Using Economics for Resource Control

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Automated negotiation systems

- **MAS = systems consisting of multiple agents whose actions interact**
- **Agents search & make contracts on behalf of owners**
- **Increasingly important**
  - Developing communication infrastructure (NII, Internet, WWW, EDI, KQML, FIPA, Telescript, Java...)
  - Electronic commerce on the Internet: Goods, services, information, bandwidth, computation, storage...
  - Industrial trend toward virtual enterprises & outsourcing

Systems with self-interested agents

- *Protocol* specifies legal actions for each agent
- *Strategy* = Agent's mapping from history to action. Way to use protocol
- Rational self-interested agent chooses its strategy to maximize payoff given protocol
  => normative approach required
- Computation limitations bound rationality

Example applications

- **Multienterprise agile manufacturing scheduling**
- **Internet commerce, e.g. auctionbots**
- **Electricity markets**
- **Heating markets for building environments**
- **Information gathering on the web**
- **Collective article rating on the web**
- **Computer networks**
  - Bandwidth allocation
  - Video on demand
  - Mirror site allocation
  - Dynamic pricing
  - Provider collusion
- **OS & *mobile agents* : allocation of storage & computation**
- **Vehicle routing among independent dispatch centers**
- **Treatment scheduling across hospitals**
- **Electronic trading**
- **Multicontractor software engineering**
- **Multirobot systems...**

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Marginal costs in automated contracting

- **Original contract net protocol** [Smith80, Smith&Davis81]
  - Applied to simulated acoustic sensor net: Centralized
  - No formal model for bidding & awarding decisions
  - Only cooperative agents: No payments for handling tasks
- **TRACONET system** [Sandholm93]
  - Distributed, asynchronous agents
  - Safe method for dynamic entry & exit
  - An agent can take on both contractor & contractee roles
  - Iterative task reallocation -> anytime algorithm
  - Formal model for bidding & awarding based on *individual rationality*. E.g. in bid, i requires

$$Payment > MC_i(t \mid T_i) = c_i(T_i \cup \{t\}) - c_i(T_i)$$

- Contractor awards to lowest bidder – if low enough

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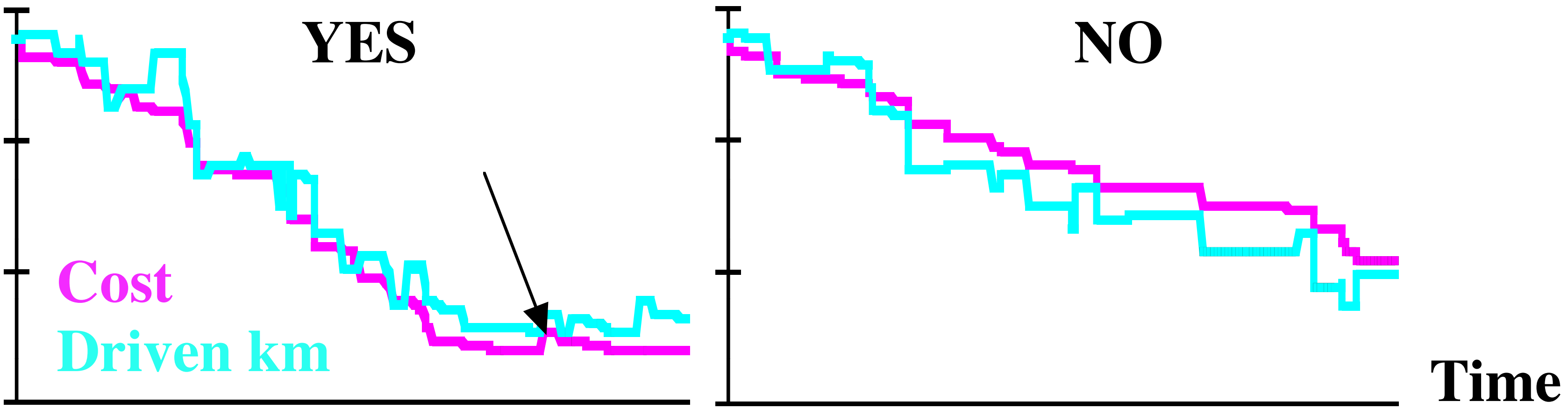
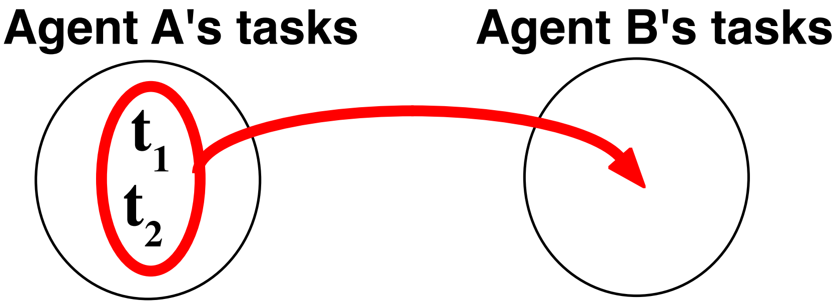
Bidding & awarding while bids pending

- $\square MC\square_i(t\square T_i)$ **depends on acceptance of pending committal bids**
- **Trade-off 1: Risks with pending offers vs. many marginal cost calculations**
  - Assume no pending bids get accepted: TRACONET
  - Assume all pending bids get accepted: Feasibility check
  - Assume worst (or best) combination gets accepted
- **Trade-off 2: Send bids & awards while bids are pending?**



Linking items: *Clustering*

- **Individually rational contracts mean hill-climbing in task allocation space -> Local optima via transfers of one task**
- **Thrm. Classic contracts become arbitrarily sparse [Sandholm97]**



- ***Clustering* of 1, 2 or 3 tasks per announcement: TRACONET [Sandholm93]**
  - m-optimality does not imply n-optimality if n ≠ m
  - Schedules for applying different clustering contracts
  - Domain independent clustering heuristics

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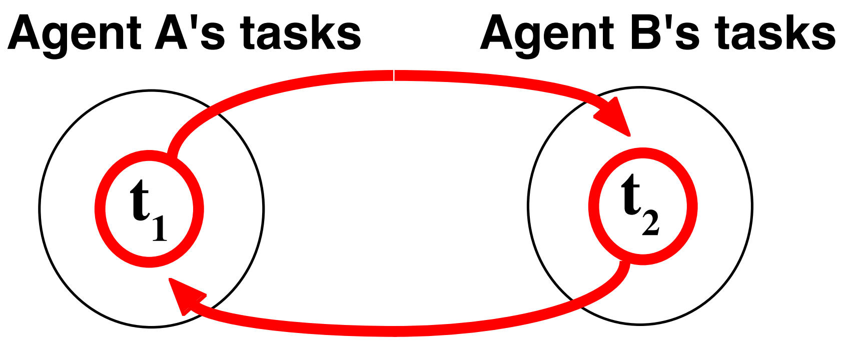
Linking items: *Swaps*

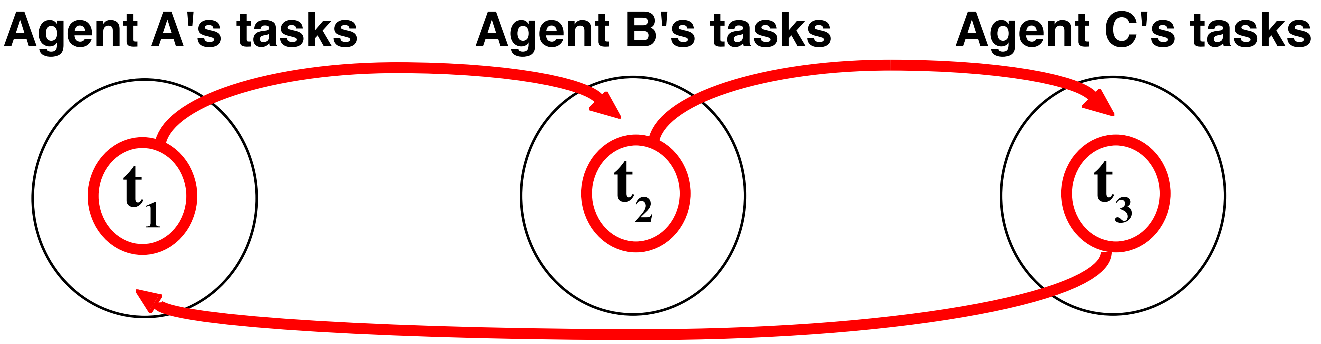
- Local optima even with clustering



- *Swaps* : exchanging tasks for tasks [Sandholm96, 97]
- Thrm. Reachable set vanishes [Sandholm97]

Linking items: *Multiagent contracts*

- **Local optima via mutual contracts (clustering & swaps)**



- ***Multiagent contracts*** **[Sandholm96, 97]**

  ([Sathi&Fox89]: heuristically in a simpler domain)

Linking items: Results

- **Thrm** [Sandholm97]**. With a contract operator that allows *clustering*, *swaps* & *multiagent contracts* of any size, any sequence of individual rational contracts (i.e. any hill-climbing algorithm) leads to globally optimal task allocation in finite #contracts**

- **Thrm** [Sandholm97]**. No subset of contracts suffices - even with an oracle for choosing the sequence of contracts**

- **Thrm** [Sandholm97]**. *Clustering*, *swaps* & *multiagent contracts* do not suffice individually or in pairs (or even all three together when applied non-atomically)**

- **Global optimum vs. anytime**

Leveled commitment contracts

- **Decommitting among cooperative agents** [Smith80, Sen93]
- **Classically full commitment among self-interested agents**
- **Leveled commitment protocol for self-interested agents** [Sandholm&Lesser96]
  - Decommitment penalties (α, β) for both agents
  - Allows accommodating domain events & negotiation events
  - Allows marginal cost calculation to continue after contract
  - Allows same low-commitment offer to many agents
  - Allows risk reduction in implicit clustering, swaps & multiagent contracts
  - Makes feasibility check unnecessary
- **More practical than contingency contracts**

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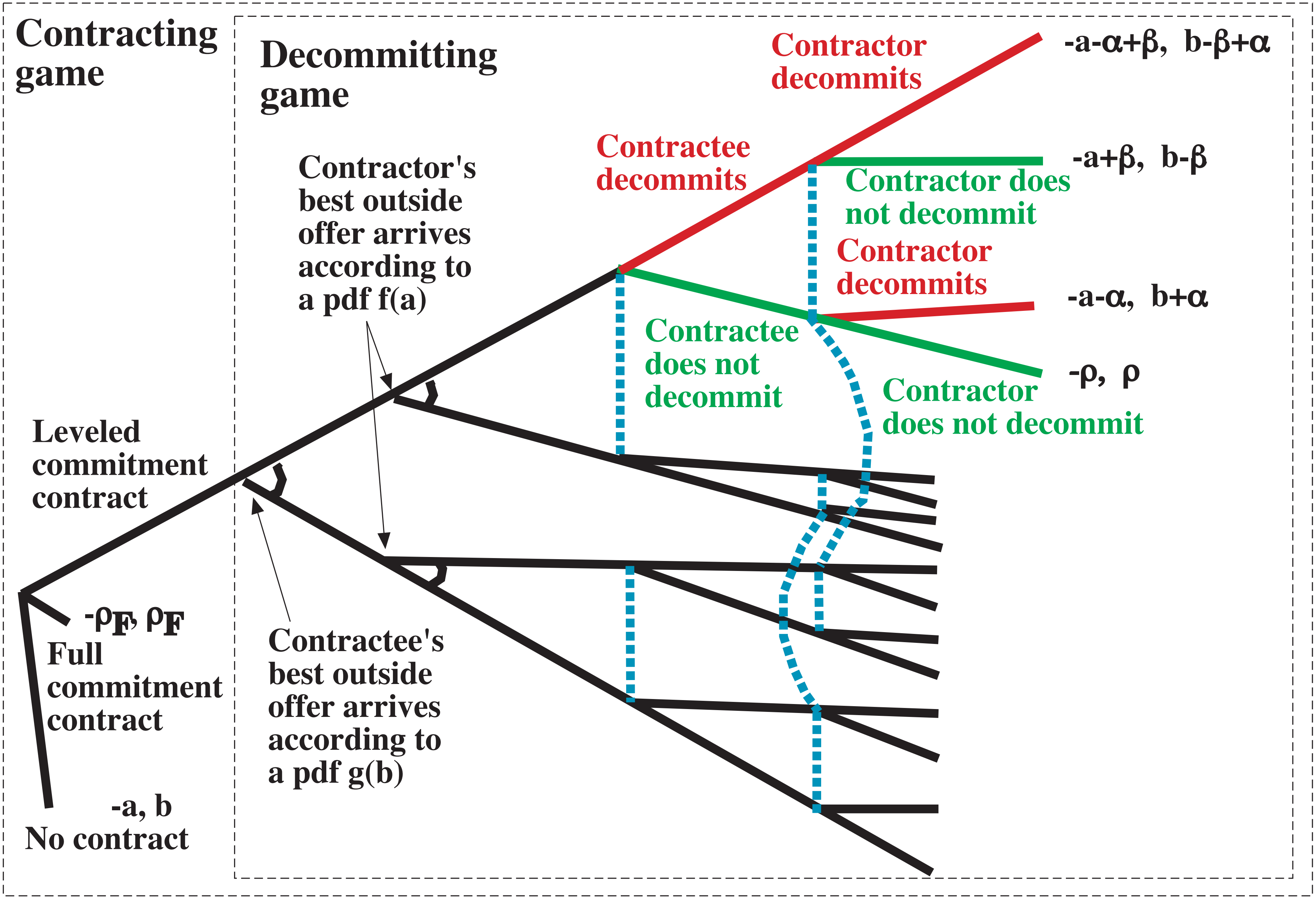
Leveled commitment: Example game



Contracting game

Decommitting game

Contractor's best outside offer arrives according to a pdf f(a)

Contractee's best outside offer arrives according to a pdf g(b)

Leveled commitment contract

Full commitment contract

$-\rho_F, \rho_F$

No contract

$-a, b$

Contractee decommits

Contractee does not decommit

Contractor decommits

$-a-\alpha+\beta,\ b-\beta+\alpha$

Contractor does not decommit

$-a+\beta,\ b-\beta$

Contractor decommits

$-a-\alpha,\ b+\alpha$

Contractor does not decommit

$-\rho,\ \rho$

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Leveled commitment enables contracts

Contractor decommits whenever it is profitable:

$$a < \rho - \frac{\alpha}{1-p_b} \overset{def}{=} a^* \qquad (p_b < 1)$$

Contractee decommits whenever it is profitable:

$$b > \rho + \frac{\beta}{1-p_a} \overset{def}{=} b^* \qquad (p_a < 1)$$

$$p_a = \int_{-\infty}^{a^*} f(a)\,da \qquad p_b = \int_{b^*}^{\infty} g(b)\,db$$

Nash equilibrium [Nash50]

Thrm [Sandholm&Lesser96]**. There are instances of the game where no full commitment contract is individually rational for both agents, but some leveled commitment contract is. Never reverse.**

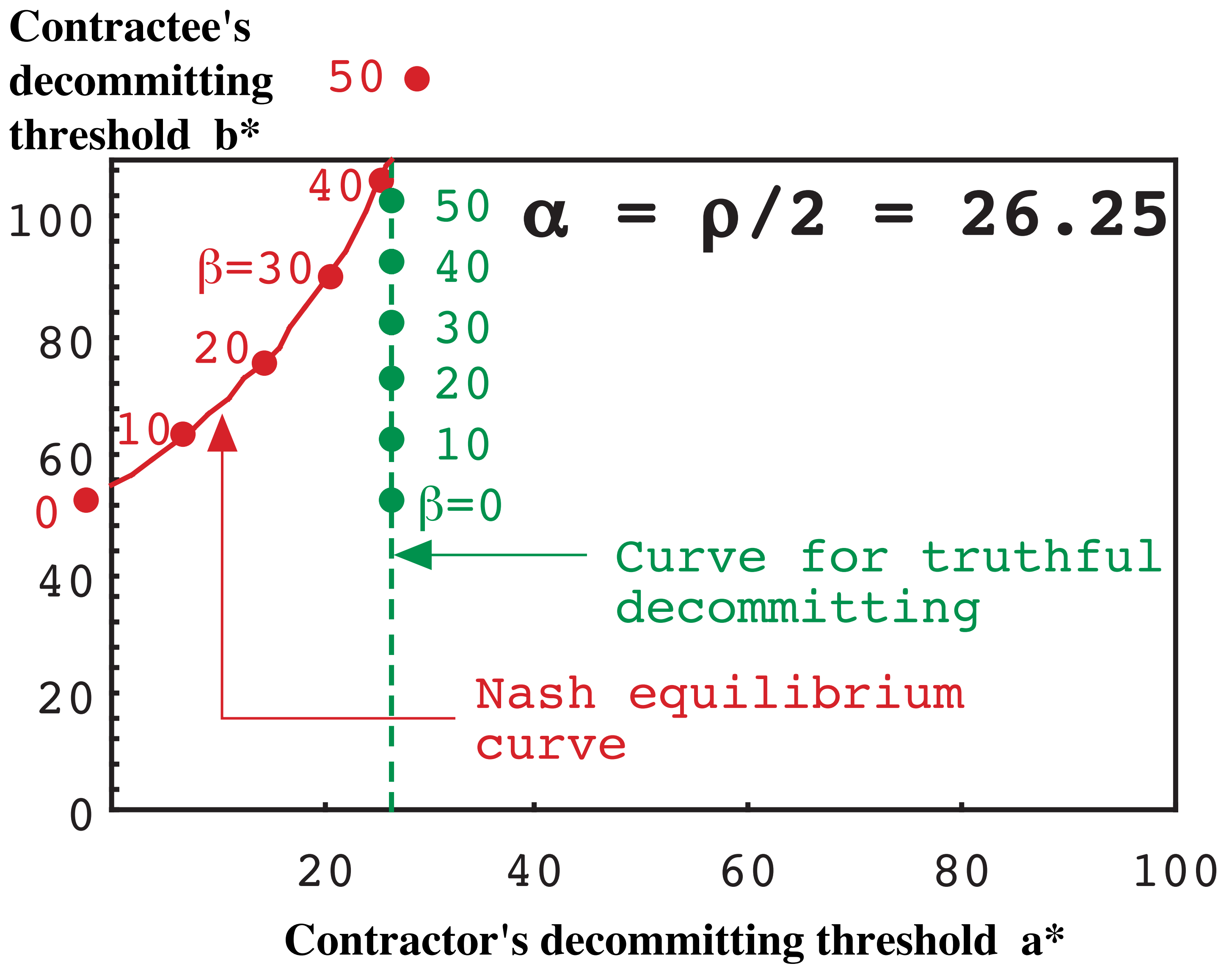
Example

$$f(a) = \begin{cases} 1/100 & \text{if } 0 < a < 100 \\ 0 & \text{otherwise} \end{cases} \qquad g(b) = \begin{cases} 1/110 & \text{if } 0 < b < 110 \\ 0 & \end{cases}$$

Choose ρ = 52.5

Leveled commitment enables contracts...

Nash equilibrium location depends on penalties α *and* β



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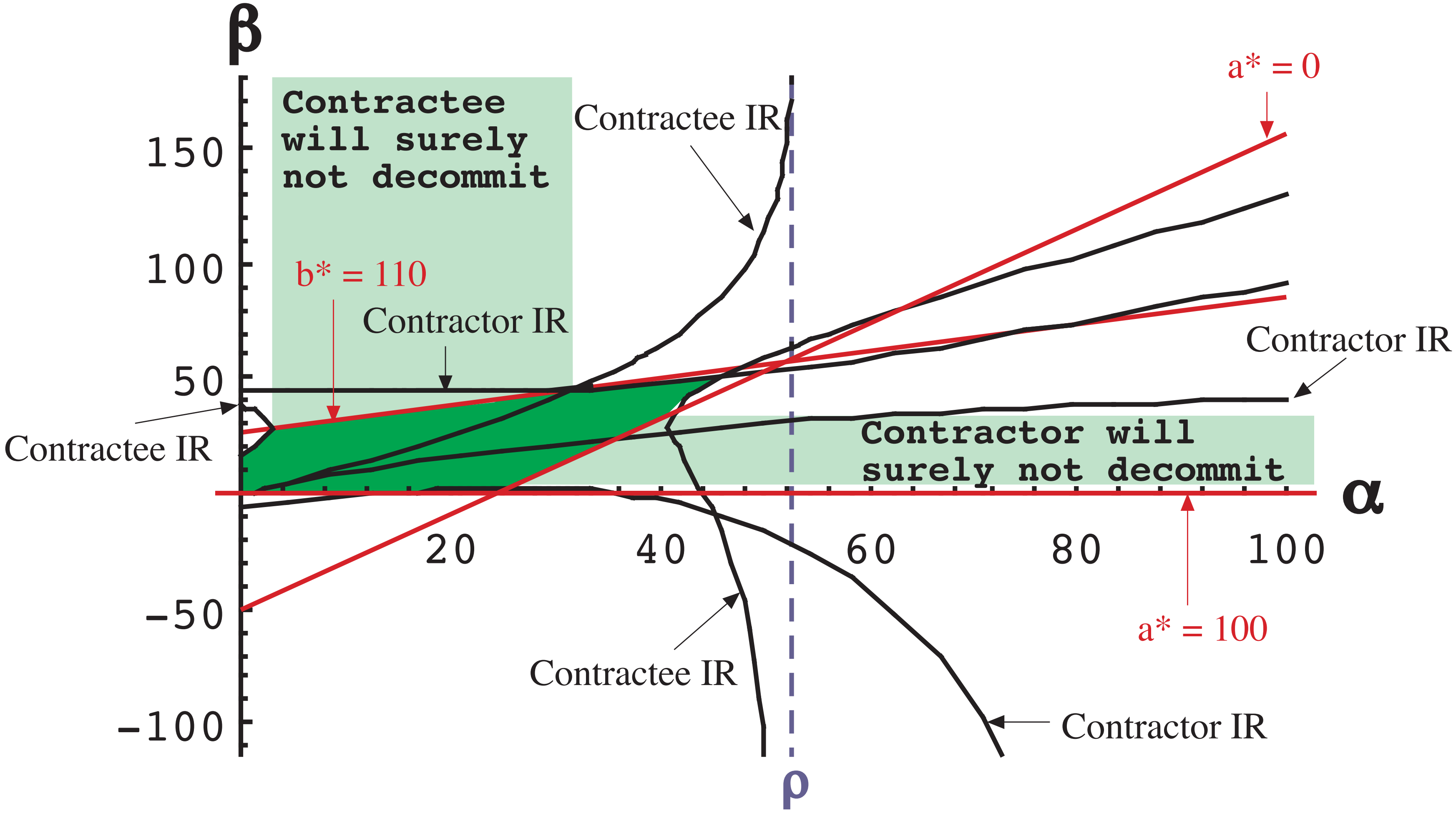
Leveled commitment enables contracts...

Which decommitment penalties α and β allow a contract?



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Leveled commitment improves efficiency

Thrm [Sandholm&Lesser96]**. Let *a* be bounded from below and *b* from above. If a game instance has at least one full commitment contract that is individually rational to both agents, and**

1. **there is positive probability that $a < E[b]$, or**
2. **there is positive probability that $b > E[a]$**

then that game instance has a leveled commitment contract that has greater expected payoff to both agents than any full commitment contract.

Leveled commitment in other games

- **Contract enabling & efficiency theorems for other games** [Sandholm&Lesser96]
  - Agents do not pay penalties if both decommit
  - Decommitting one agent at a time
  - Only one agent's future offers uncertain
  - Fallback positions grow void before decommitting game
  - Misperceiving agents

Unenforced exchange / contract execution

- **Contract enforcement difficult with computational agents**
- **Sometimes an exchange can be carried out without enforcement by dividing it into chunks** [Sandholm&Lesser95]
  - Top-down & bottom-up chunking algorithms
  - Sound & complete quadratic chunk sequencing algorithm
  - Optimal stable exchange strategies for given sequence
  - Role of real-time: Unenforced deadlines

Contributions - conclusions

- **Automated contracting -> self-interested agents**
    - Efficient distributed system using marginal costs
    - Risk taking under pending offers
    - Linking items: Clustering, swaps, multiagent contracts
    - Leveled commitment contracts
    - Message congestion / agent saturation
    - Negotiation termination [Sandholm96]
    - Insufficiency of second-price sealed-bid auction [Sandholm96]
- **Coalition formation under computation unit cost**
    - Performance profiles <-> Optimal coalition structure
    - Performance profiles <-> Stability of coalition structure
    - Domain classification
    - Different performance profiles => paradox [Sandholm96]
    - Coalition formation processes under belief revision & bounded
      □ rationality [Tohme&Sandholm97]
- **Unenforced contract execution via splitting**
- **Strategic behavior in market mechanisms** [Sandholm&Ygge97]

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Some questions

- What is different in computational MAS?
  - No “emotion-based” irrationality
  - Computational irrationality is quantifiable
    - Can we incorporate normative models of deliberation (bounded rationality) into game theory?
- What applications crave economic techniques?
- Which of these applications are most likely to succeed (first)?
- Which of them are most profitable?
- How can we convince standard setters of the necessity of sound economic methods? (Danny Lange’s talk)