A Multi-Agent Resource Negotiation for the Utilitarian Social Welfare

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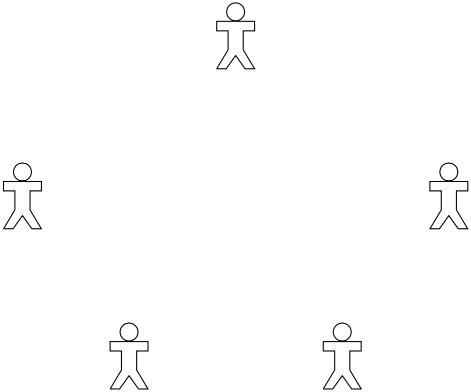
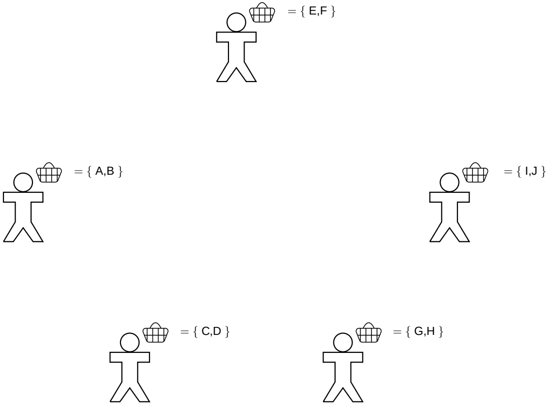
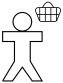
Resource Allocation Framework

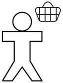


Resource Allocation Framework



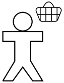
Agent Preferences



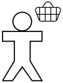


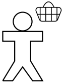
Preferences of an agent *a*

Resource	Value
⋮	⋮
r_i	v_i
⋮	⋮



$$v_i \in \mathbb{N}^*$$





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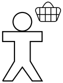

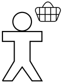

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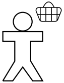
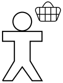
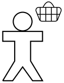
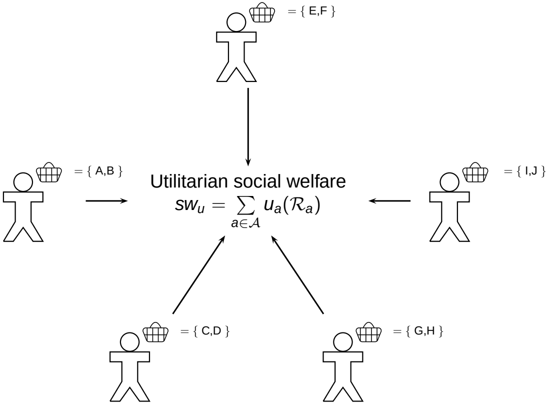
$$u_a(\mathcal{R}_a) = \sum_{r \in \mathcal{R}_a} u_a(r)$$







Allocation Evaluation



Solving Approaches

Centralized approach

An agent gathers all information, solve the allocation problem, and report the solution to the other agents (e.g., an auctioneer).

- Complete information
- Complete contact network

However, such an approach is not plausible for many applications.

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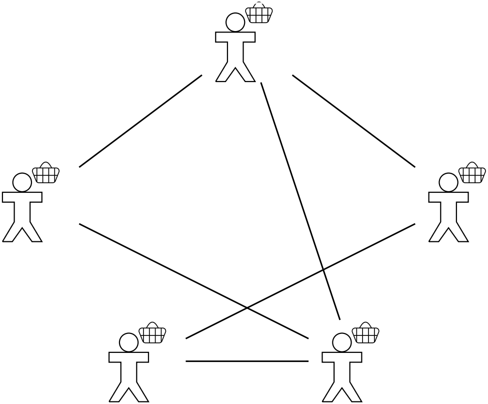
Distributed approach

The solution starts from an initial resource allocation, and evolves, little by little, by means of local negotiations among the agents.

- Any type of contact network
- Negotiation made on partial information

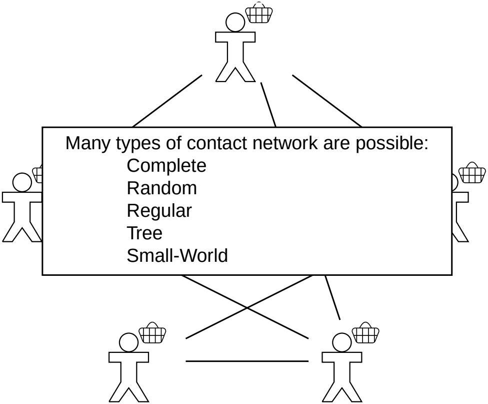
Solving Approaches

5 agents linked by means of a random contact network



Solving Approaches

5 agents linked by means of a random contact network



Solving Approaches

Distributed approach

The solution starts from an initial resource allocation, and evolves, little by little, by means of local negotiations among the agents.

- Any type of contact network
- Negotiation made on partial information

Our objective

Our objective is to define an agent behavior which leads the community to an socially optimal resource allocation thanks to the emergence of a convergence phenomenon, based on any kind of contact network.

Optimum Definition

Kind of optimum

An optimal allocation is an ashamed notion in the literature. Two types of optimum can be distinguished:

- Global Optimum

Global Optimum

- No other resource allocation associated with a greater social value
- Independent of the allowed transaction types
- The social value is unique but not the resource allocation
- May not be reachable

Optimum Definition

Kind of optimum

An optimal allocation is an ashamed notion in the literature. Two types of optimum can be distinguished:

- Global Optimum
- T-global Optimum

T-global Optimum

- No transaction sequence, belonging to the set T of allowed transactions, leads to a resource allocation associated with a greater social value
- May be suboptimal

Acceptability Criteria

Assume that a transaction transforms an initial allocation A into another resource allocation A'. The resource bundle associated with the agent a is respectively denoted by R_a and R'_a.

Rationality

Involved agents has to increase their utility in such a deal.

$$u_a(A') \geq u_a(A) \qquad a \in \mathcal{A}$$

$$\sum_{r \in \mathcal{R}'_a} u_a(r) \geq \sum_{r \in \mathcal{R}_a} u_a(r) \qquad a \in \mathcal{A}$$

Acceptability Criteria

Assume that a transaction transforms an initial allocation A into another resource allocation A'. The resource bundle associated with the agent a is respectively denoted by R_a and R'_a.

Sociality

The value of the local measure of the social welfare function has to increase in such a deal.

$$sw(A') \geq sw(A)$$
$$u_a(\mathcal{R}'_a) + u_{a'}(\mathcal{R}'_{a'}) \geq u_a(\mathcal{R}_a) + u_{a'}(\mathcal{R}_{a'}) \qquad a, a' \in \mathcal{A}$$

Transaction Kind

Three kinds of bilateral transactions, involving 2 agents a and a' can be defined. The agents own respectively m_a and $m_{a'}$ resources in their bundle.

Transaction and negotiation complexity

- the gift (m_a)
- the swap ($m_a \times m_{a'}$)
- the cluster-swap ($2^{m_a - 1} \times 2^{m_{a'} - 1}$)

The compensatory payments are not considered: if the money is not considered as a resource, payments correspond to an extension of the set of possible transaction.

Evaluation Criteria

Different facets of the negotiation process have to be considered for a fair evaluation. Otherwise, depending of the metrics considered, the results quite vary.

Metrics

- Number of performed transactions
- Number of exchanged resources
- Number of speech turns
- Number of attempted transactions

Moreover, in order to evaluate the efficiency of a negotiation process, the social value associated with the resource allocation finally reached and the optimal social value have to be compared.

Experimental Protocol

- Each agent sorts his bundle of resources before a negotiation. Indeed, he tries to involved firstly the resource which are associated with a smaller utility according to his preferences.
- The initiator is randomly chosen in the multi-agent system.
- The initiator randomly chooses a neighbor, and starts the negotiation. If no acceptable transaction are possible, then they simply abort the negotiation.

On a Complete Contact Network

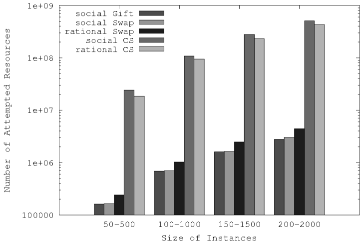
Difference(%) between the optimal social value and the one associated with the resource allocation that is finally reached by the negotiation process, on instances populated by *n* agents with *m* resources.

n	m	Social(%)			Rational(%)	
		Gift	Swap	CS	Swap	CS
50	500	0.01	0.94	0.96	2.15	4.71
100	1000	0.01	0.76	0.76	1.53	4.9
150	1500	0.01	0.65	0.71	1.31	3.9
200	2000	0.01	0.56	0.60	1.15	2.5

The social gift leads to an optimal resource allocation most of the time.

Transaction Efficiency

Here, the number of attempted transactions explodes when cluster-swap transactions are considered.



The size of the instances has a weak impact, independently of the considered metrics: the ratio among them do not vary.

On a Random Contact Network

Difference(%) between the optimal social value and the one associated with the resource allocation that is finally reached by the negotiation process, on instances populated by *n* agents with *m* resources.

n	m	Social			Rational	
		Gift	Swap	CS	Swap	CS
50	500	1.3	3.41	3.4	6.05	5.88
100	1000	0.73	1.88	1.72	3.63	3.59
150	1500	0.43	1.3	1.35	2.69	2.42
200	2000	0.31	1.22	1.02	2.3	2.05

Behavior Variants

If the agent initiator and the selected neighbor find an acceptable transaction, it is then performed. Otherwise, three different tasks:

Alternative tasks

- Abort the negotiation
- Choose another neighbor
- Choose another resource

Four different behaviors can thus be defined.

Behavior Variants

First, a behavior which involves the cheapest resource with a selected neighbor:

Table: Behavior A

```
Sort my resource bundle
Random selection of a neighbor a
Selection of my resource r associated
      with the lowest utility
If the transaction is acceptable
   Give r to a
   End the negotiation
```

Behavior Variants

Next, a behavior which allows the initiator to negotiate the resource to exchange with a selected neighbor:

Table: Behavior B

```
Sort my resource bundle
Random selection of a neighbor a
For each resource r of my bundle
  If the transaction is acceptable
    Give r to a
    End the negotiation
```

Behavior Variants

Next, a behavior which allows the initiator to change the selected neighbor but involves always the cheapest resource:

Table: Behavior C

```
Sort my resource bundle
Selection of my resource r associated
        with the lowest utility
For each neighbor a
    If the transaction is acceptable
        Give r to a
        End the negotiation
```

Behavior Variants

Finally, a behavior which allows the initiator to change either the involved resource or the selected neighbor:

Table: Behavior D

Sort my resource bundle
For each resource *r* of my bundle
  For each neighbor *a*
    If the transaction is acceptable
      Give *r* to *a*
      End the negotiation

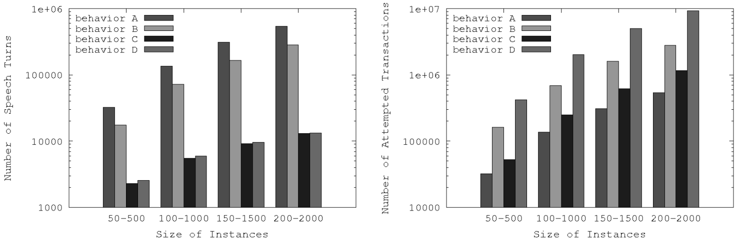
Behavior Comparisons

Comparison of the gap obtained between the different behaviors depending on instances of n agents with m resources.

n	m	A	B	C	D
50	500	1.2	0.01	1.1	0
100	1000	0.5	0.01	0.5	0
150	1500	0.3	0.01	0.3	0
200	2000	0.2	0.01	0.2	0

Flexible behaviors have similar results, by finally reaching an optimum, whereas the others stop on a suboptimal resource allocation.

Behavior Comparisons



The left-sided figure shows that the number of speech turn is higher with rooted behavior, and the rightmost figure shows the greater number of attempts with flexible behaviors.

Conclusion & Further Works

We have defined an agent behavior which leads the community to an socially optimal resource allocation thanks to the emergence of a convergence phenomenon, based on any kind of contact network.

- distributed agent-based approach
- contact network notion
- adaptive process
- anytime algorithm

New practical enhanced negotiation processes have to be designed when different social welfare function are considered.

Egalitarian social welfare

Table: Optimality gaps for the social gift when the egalitarian welfare is considered

$n - m$	50 - 500	100 - 1000	150 - 1500	200 - 2000
Gap (%)	31.08	32.61	31.50	32.4