_2: g	h	i
x_3: m	4	2	2
n	3	5	6
o	1	3	2



	x_1: d	e	f
x_4: j	3	4	2
k	4	2	3
l	2	6	2

4	+	9	=	13 d
6		8		14 e
3		8		11 f

DFS orderings [Dechter, 1991]



- Tree and back edges
- Nodes have ≤1 ancestor
- Separator S(x) isolates subtree below x
- Utility of subtree = message of dimension S(x)

MDPOP [Petcu et al., 2006]

- Apply DPOP to compute both
- full economy V^*_R and
- marginal economies $V^*_{R \setminus R_i}$, for all agents i
- Many messages are identical in marginal and full economy => savings
- VCG mechanism makes this algorithm/message-compatible

VCG in MDPOP

- VCG tax:

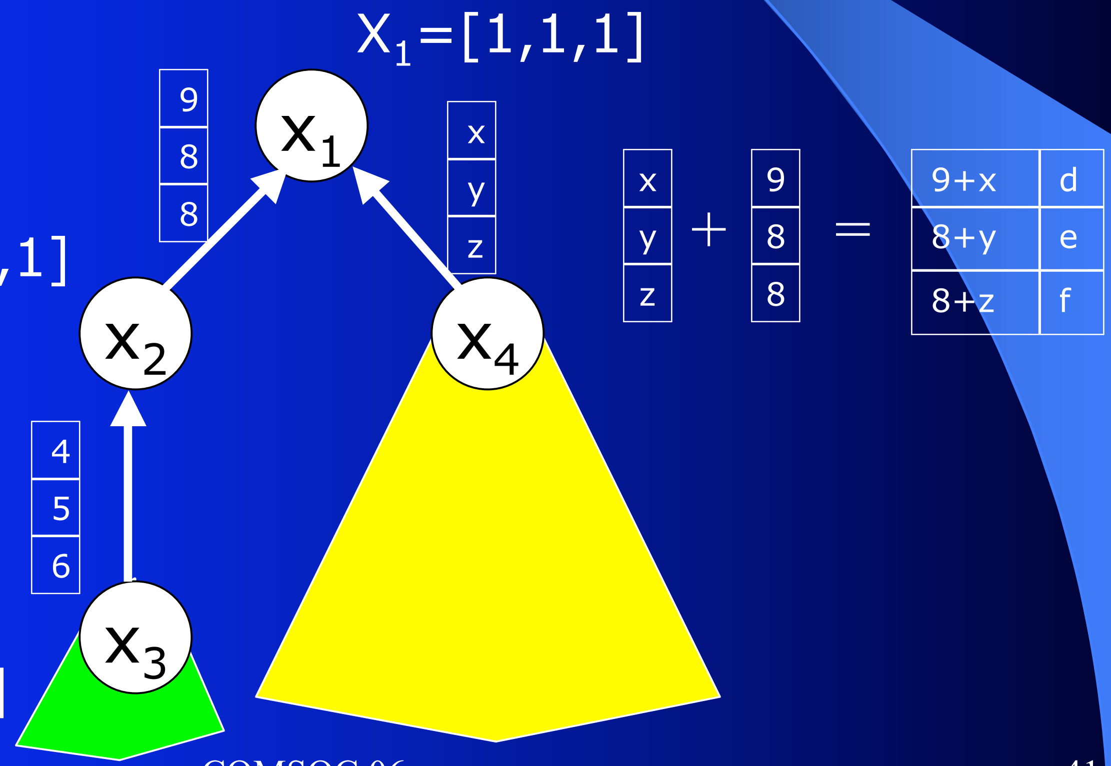
  $Pay(A_i) = \sum_{j \neq i} R_j(V^*_{R \setminus R_i}) - R_j(V^*_R)$
- Tax decomposes by relations:

  $Pay_r(A_i) = r(V^*_{R \setminus R_i}) - r(V^*_R)$
- computed locally by agents controlling variables in r
- Can be paid to agents that cannot influence variables in r

Agent influence

x_2 \ x_1	d	e	f
g	6	7	4
h	8	6	8
i	9	8	7

x_3 \ x_2	g	h	i
m	4	2	2
n	3	5	6
o	1	3	2



Label propagation

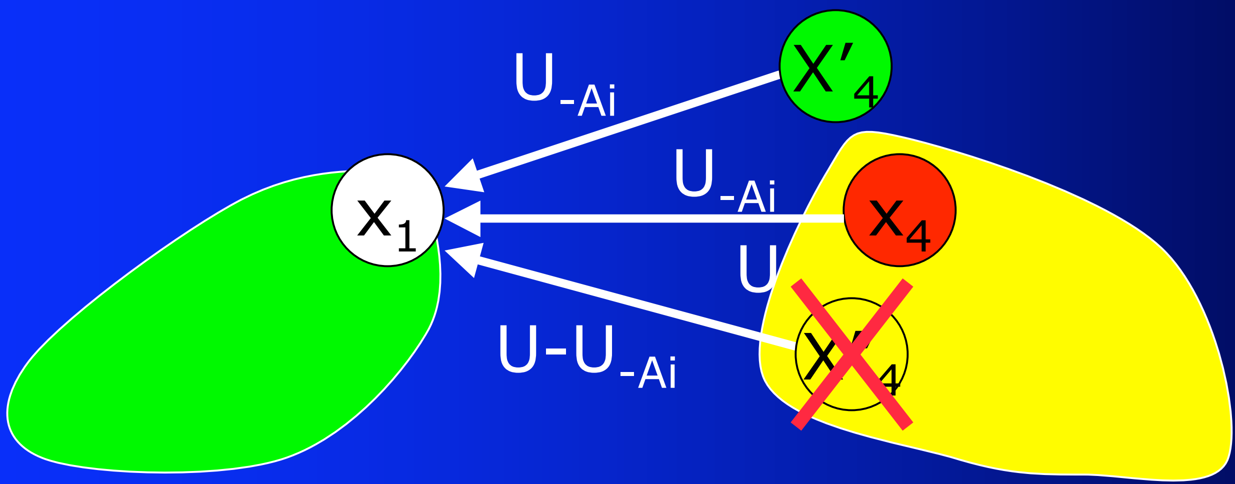
- Let z be the highest node influenced by agent A (here: z=x4)
- Consider the parent of z to be the root (omnidirectional propagation)
- Assume A can set the root to any value
- Downward propagate possible values
- Eventually only 1 value remains: A can no longer influence

Tax redistribution

- For each relation, choose an agent that will receive the tax (independently of relations)
- Carry out propagation, if agent is irrelevant for all variables in the relation, it will receive the tax
- Problem: have to choose agent *before* knowing its influence => redistribution not guaranteed

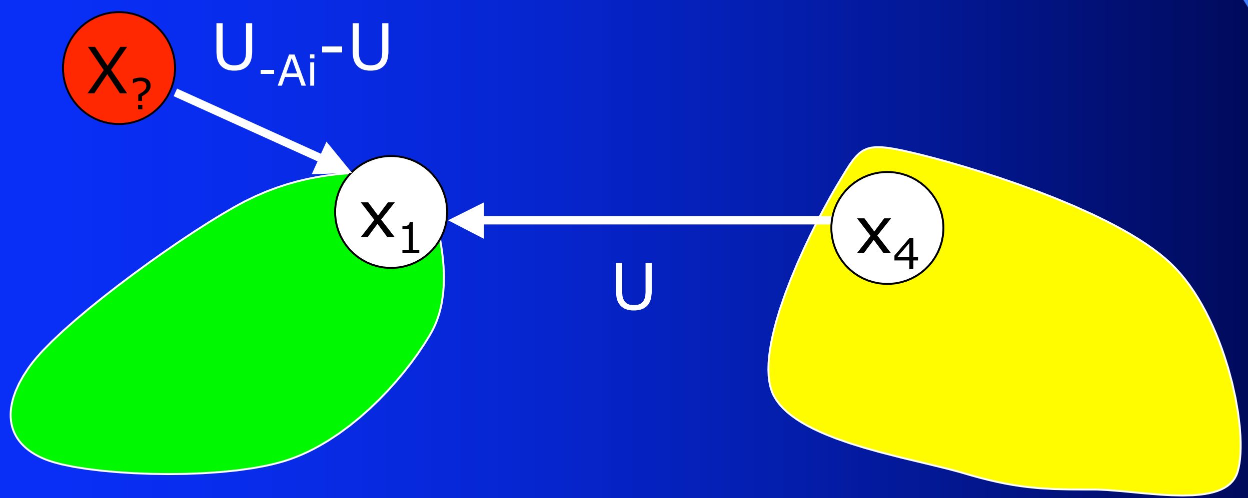
Eliminating influence

- Util messages carry all influence of the subtree below
- Eliminate all relations posed by Ai in subgraph beyond x_1
- Consider messages U and U_{-Ai}(for marginal economy E_{-Ai}): influence of agent Ai = difference U - U_{-Ai}
- X_1 cannot distinguish from presence of X''_4
- Propagate U_{-Ai} instead of U



Value propagation

- X1 set to value that is optimal with U_{-Ai}
- X4 cannot distinguish from situation where x1 was influenced by declarations of other agents
- X4 and subtree below should take Ai into account
- Propagate downward using U



Incentive-compatibility

- MDPOP without limiting influence is IC/IR
- Assignments and taxes in green area as as in problem without Ai => IC/IR
- Assignments and taxes in yellow area are optimal with respect to the context set by x1 => IC/IR for Ai
- Assignments and taxes across the problem are optimal for problem with additional utility imposed on x1 influenced by Ai => IC/IR for agents other than Ai
- => IC/IR for all agents

Exact budget-balance

- For each agent, decide its spheres of influence
- Decide redistribution scheme: which agent gets which tax outside its scope of influence
- Collect utility declarations
- Carry out propagation, substituting U_{-Ai} for U wherever scope of Ai ends
- Pay taxes as in MDPOP, using redistribution scheme

Issues

- DFS tree stability
- Self-interest in DFS tree generation
- Criteria for deciding participation and redistribution scheme
- Positive externalities

Conclusion

- Increasing population means increasing contention of resources

=> increasing need for social choice

- Traditional protocols are inefficient
- Market mechanisms create wrong incentives
- Agent-based systems can implement new decision mechanisms that provide the right incentives to everyone