Coalitions of Information Agents

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Basics of Cooperative Game Theory In Very Brief ...

Rational agents collaborate in stable coalitions to gain and increase individual, and share joint benefits.

- Cooperative game (*A, v*) $v : 2^A \rightarrow \Re$
  - Finite set *A* of n agents
  - **Coalition value** *v(C)* as maximum joint (production) utility value of m<=n agents in **coalition** $C \subseteq A$
  - *Super-additive* $\forall C_1, C_2 \subseteq A : v(C_1 \cup C_2) \geq v(C_1) + v(C_2)$
- **Solution** *(S, u)* of game *(A, v)*
  - **Partition** *S* **of** *A* into coalitions
  - **Payoff distribution** *u* of coalition values *v* $u : A \rightarrow \Re$
    - Efficiency („nothing gets lost")

Example: Simple Coalition Game ({a1, a2, a3}, v)

Information agents a1, a2, a3 get paid by their users for relevant items.

<u>Goal</u>: ***Maximize individual profits by collaboration in joint coalitions***

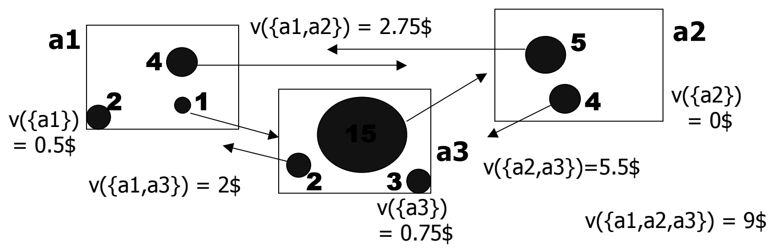
Let be

- Homogeneous **production utility** *U(p)* = 0,25$ f.e. relevant (produced) item *p* in production set P(a) of each agent.
- **Local value** *worth(a, C)* of agent *a* in coalition *C* = Sum of monetary paments U(p) agent *a* can obtain from its user for relevant items p it has produced itself, or jointly with potential coalition partners in *C.*

"Local": *Total amount of money, the agent gets from its local user(s), hence can contribute to the joint coalition value v(C) in case C forms.*

- **Coalition value** *v(C)* = Sum of local values of its members.

Example: Simple Coalition Game ({a1, a2, a3}, v)



Local agent value:

worth(**a1, {a1, a2}**)= 2*0.25$ + 5*0.25$ = 1.75$
worth(a2, {a1,a2}) = 0 + 4*0.25$ = 1$

Coalition value:

v({a1,a2}) = worth(a1, {a1, a2}) + worth(a2, {a1,a2}) = 2.75$

Properties of Coalition Games (A, v)

Super-additive: $\forall C, C' \subseteq A, C \cap C' = 0 : v(C \cup C') \geq v(C) + v(C')$

Sub-additive: $\exists C, C' \subseteq A, C \cap C' = 0 : v(C \cup C') < v(C) + v(C')$

Essential: $\exists C, C' \subseteq A, C \cap C' = 0 : v(C \cup C') > v(C) + v(C')$

Symmetric Players: $\forall C \subseteq A, a, a' \notin C : v(C \cup \{a\}) = v(C \cup \{a'\})$

Desirable Players: $\forall C \subset A, i, j \notin C : v(C \cup \{a_i\}) \geq v(C \cup \{a_j\})$

Game-Theoretic Concepts of Rationality

Individual rationality $\forall a \in A : u(a) \geq v(\{a\})$

- agents obtains at least its self-value as payoff
- assumed to hold for any configuration (S, u) under consideration.

Group rationality $\sum_{a \in A} u(a) = v(A)$

- Collectivity A of all players is rational, i.e. maximizes joint payoff for A:
  Any GR agent will refuse any proposed (S, u) with u(A)<v(A), no matter how agents split into coalitions in S.

  If u(A)<v(A) then something is lost. Set u'(a) = u(a) + (v(A)-u(A))/n
  u(A)>v(A) not possible in super-additive games
- For superadditive games, GR payoff distributions are **Pareto-optimal**

Game-Theoretic Concepts of Rationality (2)

Vilfredo F. S. Pareto (1848 – 1923)

Pareto-optimal payoff distribution u

$$\neg \exists u' \in U((A,v),S):$$
$$(\exists a \in A: u'(a) > u(a), \forall a' \in A \setminus \{a\}: u'(a) \geq u(a))$$

Local Pareto-optimality („Pareto-optimal in L"):

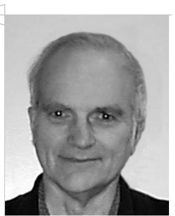
$$L \subseteq U((A,v),S): \neg \exists u' \in L:$$
$$(\exists a \in A: u'(a) > u(a), \forall a' \in A \setminus \{a\}: u'(a) \geq u(a))$$

Coalitional rationality $\forall C \subseteq A: \sum_{a \in C} u(a) \geq v(C)$

- Group rationality principle of payoff maximization applied to *any* subset of A

$$CR \Rightarrow GR \Rightarrow IR \text{ (not vice versa)}$$

Sidepayments: Transfer Schemas by Stearns (1968)



Richard Edwin Stearns

In sequence of configurations $(S,u^{(1)}),\ldots,(S,u^{(i)}),\ldots$
sidepayments α between pairs of agents *(k,l)*
are iteratively exchanged following the scheme

$$(S,u^{(i+1)}) = \begin{cases} u_k^{i+1} := u_k^i + \alpha \\ u_l^{i+1} := u_l^i - \alpha \\ u_j^{i+1} := u_j^i \, (j \neq k,l) \end{cases}$$

- The computation of the specific amount of sidepayments depends on the used concept of coalition stability (coalition theory CT)
- For initial configuration (S, u*), an iterative transfer schema for CT *converges* towards a CT-stable configuration (S, u) - a solution of (A, v)

Concepts of Coalition Stability (Coalition Theories)

- **Core based stability**
  - Maximises social welfare for *any* sub-group of agents.
  - Exponentially hard to compute; core may be empty
  - Wu 1977; Sandholm et al. 1999
- **Shapley value based stability**
  - Fair payoff distribution based on marginal contributions of agents averaged over joining orders for grand coalition.
  - Exponentially hard to compute; axiomatic foundation
  - Polynomial bilateral variant (Ketchpel 1994; Klusch/Shehory 1996)
- **Kernel based stability**
  - Equilibrium: in each coalition no agent can outweigh another agent by having the option to get a better payoff in an alternative coalition excluding the opponent agent.
  - Exponentially hard to compute; exists; locally Pareto-optimal
  - Polynomial variant (Shehory/Kraus 1996; Klusch/Shehory 1996)

Relevant Literature

- R.E. Stearns: Convergent Transfer Schemes for N-Person Games, Trans. Am. Math. Soc., 134, pp. 449-459, 1968.
- D-B- Gillies: Solutions to General Non-Zero-Sum Games, pp. 47-85 in Contributions to the Theory of Games, Vol IV, Annals of Mathematics Studies, 40, A. W. Tucker and R. D. Luce (eds.), Princeton University Press, 1959.
- L.S. Shapley: A Value for n-Person Games, pp. 307-317 in Contributions to the Theory of Games, Vol II, Annals of Mathematics Studies, 28, H. W. Kuhn and A. W. Tucker (eds.), Princeton University Press, 1953.
- M. Davis, and M. Maschler: The Kernel of a Cooperative Game, Naval Research Logistics Quarterly 12, 223-259, 1965.

The Core (Shapley & Gillies, 1953)

The Core of a game (A,v) for given coalition structure S is the set of Allocations that cannot be improved by any coalition, i.e., it is the set of *coalition rational payoff configurations* (S,*u*)

$$Core = \left\{ (S,u) : \forall C \subseteq A : \sum_{a \in C} u(a) \geq v(C) \right\}$$

- Computationally expensive (exponential complexity)
- May be empty, and not unique

  Ex: This game has no Core stable solution ...

  $A = \{a_1, a_2, a_3\}; v(\{a_1, a_2\}) = 90, v(\{a_1, a_3\}) = 80,$
  $v(\{a_2, a_3\}) = 70, v(A) = 105$

A Transfer Schema for C-Stable Payoff Configurations

Given any initial (S,u) for game (A, v). Each agent iteratively does

- Compute sidepayments

$$u^{i+1}(a) = u^i(a) + \alpha,\ \alpha = \frac{v(C) - \sum_{a' \in C} u^i(a')}{|C|},\ a \in C$$

  „Every's agent's payoff is decremented equally just enough to keep the total payoff vector u feasible."

- Update coalitions by the ordering of
  - round-robin, or
  - largest value $v(C) - \sum_{a' \in C} u(a')$ first
- If the core of the game is non-empty the scheme converges toward a payoff distribution u in the core of (A,v), and oscillates otherwise.

The Shapley Value (Shapley, 1953)

Lloyd Shapley

The Shapley value of agent *a* is its fair individual payoff in the grand coalition *{A}*

$$sv(a) = \sum_{C \subseteq A} \frac{(|A| - |C|)!(|C| - 1)!}{|A|!} \cdot (v(C) - v(C \setminus \{a\}))$$

Agent a gets its added value, i.e. marginal contribution v(C) - v(C\{a}), that it brings to the grand coalition C=A, averaged over joining orders.

- Most prominent solution in economics for a „*fair*" distribution of joint profits. Originally defined for S={A} and super-additive coalition games.
- It exists, is unique, and Pareto-optimal.
- Satisfies symmetry, individual, group (but not coalition) rationality.
- Computationally expensive (exponential complexity).

SCA: A Coalition Algorithm for Shapley Value Stable Coalitions

Each agent does

- Compute the self-value *v(a)* and local values *worth(a,a')* f.e. a' in A.
- Exchange these values with all agents a' in A.
- Compute the coalition value v(C) for each potential coalition C in A

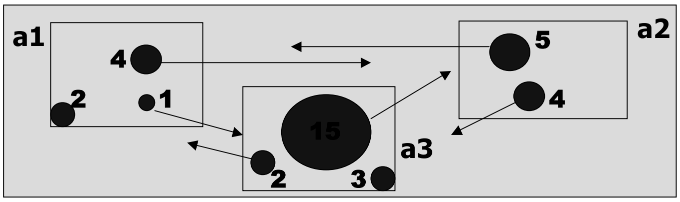
$$v(C) = \sum_{a,a' \in C} worth(a,a') - (|C| - 2) \sum_{a \in C} v(a)$$

- Compute its own benefit of joining a grand coalition as Shapley value, and individual demand for payments, in case A forms: sv(a) - worth(a, A)
- Form grand coalition with all other agents in the configuration

$$(\{A\}, (sv(a))_{a \in A})$$

The computational and communication complexity of SCA is, respectively, $O(2^n \cdot n^2)$ and $O(n^2)$

Example: Coalition Formation Using the SCA



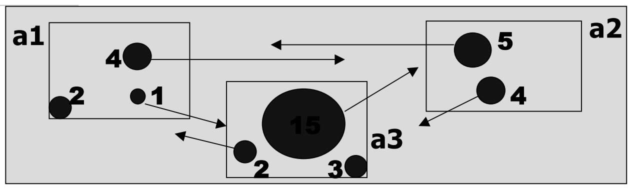
Coalition game: v(a1)=0.5, **v(a2)=0** , v(a3)=0.75, v({a1,a3})=2, v({a1,a2})=2.75, v({a2,a3})=5.5, v({a1,a2,a3})=9

Local values: worth(**a1**,a2)=0.5$ + 5*0.25$=1.75$, worth(a1,a3)=1, worth(a1, A)= 2.25$

worth(**a2**,a1)=0$ + 4*0.25$=1.25$, worth(a2,a3)=3.75$, **worth(a2, A)= 4.75$**

worth(**a3**,a1)=0.75$ + 1*0.25$=1$, worth(a3,a2)=1.75$, worth(a3, A)= 2$

Example: Coalition Formation Using the SCA



Shapley values, local user payments, and final money transfer:

**sv(a1) = 2.01$** > v(a1) = 0.5$
Payment by local user: sv(a1) - worth(a1, A)= - 0.24$ < 0 : Pay 0.24$ to a3

**sv(a2) = 3.47$** > v(a2) = 0$
Payment by local user: sv(a2) - worth(a2, A)= - 1.28$ < 0 : Pay 1.28$ to a3

**sv(a3) = 3.52$** > v(a3) = 0.75$
Payment by local user: sv(a3) - worth(a3, A)= 1.52$ > 0 :
Receive side payment of 1.52$ from a1, a2

Bilateral Shapley Value

(Ketchpel, 1994; Klusch and Shehory, 1996)

- Consider bilateral
  - **coalition** C = Union of disjunct coalitions (founders of C)
  - **coalition structure** S = A partition of A into bilateral coalitions
  - **coalition founder's payoff** u **= Bilateral Shapley value**

$$C = C_1 \cup C_2,\quad C_1 \cap C_2 = 0$$

$$BSV_C(C_1) = \frac{1}{2}v(C_1) + \frac{1}{2}(v(C) - v(C_2)),\ BSV_C(C_2) = \frac{1}{2}v(C_2) + \frac{1}{2}(v(C) - v(C_1))$$

- Bilateral coalition negotiation is performed through *leaders* of potential coalition founders.
  - Each voted coalition leader represents its coalition during negotiation, and is trusted by each member of the coalition it represents.
  - Coalition is treated as a single entity with its bilateral Shapley value.

Bilateral Shapley Value (2)

- Distribute coalition's payoff $BSV_{C+C'}(C)$ to individual agents in C
  - **Recursive share** u(a)
    - Recursively compute $BSV_C(a)$ over bilateral coalition formation history tree UG(C)
  - **Equal share** u(a)

$$u(a) = v(a) + \left(bsv_C(F_i) - \sum_{a' \neq a, a', a \in F} v(a') \right) \Big/ |F_i|$$

- Reduced computation complexity compared with that of the SCA.

Properties of Bilateral Shapley Values

- Efficient and individual rational for super-additive games and any n-agent coalition.
- Computationally inexpensive
  - Linear computational complexity of BSV
  - Polynomial: With intra-coalitional distribution of BSV
- Symmetric coalition founders get equal payoffs in the same coalition:

$$\forall C \in S, cfc(S,C) = \{F_1, F_2\}, (\forall C' \subset A, F_i \not\subset C', i \in \{1,2\} : v(C' \cup F_1) = v(C' \cup F_2)) \Rightarrow bsv_C(F_1) = bsv_C(F_2)$$

- Non-essential founders obtain no payoff:

$$\forall C \in S, cfc(S,C) = \{F_1, F_2\}, i \in \{1,2\} : (v(C \setminus F_i) \wedge v(F_i) = 0) \Rightarrow bsv_C(F_i) = 0$$

BSCA: Coalition Algorithm for Forming of Bilateral Shapley Value Stable Coalitions (Klusch & Shehory, 1996)

Each agent a performs

- Vote for coalition leader a* of own coalition C.

If a = a* then

- For all other coalitions C′ in the actual coalition structure S
  - Bilaterally communicate with coalition leaders of all other coalitions C′ in *S*
    - receive: self-value v(C′), worths of agents a′ in C′ wrt coalition C+C′
    - send: self-value v(C), worths of agents a in C wrt coalition C+C′
  - Compute bilateral Shapley value of C for joint coalition C+C′ as the expected profit of C in this potential merger.
- For all C′ in the preference list of C (ordered by expected profits for C) do
  - Send offer to i.r. coalition C′= C* with maximal expected profit of C in C+C*
  - Receive offers from coalitions in the list until end of actual round

BSCA (cont'd)

<u>Each agent a performs</u>
<u>If a = a* then</u>

- Send an approval of the maximal joint coalition (C+C*) offer to C*
- Iff an approval of this coalition offer has also been received from C* (C+C* has been **bilaterally accepted**)
  - Inform other coalitions in *S* about new coalition C+C* (new coalition structure *S**)
  - Inform agents in C on their individual payoffs in this newly formed joint coalition with C* in S*

Properties of the BSCA

◈ Payoff distribution using BSCA with proportional share is efficient and individual rational for super-additive games.

◈ In general, this does not hold for sub-additive games.

<u>Ex</u>: 2-agent game with v(a1)= -5, v(a2)= 10, v({a1,a2})= 4 (Sub-additive)
Individual equal share BSV payoffs
u(a1) = -5.5 < v(a1), u(a2) = 9.5 < v(a2) are not individual rational.

◈ Computational and communication complexity is, respectively,

$$O(n^3) \text{ and } O(n^2), n = |A|$$

<u>Proof Sketch</u>:
- Only extensions of coalitions are possible: At most n rounds.
- Communication per round per agent is in O(n).
- Each round, each agent a computes its worth(a,a') in O(n), its v(a), payoffs, and equal shares in O(n^2)

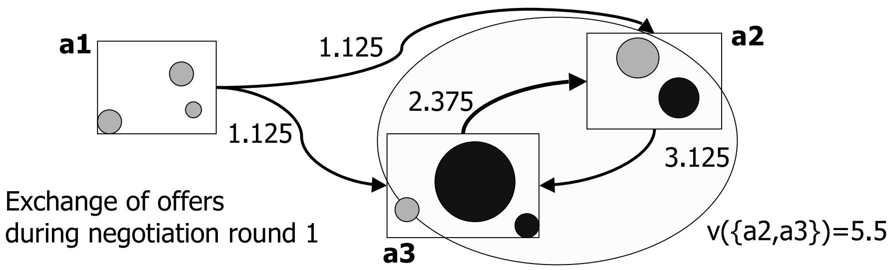
Example: Coalition Negotiation Using the BSCA

Negotiation round 1

a1: v({a1,a2})=2.75, **bsv**(a1,{a1,**a2**})= 1.625, v({a1,a3})=2, **bsv**(a1,{a1,**a3**})= 0.875
all bsv > v(a1), **a1's coalition preferences**: {a2} > {a3}

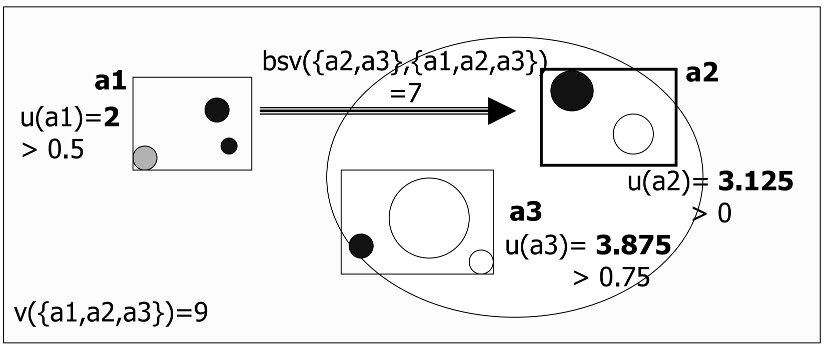
a2: v({a1,a2}), **bsv**(a2,{**a1**,a2})= 1.125, v({a2,a3})=5.5, **bsv**(a2,{a2,**a3**})= 2.375
all bsv > v(a2), **a2's coalition preferences**: {a3} > {a1}

a3: v({a1,a3})=2, **bsv**(a3,{**a1**,a3})=1.125, v({a2,a3})=5.5, **bsv**(a3,{**a2**,a3})=3.125
all bsv > v(a3), **a3's coalition preferences**: {a2} > {a1}



Example: Coalition Negotiation Using the BSCA (2)

Negotiation round 2



Polynomial BSV based coalition configuration: ({a1,a2,a3}, (2, 3.125, 3.875))

Shapley value based configuration: ({a1,a2,a3}, (2.01, 3.47, 3.52))

The Kernel (Davis & Maschler, 1965)

Michael Maschler

The Kernel of a game (A,v) for given coalition structure S is

- Set of (S,u) in which every coalition in S is *in equilibrium*

„Because I could obtain more without you than you without me, I'd deserve more payoff than you, me still respecting your individual rationality."

- Coalition C is in equilibrium if each pair of agents in C is in equilibrium.
- Pair (a,a') of agents in C is balanced if none of both agents can *outweigh* the other in (S,u) by having the option to get a better payoff in coalitions not in S excluding the opponent agent.

The Kernel (2)

Excess of C' wrt (S,u): $e(C',u) = v(C') - \sum_{a \in C, C' \notin S} u(a),$

Surplus of agent a over a': $s(a,a') = \max_{C' \notin S, a \in C', a' \notin C'} \{e(C',u)\}$

Agent a *outweighs* another agent a' in (S, u) if it holds that

$$s(a,a') > s(a',a) \wedge u(a) > v(a)$$

Pair (a, a') of agents in C is *in Kernel equilibrium* if it holds that

$$\begin{aligned} & s(a,a') = s(a',a) \vee \\ & (s(a,a') > s(a',a) \wedge u(a') = v(a')) \vee \\ & (s(a,a') < s(a',a) \wedge u(a) = v(a)) \end{aligned}$$

Properties of The Kernel

- Kernel K exists, and is unique for any 3-agent game (A,v).
- Symmetric agents of some coalition in a given coalition structure for (A,v) gain equal payoff.
- Each K-stable configuration of (A,v) is locally Pareto-optimal in K.
- Computationally expensive (exponential complexity)
- Complexity can be bound to polynomial by limiting the size of K-stable coalitions to be formed by a constant.

Weaknesses of The Kernel

- It is presumed that agents a and a' compare their surpluses s(a,a') and s(a',a) to see who could hope for more payoff in the same coalition based on the "equal intensity of feeling of individual utility". That raises the problem of **interpersonal comparison of utility for the whole set of agents**.
- Maschler (1997): Interprete K as the set of PCs for which every pair of agents is located symmetrically within *its own* bargaining range.
- <u>In coalition negotiations using the KCA</u>
  - The agents pairwisely (bilaterally) compare their surpluses to compute K-stable (S,u) proposals. Once a particular (S, u) has been accepted in one round, the **remaining agents are assumed to be content with what they receive** in (S, u). They only can try to improve in follow-up rounds.

A Transfer Schema for K-Stable Coalitions

$$(S, u^{(i+1)}) = \begin{cases} u_k^{i+1} := u_k^i + \alpha \\ u_l^{i+1} := u_l^i - \alpha \\ u_j^{i+1} := u_k^i \, (j \neq k, l) \end{cases}$$

Let (S,u) a PC, *s(a,a')* surplus of agent *a* over *a'* in (S,u).

The demand (sidepayments) of *a* from *a'* in a K-stable coalition is

$$d(a,a') := \begin{cases} \min\{\frac{s(a,a') - s(a',a)}{2}, u(a') - v(a')\}, \text{if } s(a,a') > s(a',a) \\ 0, \text{else} \end{cases}$$

A Transfer Schema for K-Stable Coalitions (2)

Modified transfer scheme

- Terminate transfer if its **relative error** is sufficiently small

$$re(u) := \max\{s(a,a') - s(a',a) : a, a' \in A\} / u(A) \leq \varepsilon, \varepsilon \in [0,1]$$

- The modified transfer scheme converges against an approximativ K-stable PC (S,u*) after at most $n \cdot \log_2(re(u)/\varepsilon)$ iterations with complexity of $O(n \cdot 2^n)$ each.

KCA Coalition Algorithm (Klusch & Shehory, 1996)

Each agent a in C in coalition structure S with payoff distribution u:

Broadcast tasks, items, and local values *lworth(a,C)* for all C in S

If coalition leader of C then

- Generate and send beneficial Kernel stable proposals (S',u') *for C+C'*
- Evaluate incoming proposals
- Accept most beneficial proposal; broadcast decision to other agents
- Stop if no agent accepted any proposal
- Decide which accepted proposal is the next configuration
- Inform coalition members on new coalition and payoff

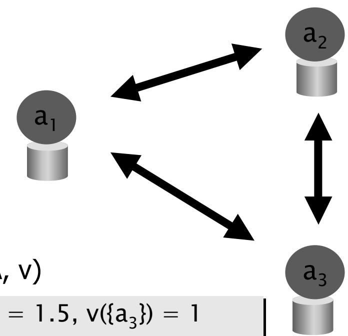
Vote for new coalition leader of C+C'

Example: Car Retailer Agent Coalition Game

Local items (a1)
car_{11}, car_{12}, car_{13}

Car sales

k1
car_{11}: 2
car_{22}: 1.5
car_{32}: 1



Local items (a2)
car_{21}, car_{22}, car_{23}

k2
car_{21}: 1.5
car_{12}: 1
car_{31}: 1
car_{33}: 2

Local items (a3)
car_{31}, car_{32}, car_{33}

k3
car_{31}: 1
car_{12}: 2
car_{13}: 2
car_{21}: 2
car_{23}: 2

Coalition Game (A, v)

$v(\{a_1\}) = 2$, $v(\{a_2\}) = 1.5$, $v(\{a_3\}) = 1$
$v(\{a_1,a_2\}) = 6$, $v(\{a_1,a_3\}) = 8$,
$v(\{a_2,a_3\}) = 7$, $v(\{a_1,a_2,a_3\}) = 15$

Coalition value: Maximum joint car sales
Local customers k1 of a1, k2 of a2, and k3 of a3.

Example: Coalition Forming Using the KCA

$v(\{a_1\}) = 2$, $v(\{a_2\}) = 1.5$, $v(\{a_3\}) = 1$,
$v(\{a_1,a_2\}) = 6$, $v(\{a_1,a_3\}) = 8$, $v(\{a_2,a_3\}) = 7$, $v(\{a_1,a_2,a_3\}) = 15$

KCA Negotiation Round 1:

K-stable solution $(\{\{a_1,a_2\}, \{a_3\}\}, (3.5, 2.5, 1))$ balancing

$s(a_1,a_2) = v(13) - (u(1) + u(3)) = 8 - 3.5 - 1 = 3.5$,
$s(a_2,a_1) = 7 - 2.5 - 1 = 3.5$

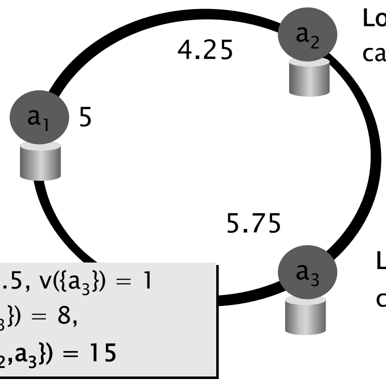
KCA Negotiation Round 2:

Final K-stable solution $(\{\{a_1,a_2, a_3\}\}, (5, 4.25, 5.75))$ balancing

s(a1,a2)=e({a1,a3})=-2.75, s(a2a1)=e({a2})=-2.75,
s(a1,a3)=e({a1,a2})=-3, s(a3,a1)=e({a2,a3})=-3,
s(a2,a3)=e({a2})=-2.75, s(a3,a2)=e({a1,a3})=-2.75

Example: K-Stable Car Retailer Agent Coalitions

Local items
car_{11}, car_{12}, car_{13}
Car sales
k1 car_{11}: 2
car_{22}: 1.5
car_{32}: 1



Local items
car_{21}, car_{22}, car_{23}
car_{21}: 1.5
car_{12}: 1
car_{31}: 1
car_{33}: 2
k2

Local items
car_{31}, car_{32}, car_{33}
car_{31}: 1
car_{12}: 2
car_{13}: 2
car_{21}: 2
car_{23}: 2
k3

$v(\{a_1\}) = 2$, $v(\{a_2\}) = 1.5$, $v(\{a_3\}) = 1$
$v(\{a_1,a_2\}) = 6$, $v(\{a_1,a_3\}) = 8$,
$v(\{a_2,a_3\}) = 7$, $v(\{a_1,a_2,a_3\}) = 15$

K-stable solution
$S = \{a_1,a_2, a_3\}$, $u = (5, 4.25, 5.75)$

Other Approaches to Coalition Forming

Fuzzy cooperative games

- Coalition value is fuzzy (**Fuzzy-valued** coalitions)
  - Fuzzy Shapley value; Fuzzy Core (Mares 2001; Aubin 1981)
  - Fuzzy Kernel (Blankenburg, Klusch and Shehory 2002)
- Coalition membership is fuzzy (**Fuzzy** coalitions): Butnariu 1987

Stochastic cooperative games (De Suijs, 2000)

- Stochastic knowledge about the environment with
  - One set of possible actions assigned to each of the possible coalitions
  - Fixed stochastic pay-off for each action: probability of coalition values

Developed Applications of Coalition Forming

Static coalition negotiations between agents to

- Negotiate **access to pay-per-use data and services** in cooperative information systems (Klusch & Shehory 1996ff)
- Maximize individual **bargains on free e-markets** (Sycara & Tsvetovat, 2001)
- Completely decentralize **power transmission planning** (Contreras, Klusch & Shehory, 2001)

Dynamic coalition negotiations between agents for

- Dynamic resource allocation planning of cereal harvesting in the agricultural domain (Klusch & Gerber 2004) - AGRICOLA

The Problem of Dynamic Coalition Forming

In open environments, non-deterministic (dynamic) changes may occur *during the coalition forming process*

- **Information** on used data, knowledge, network, and user environment of each agent, and the system as a whole
- **Tasks** to be accomplished, and availability of computational resources
- **Agents** may hide in, enter, or leave the agent society at any time

"How to efficiently form (what kind of) stable coalitions among rational agents in face of (what kind of) non-deterministically occurring events **without complete restart of the CF process**?"

The domain of **dynamic coalition formation (DCF)** is defined by the set of co-operation methods, schemes, and key enabling technologies for dynamically forming rational coalitions in open environments.

Dynamic and Trusted Coalition Forming

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