

# Preventing Selfish Behaviour in Distributed Tactical Airport Planning



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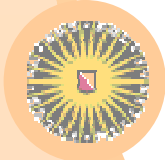


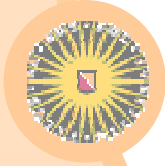
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# Overview

- Introduction: Distributed Decision Making
- Problem: Efficient and equitable plan repair
- Method: Use of normal Market Mechanism
- Issues with normal Market Mechanism
- Solution: Spender-signed money
- Conclusion

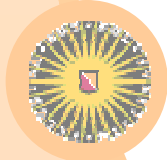




# Introduction

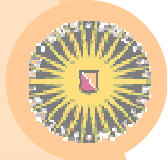
# Distributed Decision Making

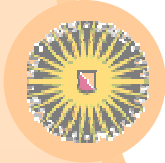
- Trend in Air Traffic Management from *centralized* to *distributed* decision making.
- Examples:
  - Free Flight
  - Collaborative Decision Making
  - Total Airport Management [Meier et al. 2006].
  - Arrival self spacing and merging [Barhydt et al. 2005]
  - Inbound priority sequencing [Hesselink 2004]
  - Pre-departure sequencing [Airport CDM Munchen 2006]
  - Recent Ground Delay Programs Extensions.



# Distributed Decision Making

- Greater autonomy for different parties
- Pro-active behaviour
- Greater involvement of preferences / priorities
- Solving local problems locally. Local information
- Goals:
  - Increase efficiency of operations
  - Increase capacity of resources
  - Increase stakeholder satisfaction
- Equity must be guaranteed
- *Important assumption:*  
*Agents will cheat if they see a chance*

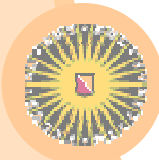
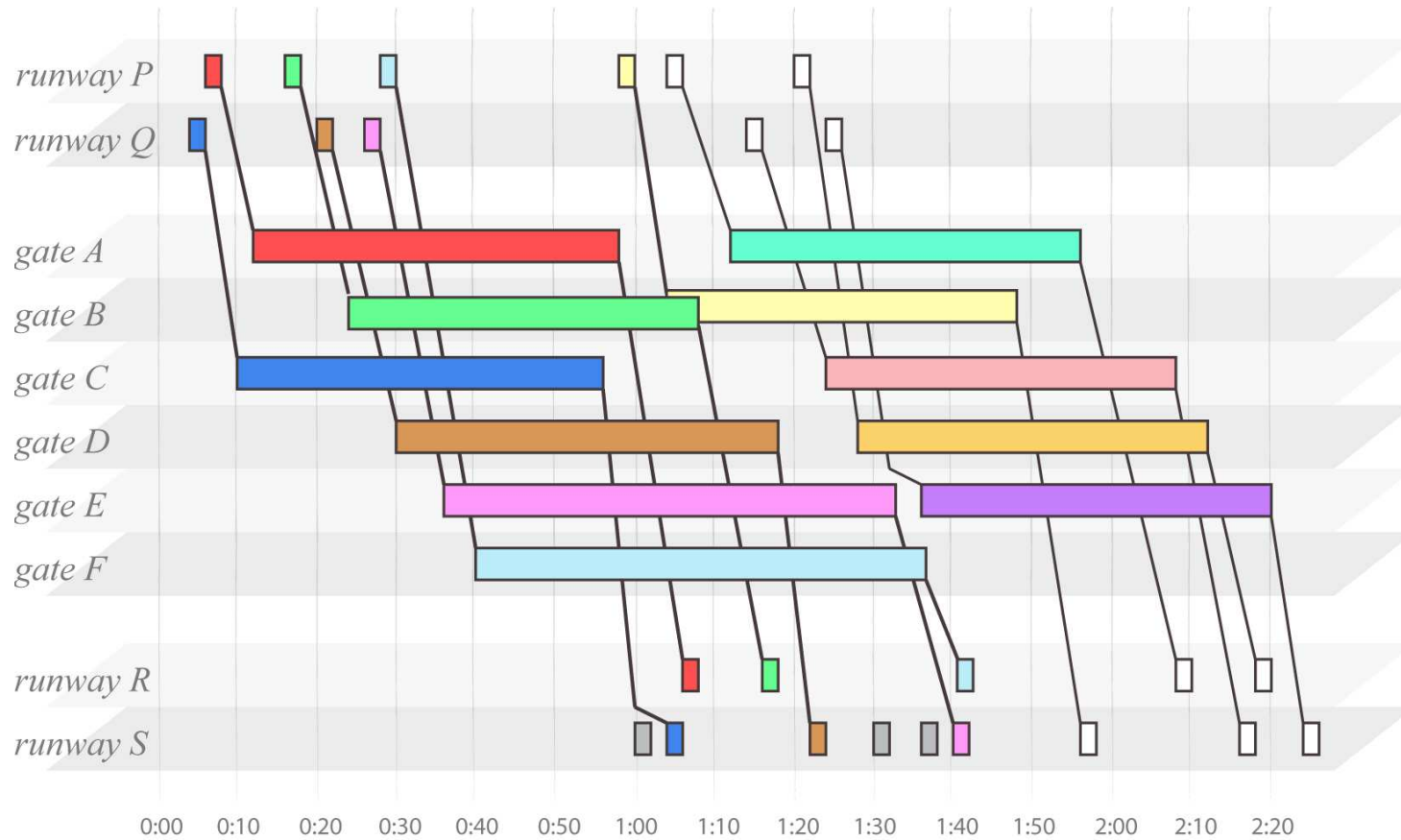




# Problem description

# Domain: Tactical Airport Plan Repair

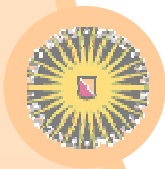
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# Problem description

Design an **incentive-compatible** mechanism by which airline-representing **agents** can jointly make plan decisions, such that the resulting plans are **efficient** and the allocation of actions is **equitable**.





# Formal representation

- Each round  $r$  a conflict with problem owner  $w_r$

- $m$  repair candidates:

$$1: \quad \langle 0, 0, -50, 0, 0 \rangle$$

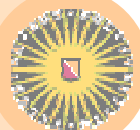
$$2: \quad \langle 0, 0, 0, 0, -10 \rangle$$

$$3: \quad \langle -10, -10, 0, 0, 0 \rangle$$

...

$$m: \quad \langle \dots, \dots, \dots, \dots, \dots \rangle$$

- $e_r$  elected candidate.

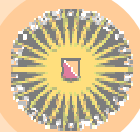


# Formal representation

- after  $n$  rounds: allocation  $A_n = \langle e_1, e_2, \dots, e_n \rangle$

- utility of agent  $x$ : 
$$U_x(A_n) = \sum_{r=1}^n u_{x,r,e_r}$$

- efficiency: 
$$\text{eff}(A_n) = \sum_{i=1}^k U_i(A)$$

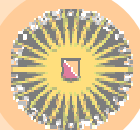


# Equity

- Adams:  $\frac{O_x}{I_x} = \frac{O_y}{I_y}$

where  $O$  and  $I$  are “the sums of such outcomes and inputs as are perceived to be relevant to a particular exchange”.

- Inputs: social status, rank, etc.
- Outputs: rewards minus costs.

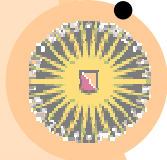


# Equity

- All airlines equal:  $I_x = I_y$
- Equity:  $O_x = O_y$
- Output is difference between utility of services given and received

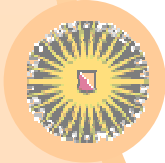
	util. svc. given	util. svc. received	Output
Ag 1	-100	-95	-5
Ag 2	-90	-90	0
Ag 3	-5	-10	5

- Inequity equal to lowest output



# Equity

- Note: equity both morally desirable and incentive providing – reciprocal cooperation.



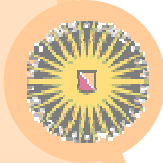
# Equity and efficiency

- Equity and efficiency often incompatible

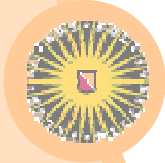
round 1:  $\langle 0, -4, 0 \rangle$

round 2:  $\langle 0, -2, 0 \rangle$  or  $\langle 0, 0, -4 \rangle$  ?

- Achieve some desirable trade-off

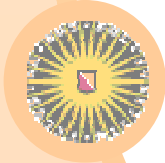


# Approach: Use Market Mechanism



# Virtual money

- Money facilitates reciprocal exchange





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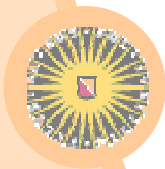
KLM

req.

BA

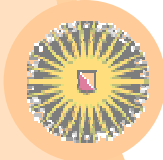
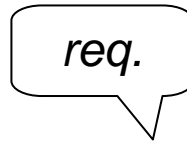
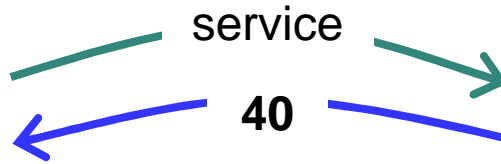


LH

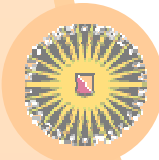
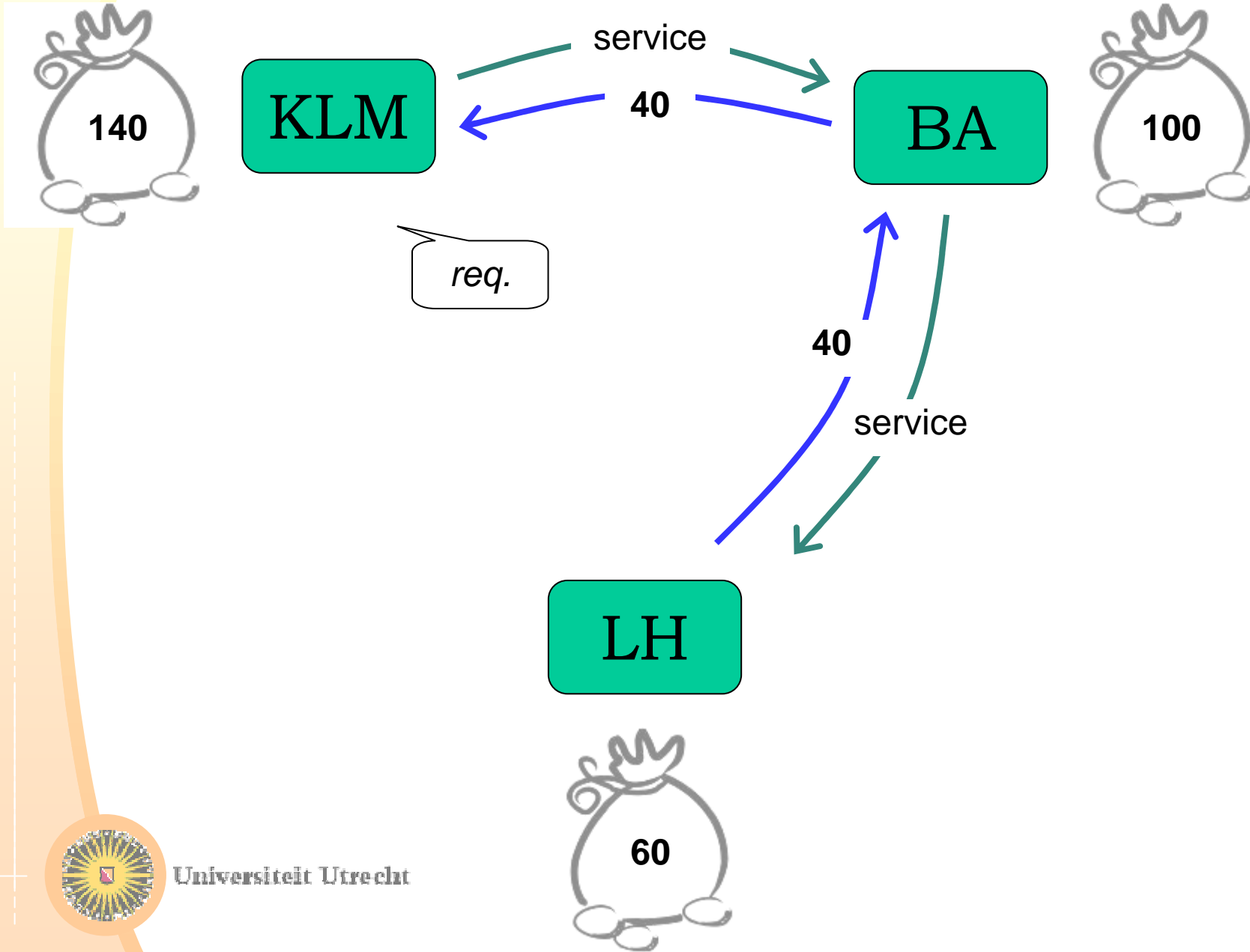


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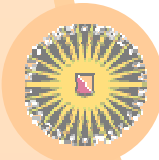
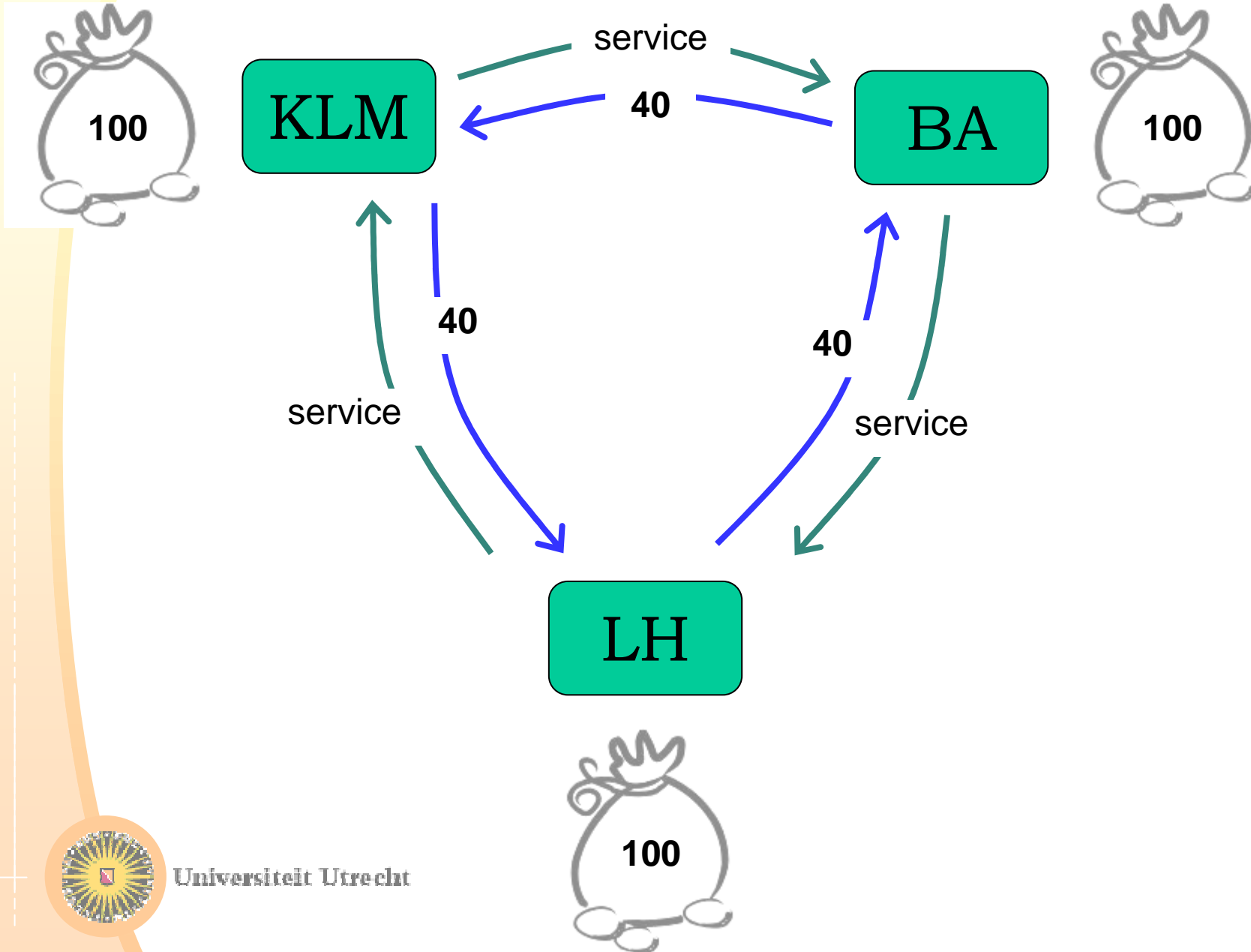
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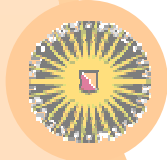


# Virtual money

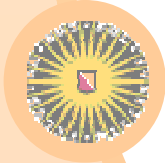
- Money facilitates reciprocal exchange
- Prices correspond to disutilities of provided services

$$p_{x,r} = -u_{x,r,e_r}$$

- Elect cheapest candidate
- Lower bound for balances
- Trade-off between efficiency and equity

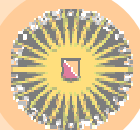


# Problem with Normal Market Mechanism

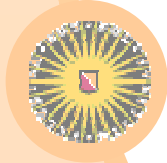


# Problem: Exploitation

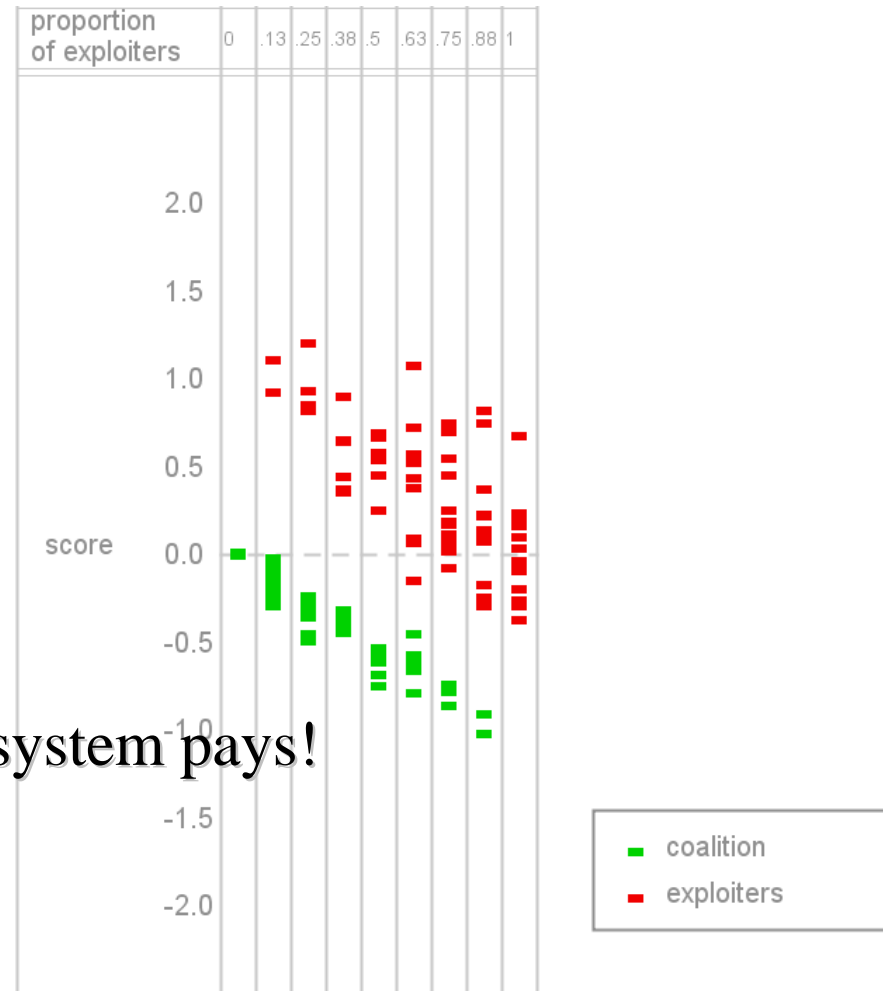
- Agent can *exploit*
- Exploitation: asking a price just below that of the second-cheapest candidate
- Likely to cause significant inequity when agent sizes vary.
- Experiment: gate assignment. Airlines are cooperative by sharing information or can exploit by manipulating information.



# Exploitation



cheating the system pays!

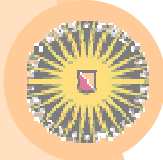




# Retaliation

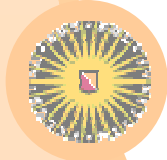
- Can we adapt the mechanism such that exploitation is counteracted?
- Coalition vs. exploiters
- Can the coalition agents retaliate exploiters by asking higher prices to them?
- New coalition price rule:

$$q_{x,r,e_r} = \frac{-u_{x,r,e_r}}{r w_r} + c^p \quad r_x = \frac{E_x}{P_x}$$



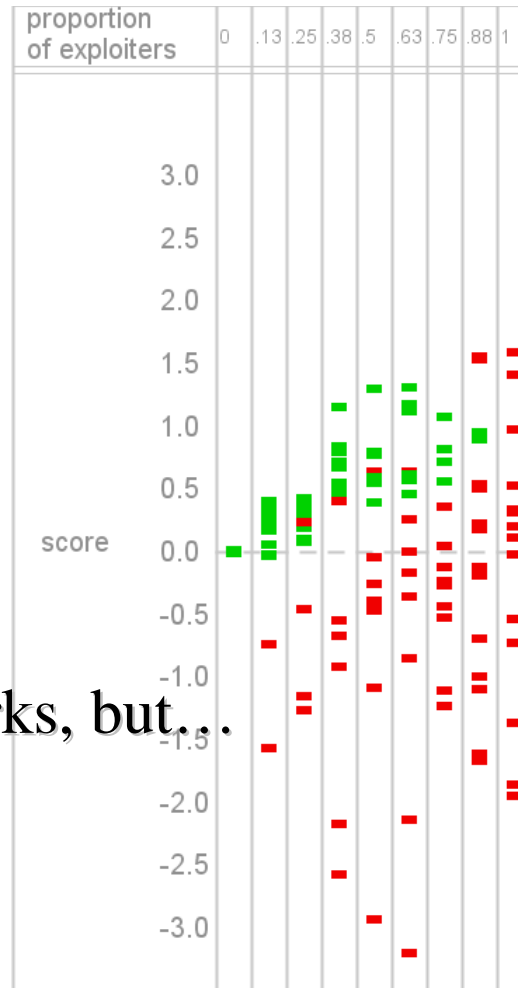
# Retaliation

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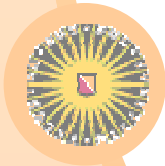
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retaliation works, but...

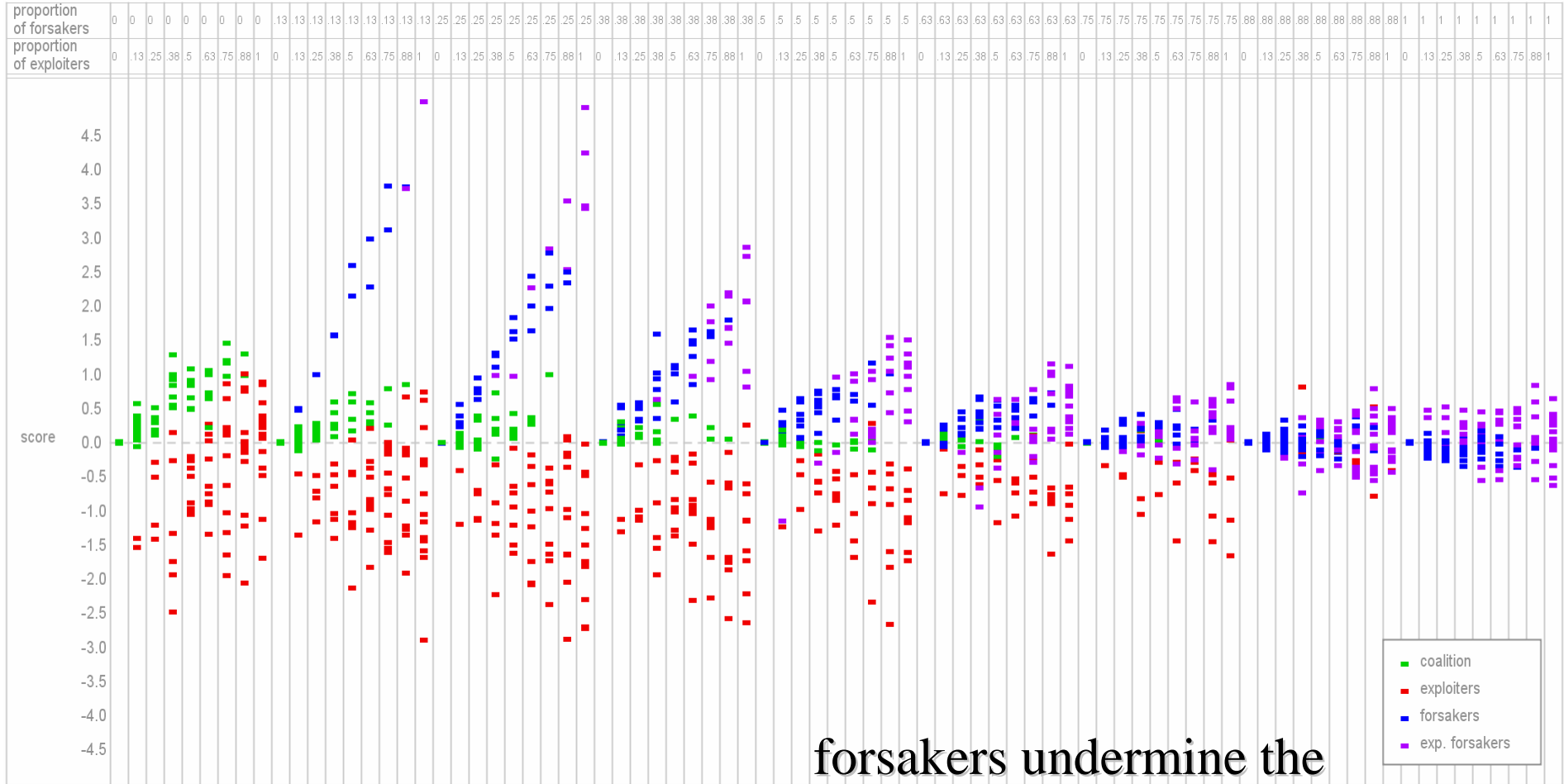


# Forsaking

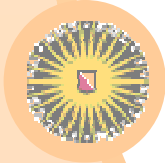
- Coalition undermined by *forsaking agents*: deviating from the retaliation rule such that one wins the auction.
  - cf. armament embargo
- Forsakers compete and can sometimes fully undo the effect of retaliation.



iterations: 1050 agents: 15 candidates: 15 scenario: RETALIATION



# Solution: use of Alternative Currencies

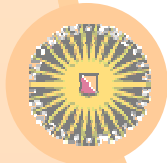


# Issuer-signed money

- Proposed in [Turner et al. 2004]
- Each agent may issue its own currency
- Rate of currency coupled to ones reliability.  
*credit = promisory note.*

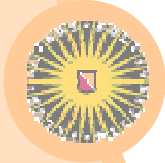
$$v(c) = r_i$$

- Exploitation → low reliability → low currency rate → low utility.



# Issuer-signed money

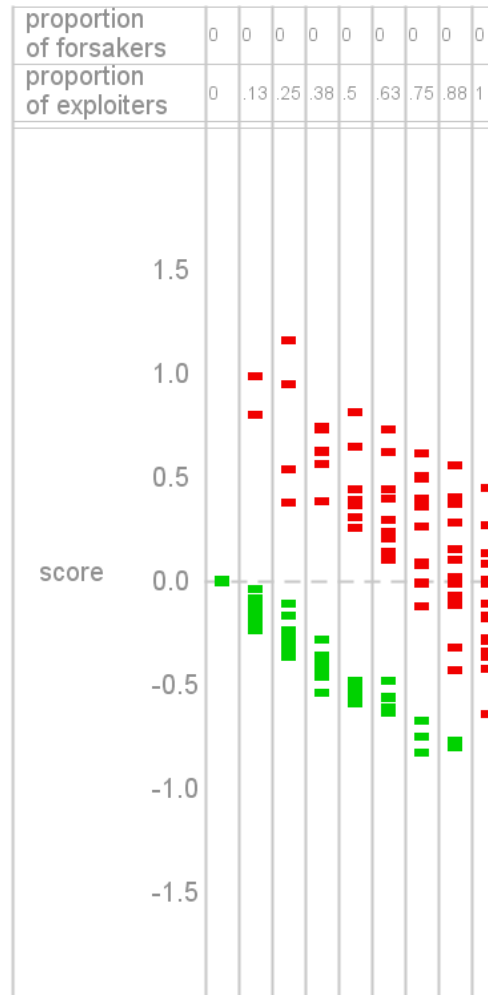
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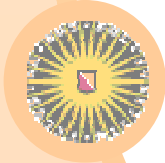
iterations: 1050 agents: 15

candidates: 15 scenario: ISSUER\_SIGNED



# Issuer-Signed Money

- Increased issuing
- Currency-swapping



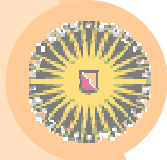


# Spender-Signed Money

- Each user may issue money.
- Each user signs every credit it issues or spends. Each credit carries list of spenders.
- Each credit is valued according to its signatures. For credit  $c$  with spenders  $\{s_1, s_2, \dots, s_l\}$  :

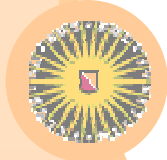
$$v_x(c) = r_{s_1} * r_{s_2} * \dots * r_{s_l}$$

- Based on currency system WAT [Saito 2005]

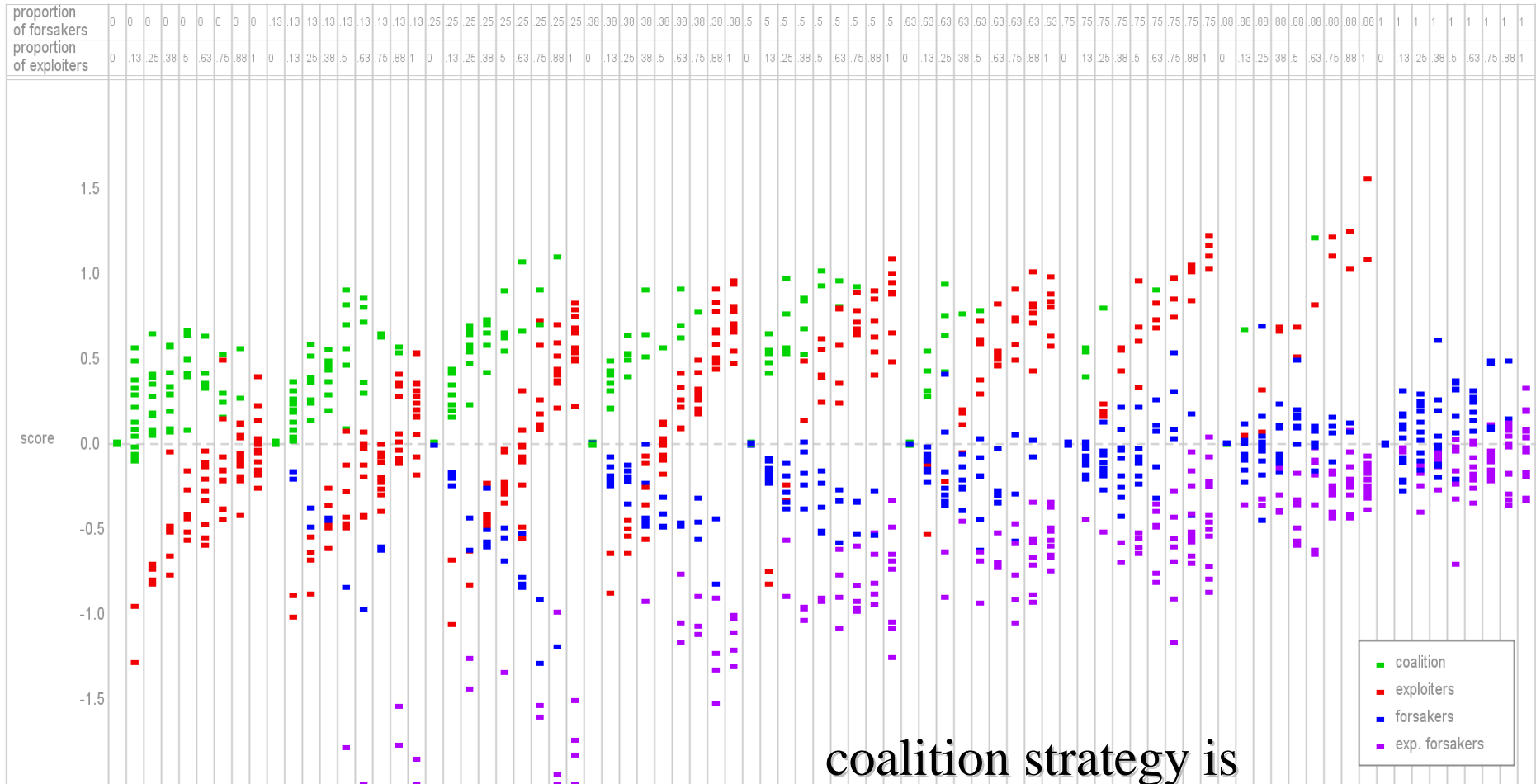


# Spender-Signed Money

- System effectively retaliates exploiters.
  - Exploiting -> lower rating -> lower value of all money in possession
- Forsaking is unattractive
  - Instead of gaining normal credits, a forsaker gains credits that have devaluated.



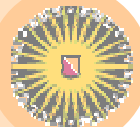
iterations: 1050 agents: 15 candidates: 15 scenario: SPENDER\_SIGNED



coalition strategy is dominant

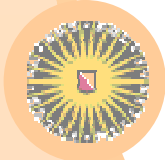
# Possible vulnerabilities

- Unintentionally mis-estimating one's true utility
  - Allow agents to give information / arguments
- Intentionally mis-estimating one's true utility.
  - No direct advantage.
- Communication overload
- Lack of trust because of few previous encounters



# Future Work

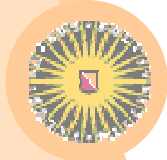
- Agents typically do most business with few other agents.
- Let agents communicate only to those other agents 'close by'.
- Incorporate unfamiliarity in reputation.
- Result: credits stay close to signers.
- Measure effect on efficiency and equity.



# Conclusion

- Distributed approach to tactical plan repair.
- Money facilitates reciprocal exchange.
- Exploitation causes inequity.
- Use of spender-signed money robustly counteracts exploitation.

**A robust mechanism achieving  
efficient and equitable plan repair.**



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