Agents Supporting Cooperative and Self Interested Human Interactions in Open, Dynamic Environments

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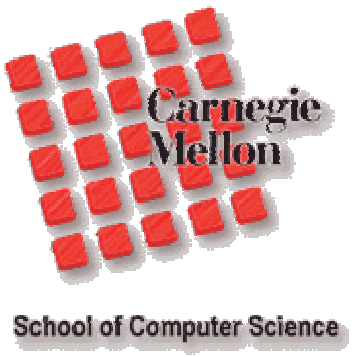

Talk Outline

- **Agents in Open Environments**
- **Agents Supporting Human Teams**
  - **Information processing (memory intensive) Tasks**
  - **Planning Tasks**
- **Agents Supporting Organizations**
  - **E-commerce activities (negotiation, coalition formation, auctions)**
- **Forward to the Past: Agent-Based Web Services**

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Vision: Agents on the Web

- A Wired/Wireless World populated with interoperating agents not just data

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Overall Research Goal

Develop multiagent technology that allows agents (cooperative and self-interested) to coordinate autonomously and also assist individuals and human teams in environments that are:

- time stressed
- distributed
- uncertain
- open (information sources, communication links and agents dynamically appear and disappear)

Team members (humans and agents) are distributed in terms of:

- time and space
- expertise

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Reusable Environment for Task Structured Intelligent Networked Agents

- **Adaptive, self-organizing collection of Intelligent Agents infrastructure that interact with the humans and each other.**
  - integrate information management and decision support
  - anticipate and satisfy human information processing and problem solving needs
  - perform real-time synchronization of actions
  - route and present the right information to the right person at the right time
  - adapt to user, task and situation
- **Develop schemes for autonomous agent coordination**
- **Multi-agent discovery and interoperation**
- **Multi-agent adaptivity and learning**

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Open Environments

- No predefined structure
- Agents leave and join the society dynamically
- Communication is not ensured all the time
- Information sources may appear and disappear

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Generic Tasks in Open Environments

Agents must be able to:

- *discover* each other. We distinguish the notion of agent *location* from the notion of agent *functionality*.
  - Location is found through Agent Name Services (ANS)
  - Functionality/capability is found through Middle Agents
- *interact/transact* with each other
- *compose* results of their reasoning
- *monitor* progress of delegated tasks

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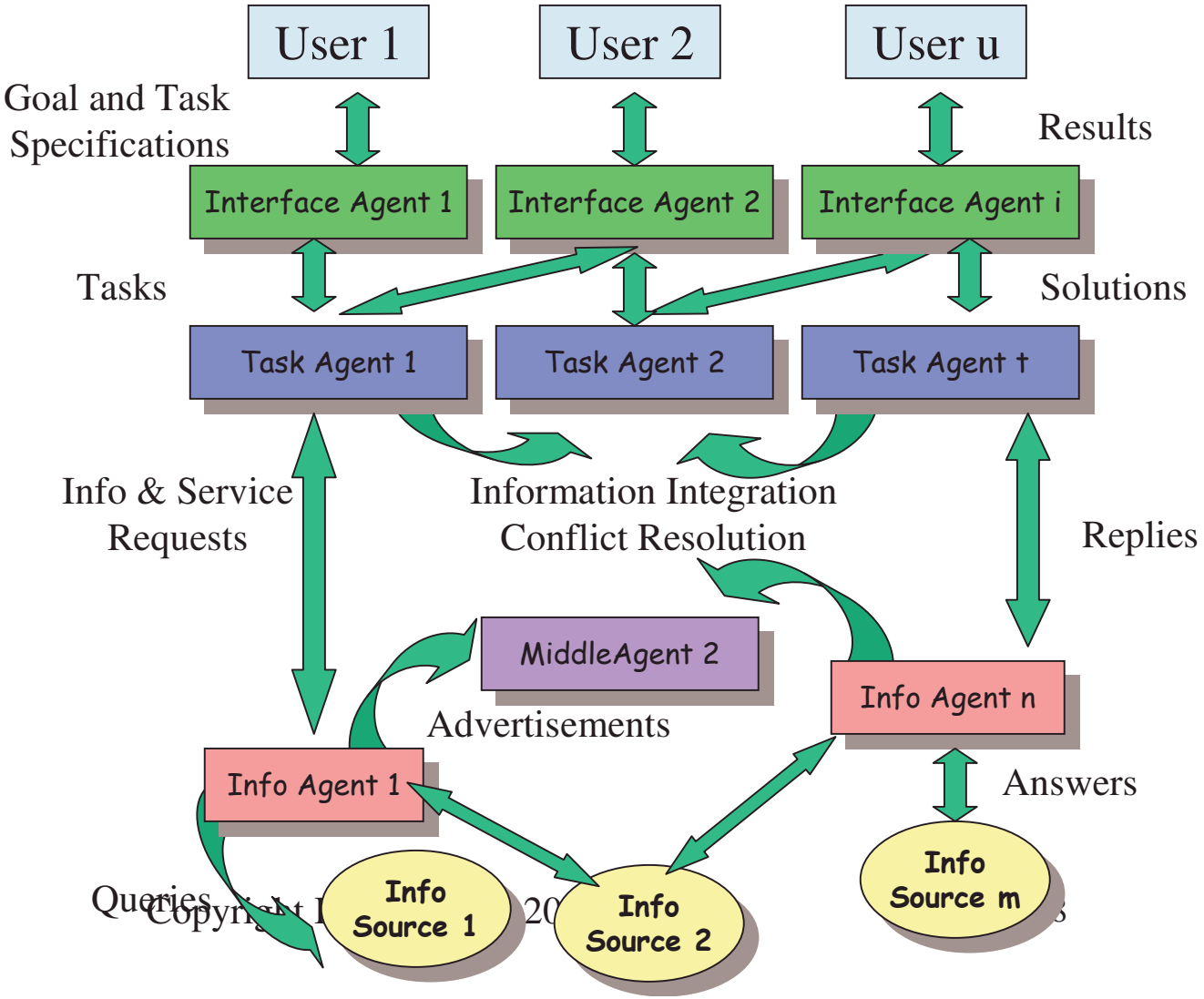
The RETSINA Multi-Agent Organization

distributed adaptive collections of information agents that coordinate to retrieve, filter and fuse information relevant to the user, task and situation, as well as anticipate user's information needs.



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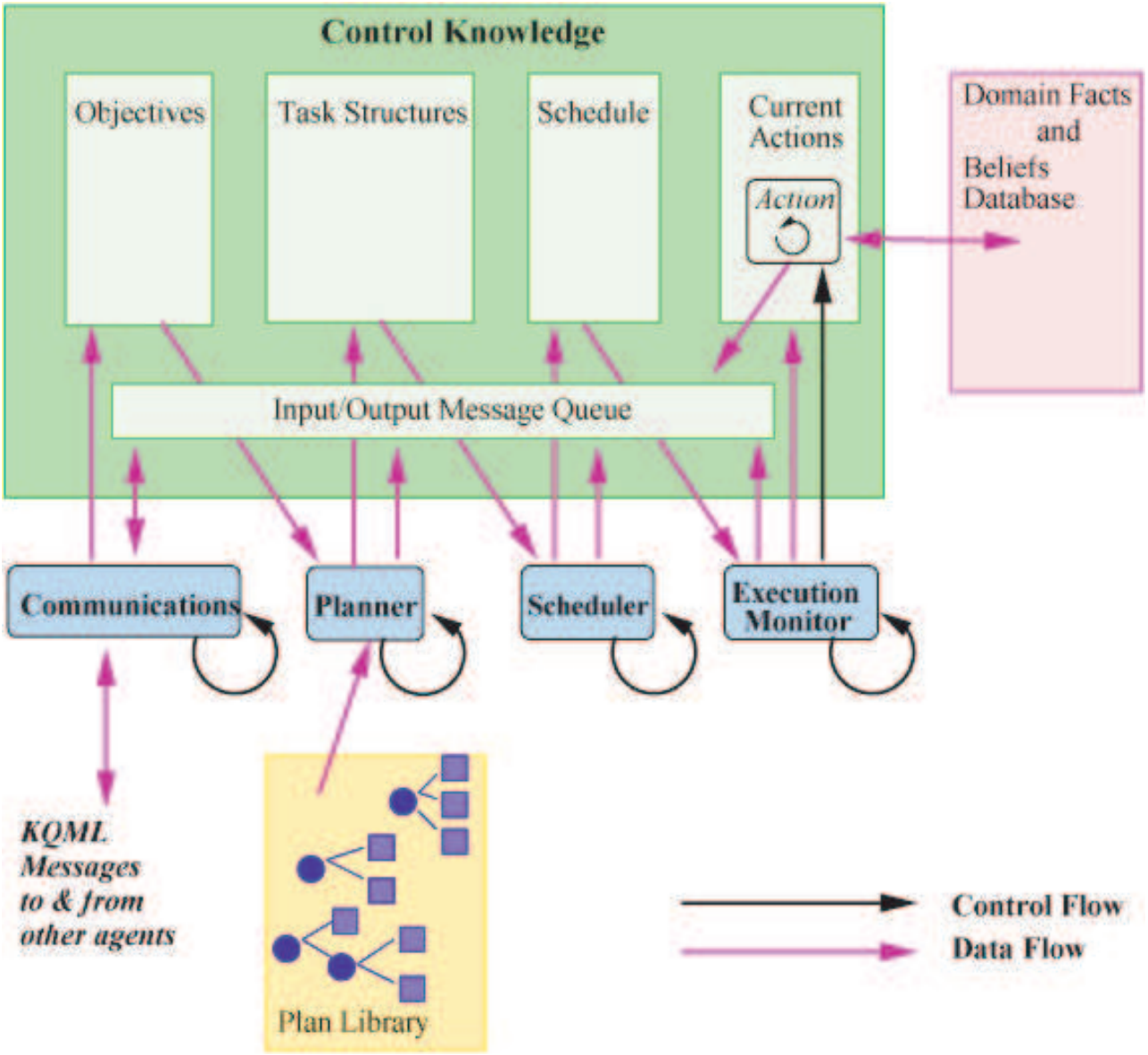
RETSINA Single Agent Architecture



Some RETSINA Applications

- Aiding Human Teams in joint mission planning (using ModSAF as a simulated battlefield)
- Agent-aided aircraft maintenance
- E-commerce in wholesale markets (agent-based auctions and negotiation)
- Agent-based Supply Chain Management
- Robot teams for de-mining
- Team Rescue Scenario (NEO)
- Agent-based financial portfolio management
- Agent-based “on the move” collaboration on mobile devices

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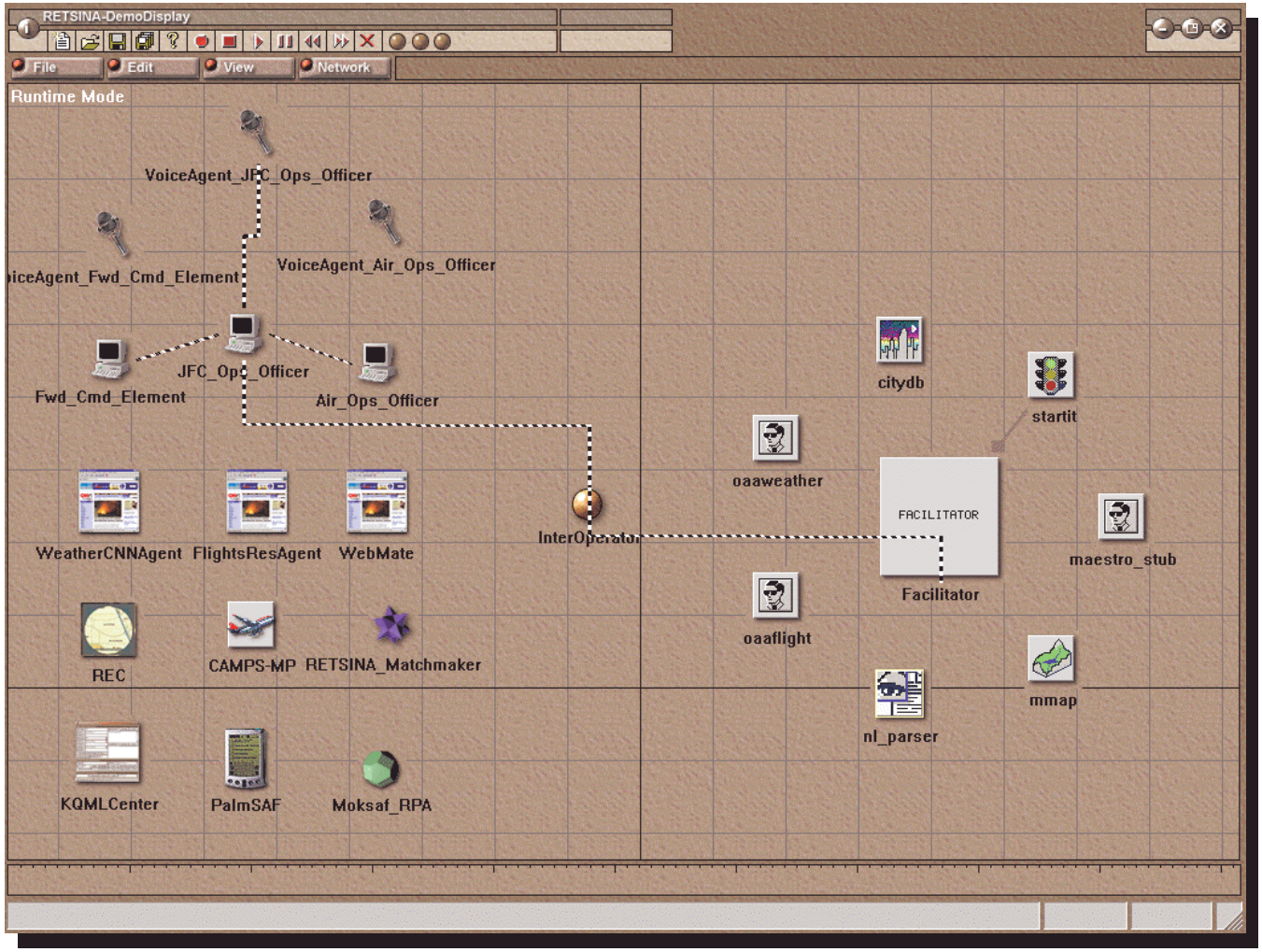
Visualization of Agent Interactions



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Agent Discovery and Interoperation

- Discovery necessary in open environments
- Interoperation necessary for heterogeneous agents
- Agents advertise their expertise/capabilities to middle agents
- Requester agents ask middle agents for agents with particular capabilities
- Middle agents match requests to advertisements and return results
- Communication protocols include formal semantics and ontologies for interoperation
- The discovery scheme enables system robustness through functional substitutability of agents

Sycara, K., Klusch, M. Widoff, S. and Lu, J. "LARKS: Dynamic Matchmaking among Heterogeneous Agents in Cyberspace", JAAMAS, vol 5, no. 2, July 2002.

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Types of Interactions

- Providers and requesters interact with each other directly
  - a negotiation phase to find out service parameters and preferences (if not taken into account in the locating phase)
  - delegation of service
- Providers and requesters interact through middle agents
  - middle agent finds provider and delegates
  - hybrid protocols
- Reasons for interacting through middle agents
  - privacy issues (anonymization of requesters and providers)
  - trust issues (enforcement of honesty; not necessarily keep anonymity of principals); e.g. NetBill

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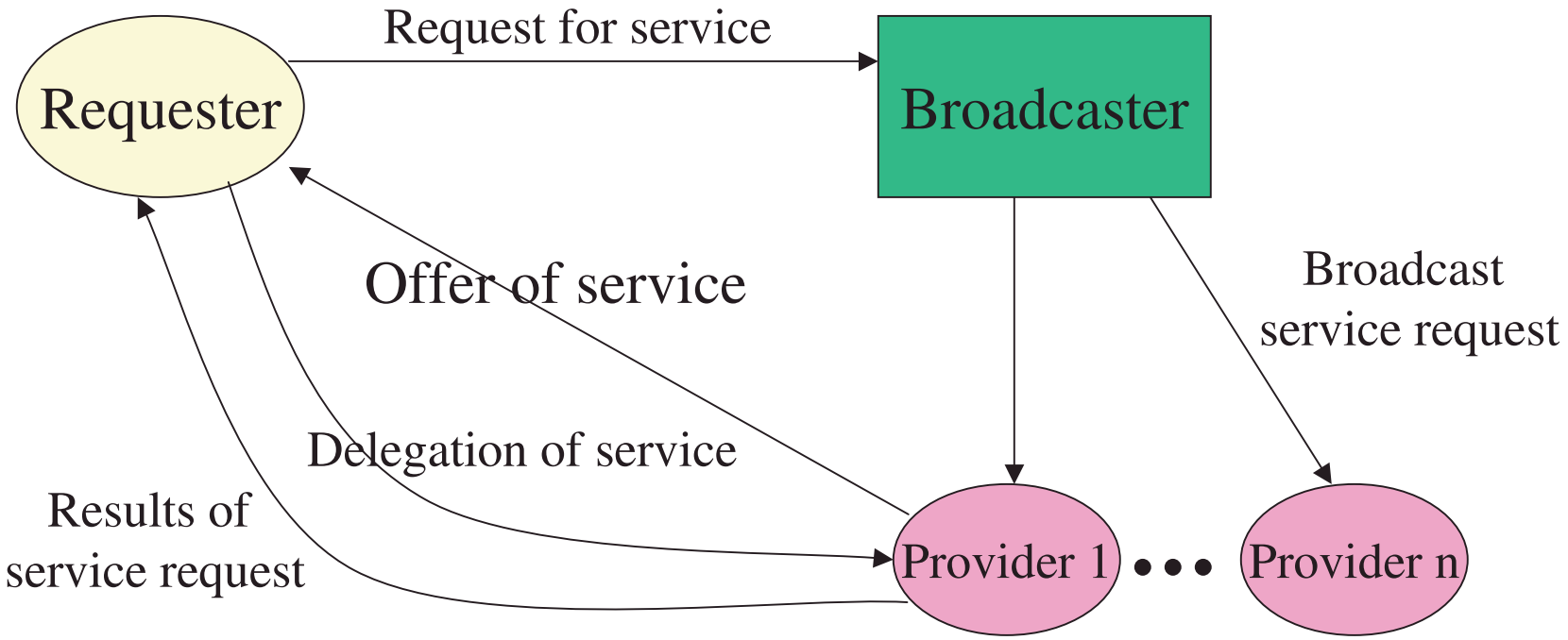
Broadcaster



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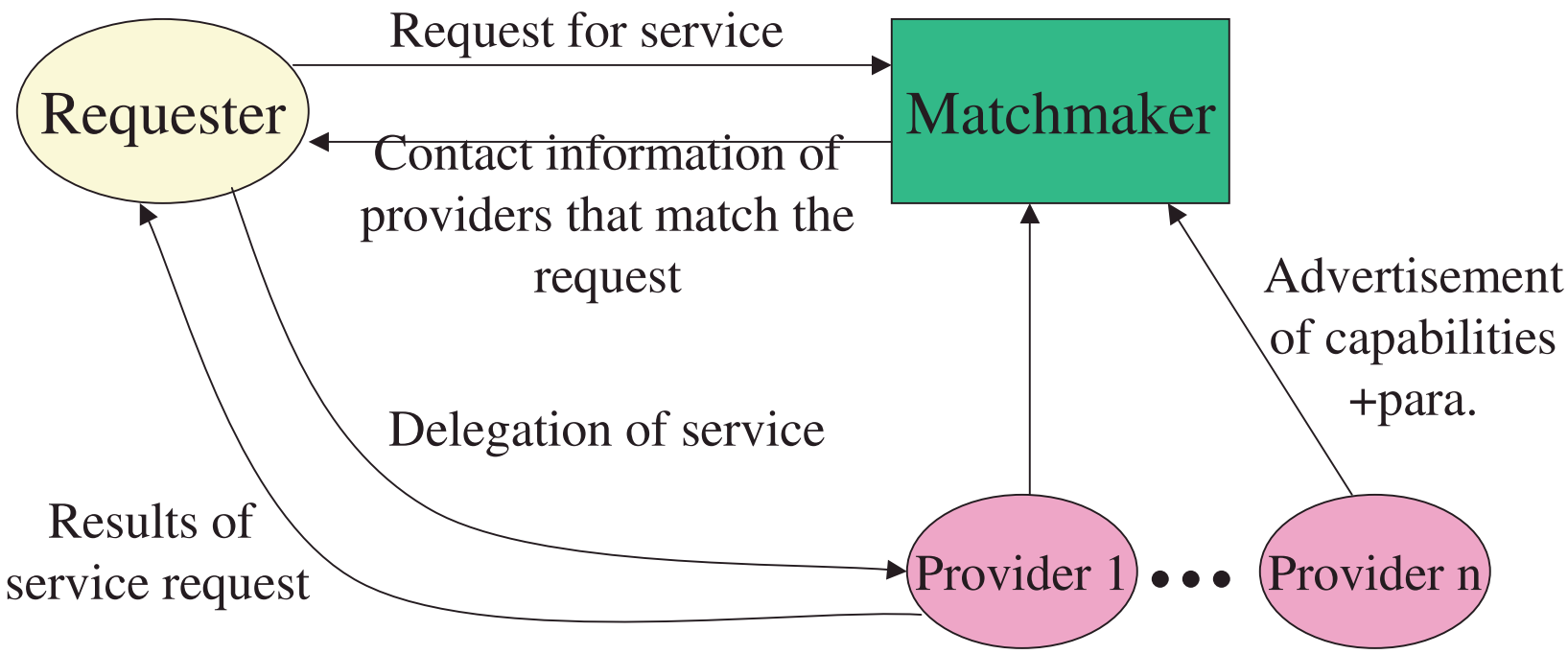
Matchmaker



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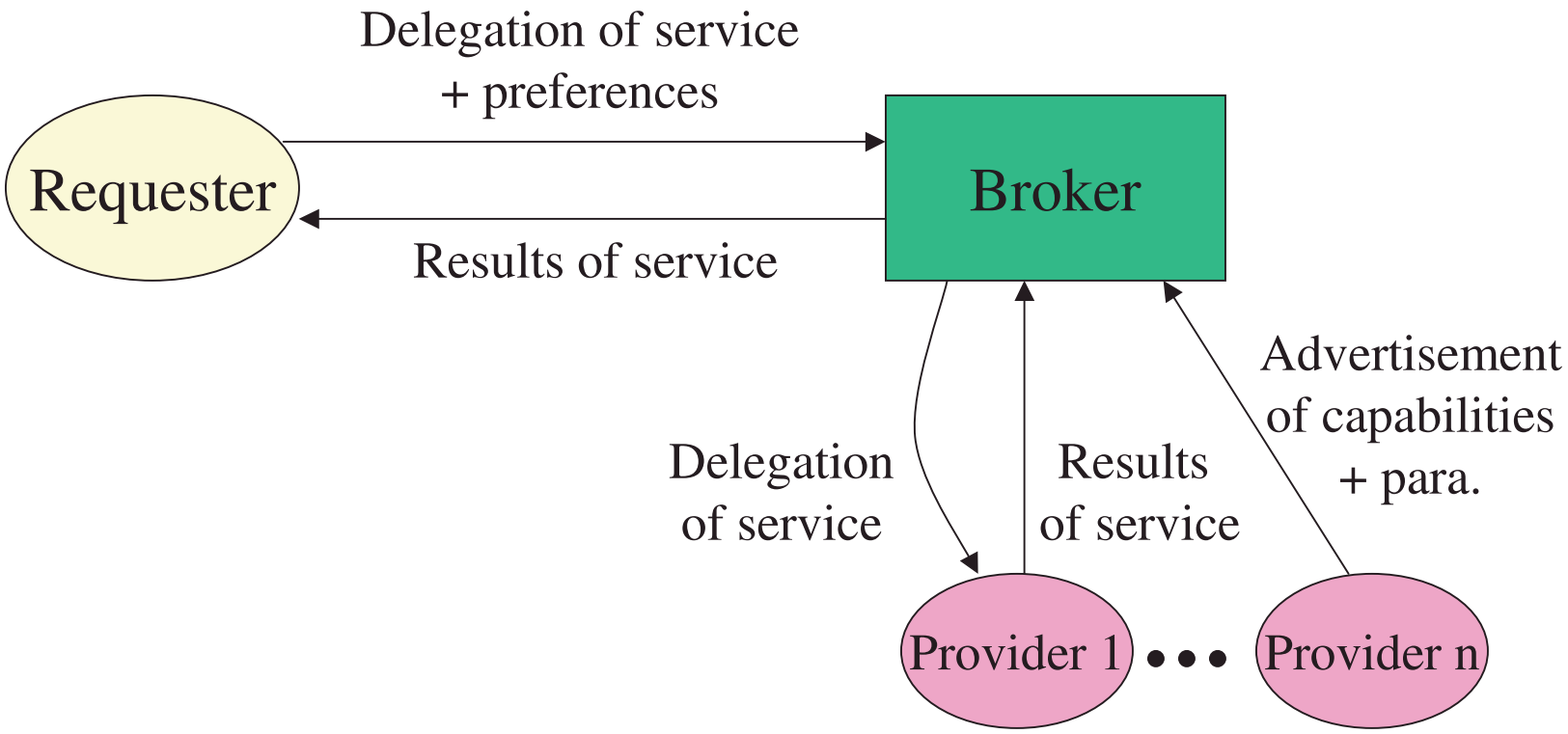
Broker



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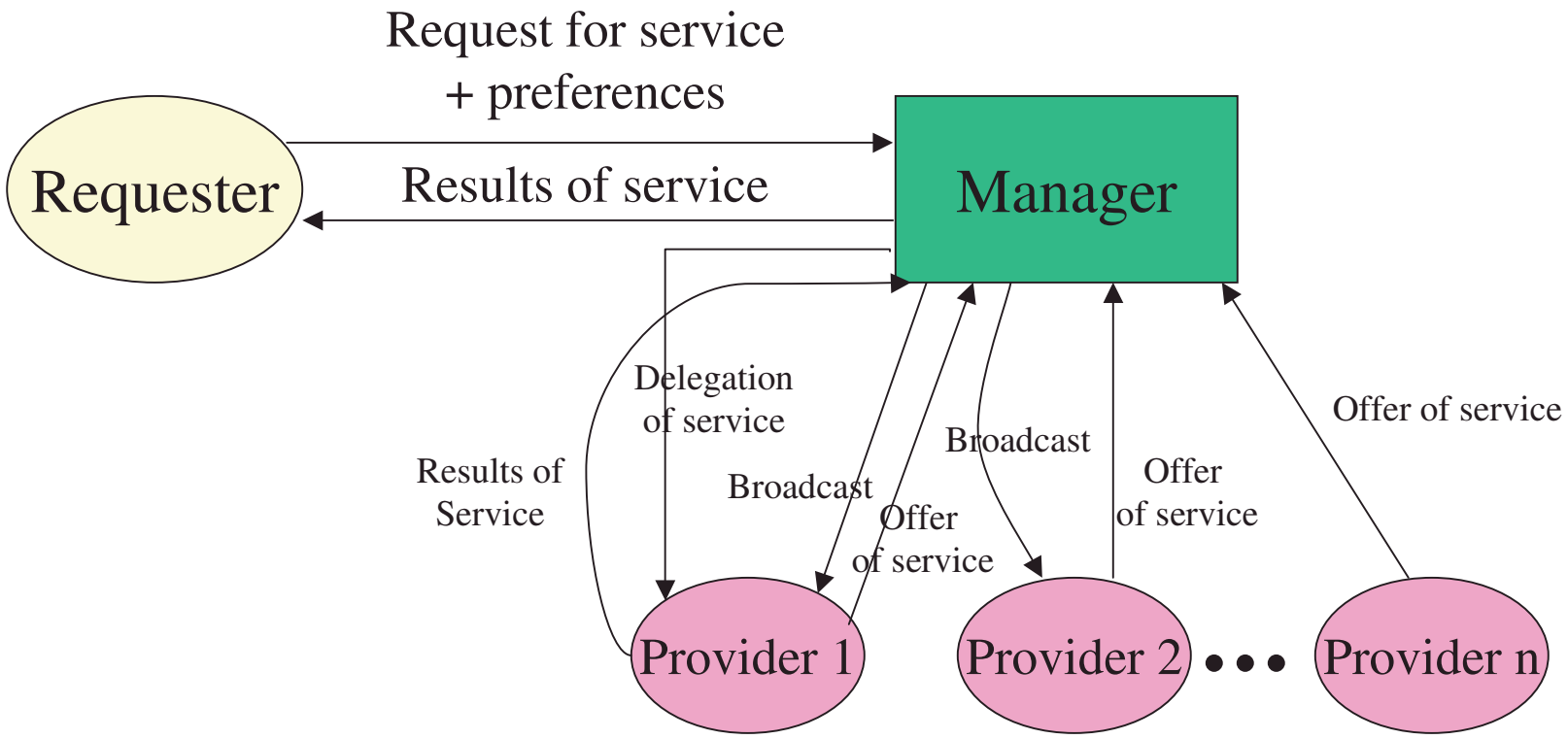
Contract Net



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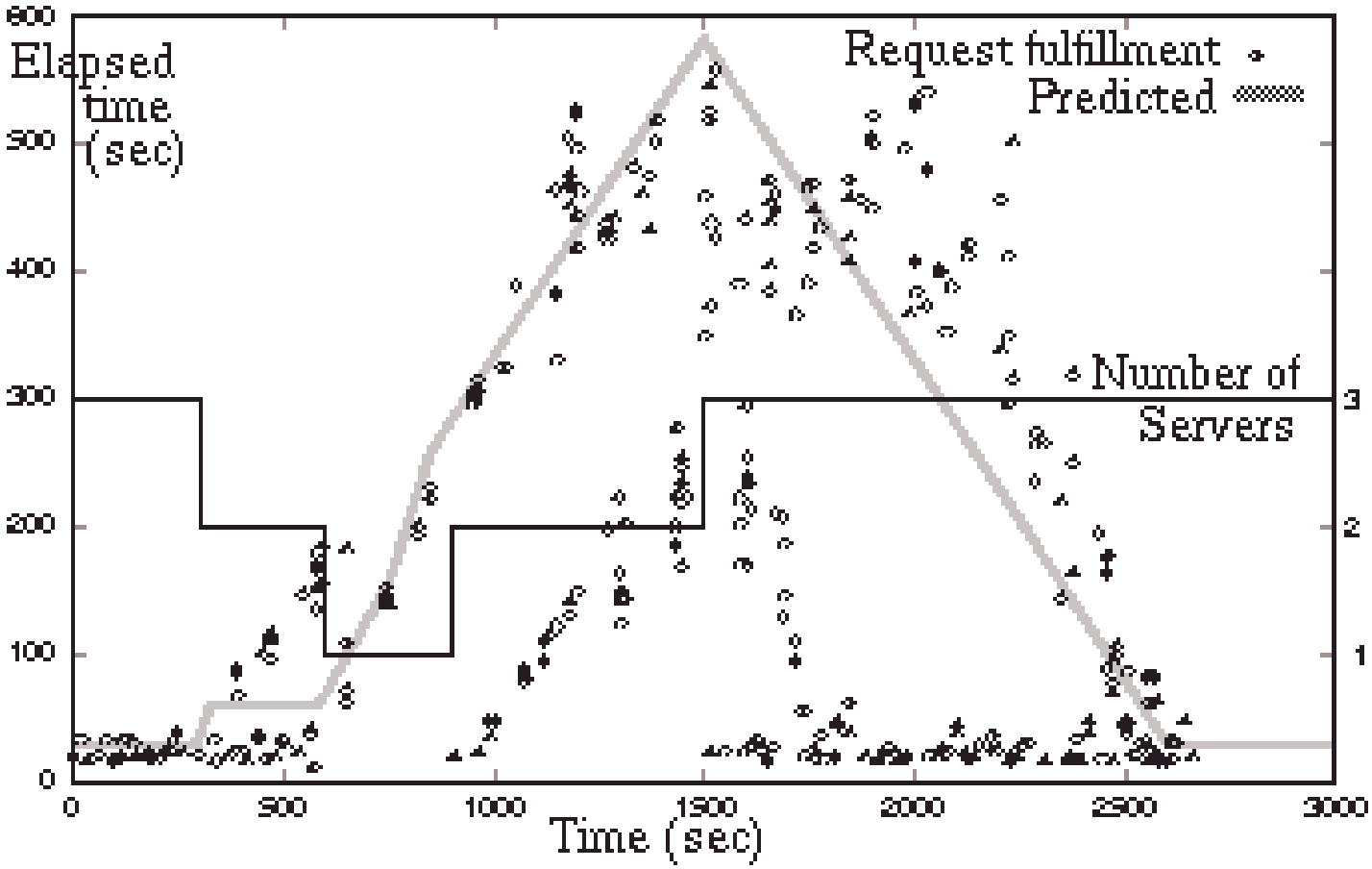
Performance of Match-made System



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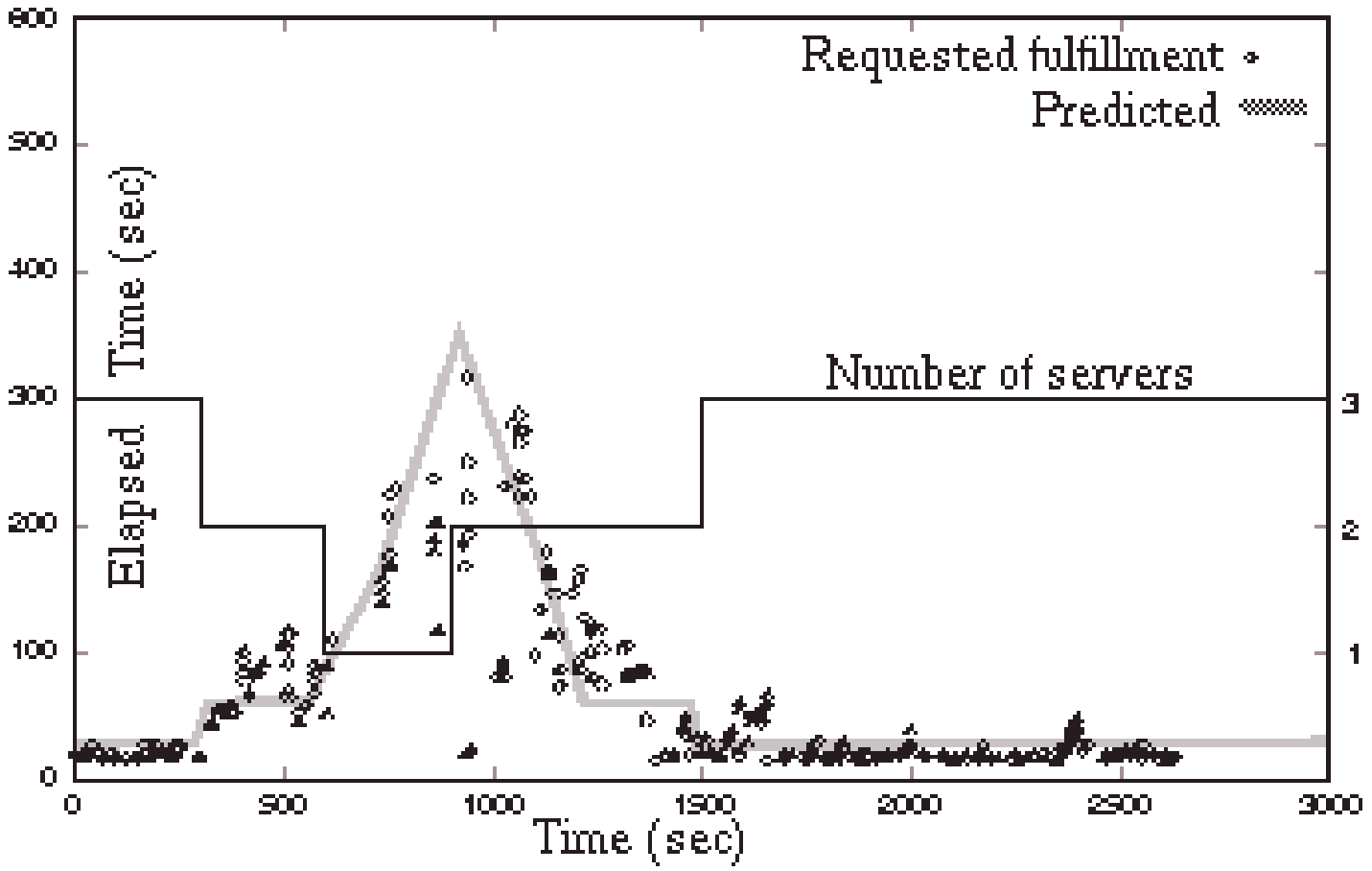
Performance of Brokered System



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Hybrid Human-Agent Teams

Human and software agents working together as a team to perform complex tasks in a distributed environment

Agents providing information access as well as user-centered problem-solving and decision support

Agents monitoring team activity and the environment so that effective assistance can be provided

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Human-Agent Teams

Agent Roles

support for individual team members

- simple reactive agents: manage and present information meaningfully, react to event stimuli
- planning agents: present courses of action based on emerging events

support for team activity

- situation assessment: provide information to the team on environment
- facilitate communication within the team
- supportive behaviours: correcting other team member, requesting backup

as an autonomous team member

- cannot use human team member roles directly
- probably feasible for information access, event monitoring, planning of member roles

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Agents in Teams: Expected Improvements

- **Reduce time for human teams to arrive at a decision**
- **Allow teams to consider a broader range of alternatives**
- **Enable teams to flexibly manage contingencies (replan, repair)**
- **Reduce individual and team errors**
- **Increase overall team performance**

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NAWCTSD TeamWork Dimensions

Information Exchange

- Seeking information from all available sources
- Passing information to the appropriate persons before being asked
- Providing "big picture" situation updates

Communication

- Using proper phraseology
- Providing complete internal and external reports
- Avoiding excess chatter
- Ensuring communications are audible and ungarbled

Supporting Behavior

- Correcting team errors
- Providing and requesting backup or assistance when needed

Team Initiative/Leadership

- Providing guidance or suggestions to team members
- Stating clear team and individual priorities.

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Aiding & Cognitive Resources

We might improve team performance by:

1. Making individual tasks easier freeing cognitive resources for team coordination tasks
2. Aiding aspects of individual task exercised in coordination activities
3. Supporting team coordination tasks directly

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TANDEM Synthetic Radar Task

- Lab Simulation : moderate fidelity Aegis-based simulation
- Characteristics : Real-time, reactive & inflexible
- Task : Forced Pace, High Workload, Highly Dependent on Cooperation, Shared Information, Individual Action
- Cognitive Demands: High working memory load..
  - Subjects must access from menus or obtain from teammates five parameter values and their classifications in order to reach each of their individual targeting decisions
- Studies : contrasted agent aiding for reducing memory load with assistance in communication and cooperation

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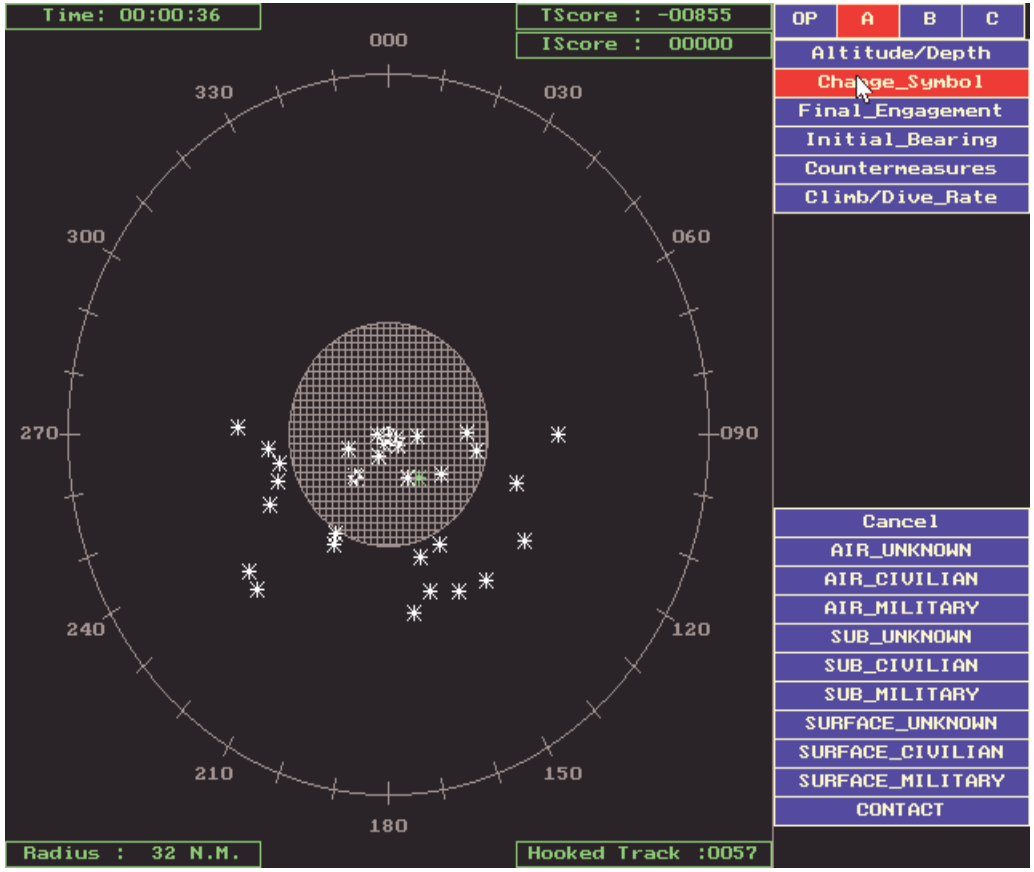
Tandem Experiments



- Three team members (Alpha, Bravo, & Charlie) each responsible for a different decision (type, classify, intent)
- Each team member has 3 menus each accessing 3 parameters
- Each team member has 3 pieces of data for his task, but the remaining two items must be obtained from teammates

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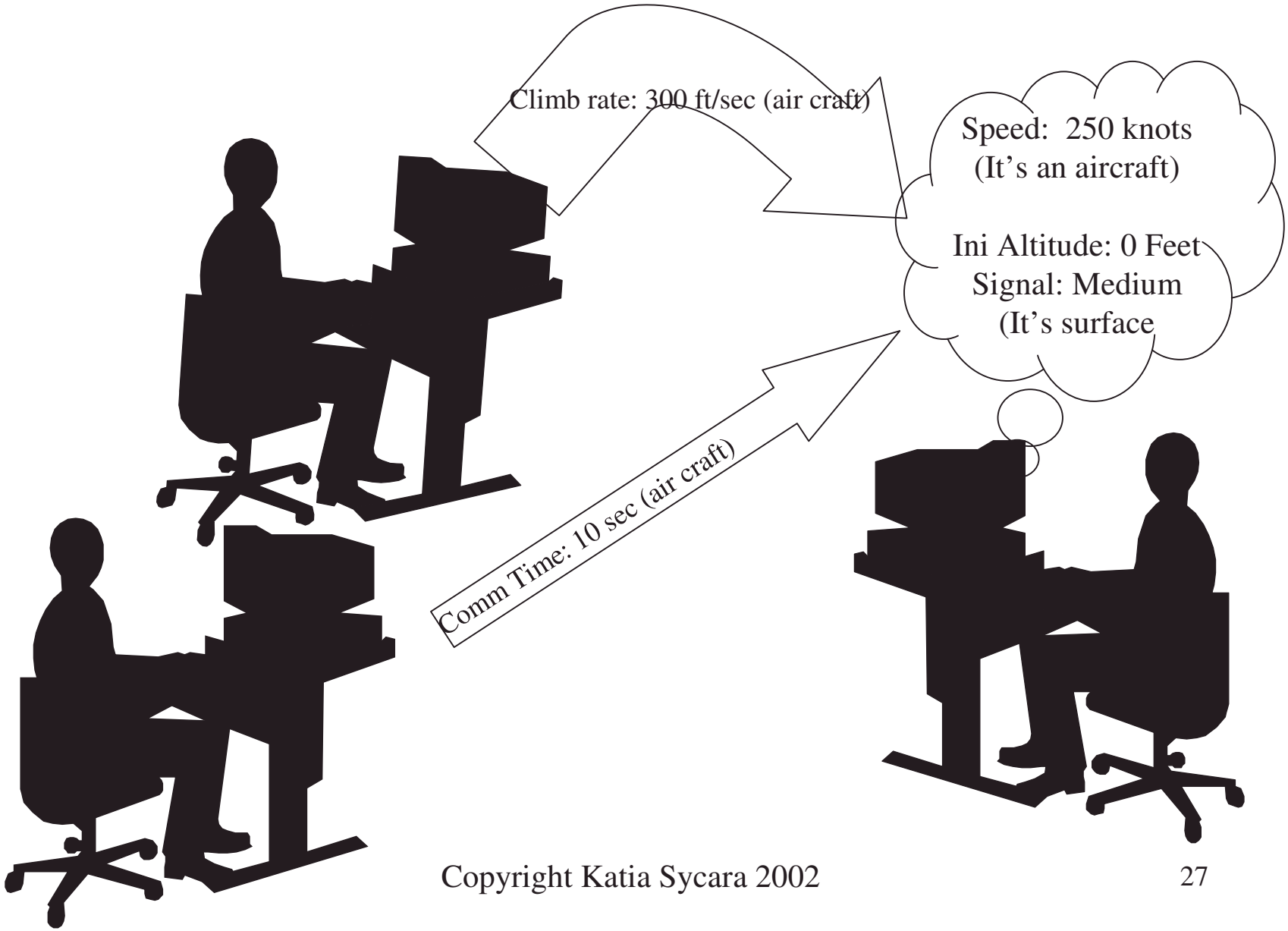
User may need information from teammates



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Agent Aiding Strategies

	Supports Individual's Task	Supports Team Work
Registry	• Shows who has what data	• **Facilitates coordination**
Persistent Memory	• **Preserves accessed values for own decision**	• Preserves accessed values for communication to team
Information Push	• Accumulates values for own task	**Pushes accessed values to teammates** • Reduces verbal communication • Reduces communication errors

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Experimental Design

Between subject design with 4 conditions:

- Individual *Memory* agent
- Team *Registry* agent
- Team *Push* agent
- Control (no agent)

Each task is defined by 5 parameter values, 3 of which a team member can access from menus, the other 2 are gotten from team mates

Three team mates Alpha, Bravo, Charlie, each responsible for a decision (type, intent, classification)

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Experimental Design (cont)

- 10 teams of 3 subjects in each condition (120 subjects)
- Each session contained 3 trials, 15 minutes each
- Each trial included 75 targets with 3 levels of target difficulty
- Target difficulty : hard (25 targets), medium (25 targets) & easy (25 targets)

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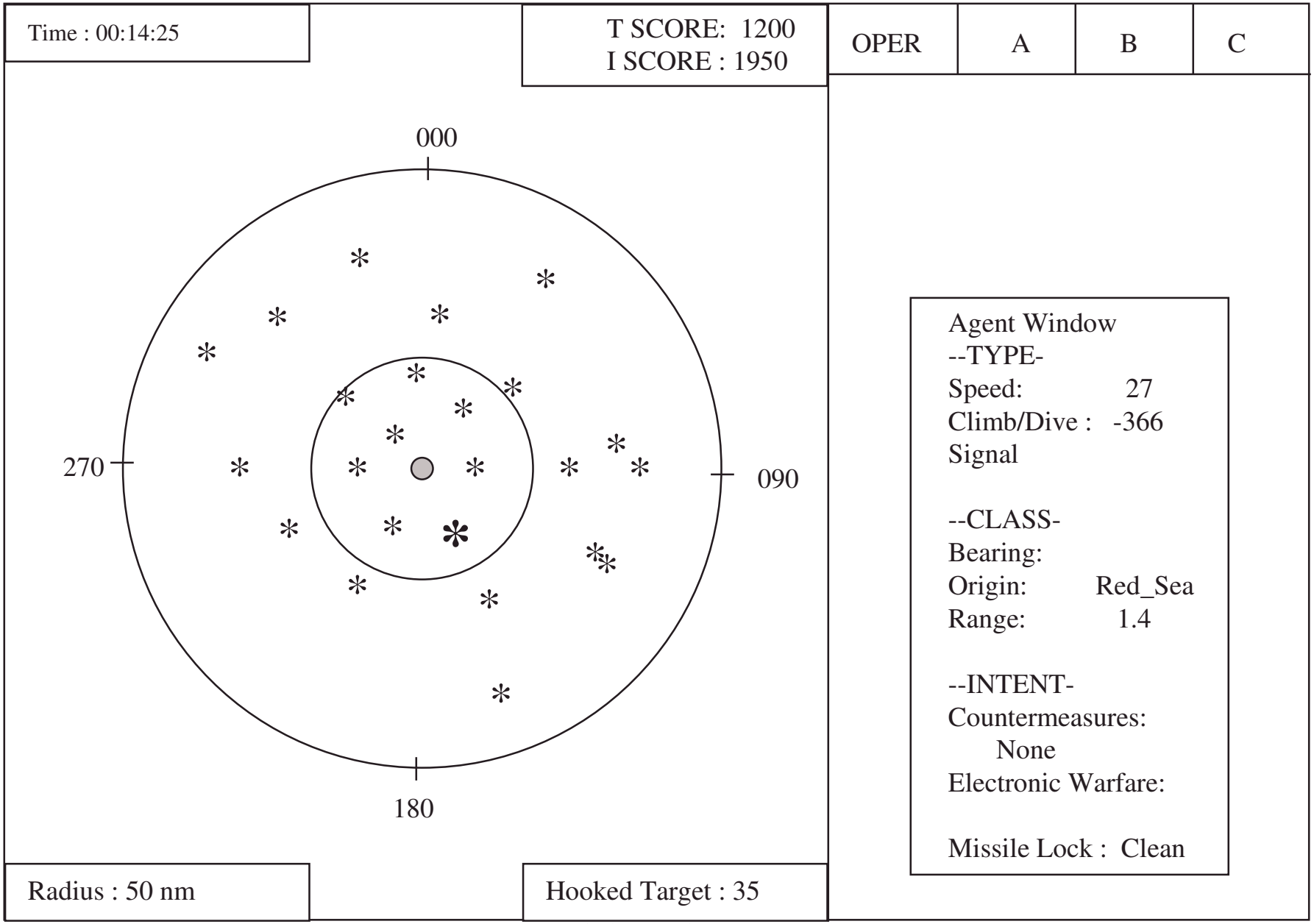

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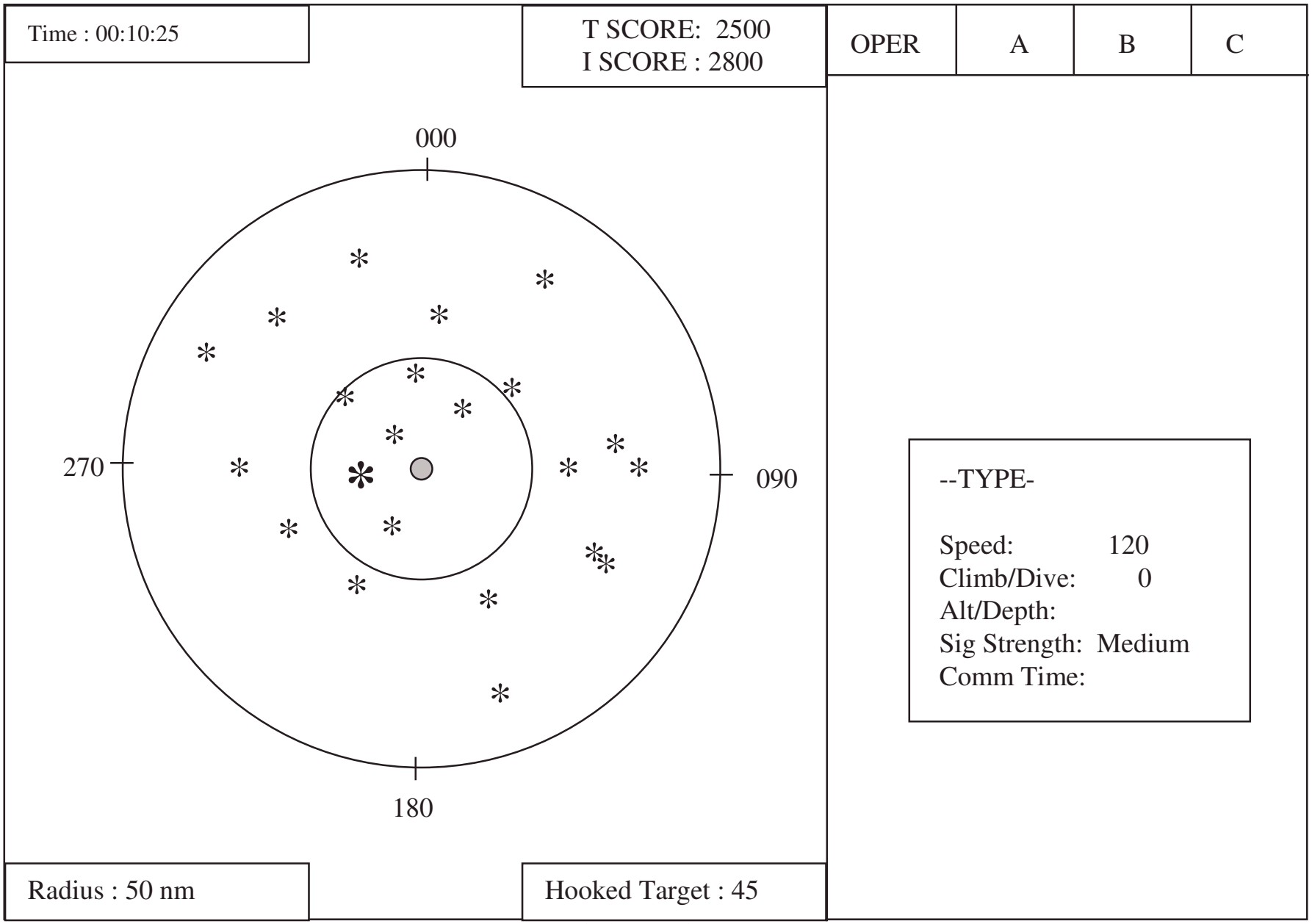

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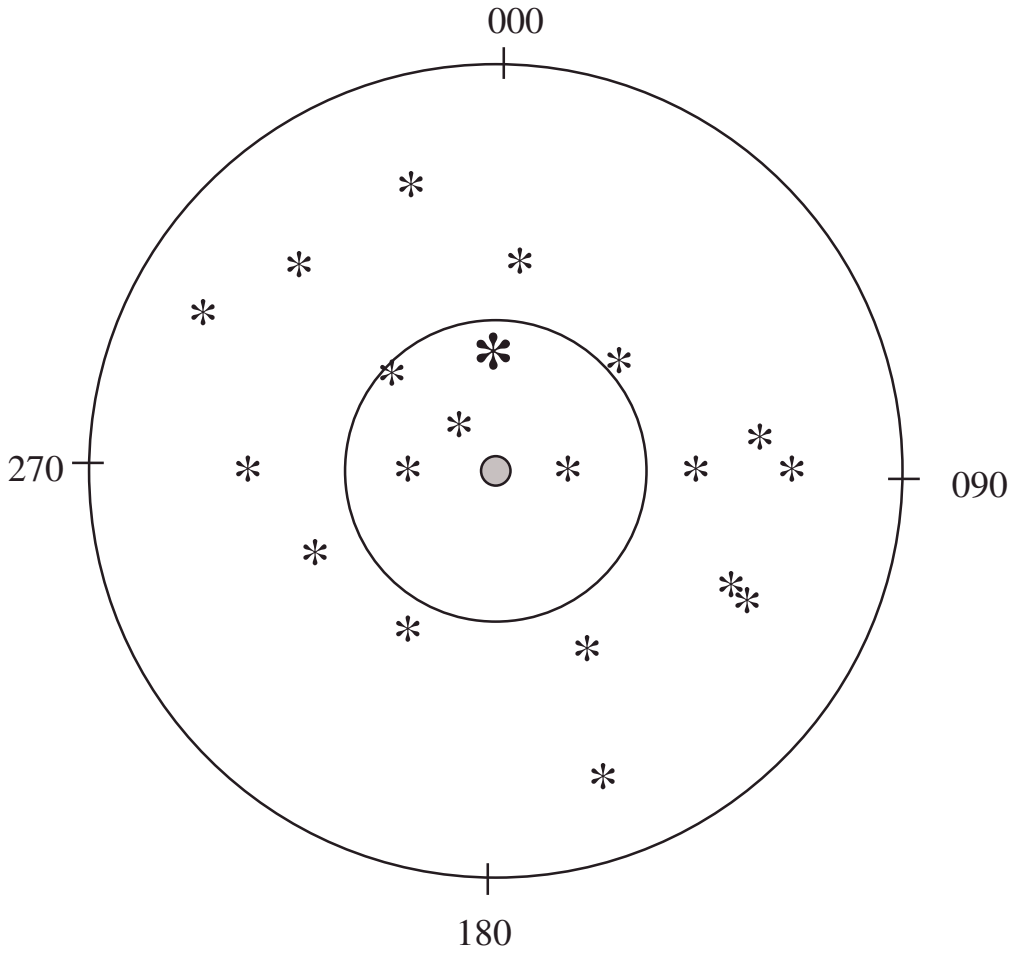
Team Push for Alpha

Time : 00:09:25	T SCORE: 2500 I SCORE : 2800	OPER	A	B	C



--TYPE-	
A B C	Speed
* B	Alt/Depth
A B	Climb/Dive
A B	Signal Strength
B C	Comm Time
--CLASS-	
B	Intel
*A B	Bearing
A C	Range
B C	Maneuver
--INTENT-	
A C	Countermeasures
A	Electronic War
A B	Missile Lock
* C	Response
B C	Threat

Radius : 50 nm	Hooked Target : 23

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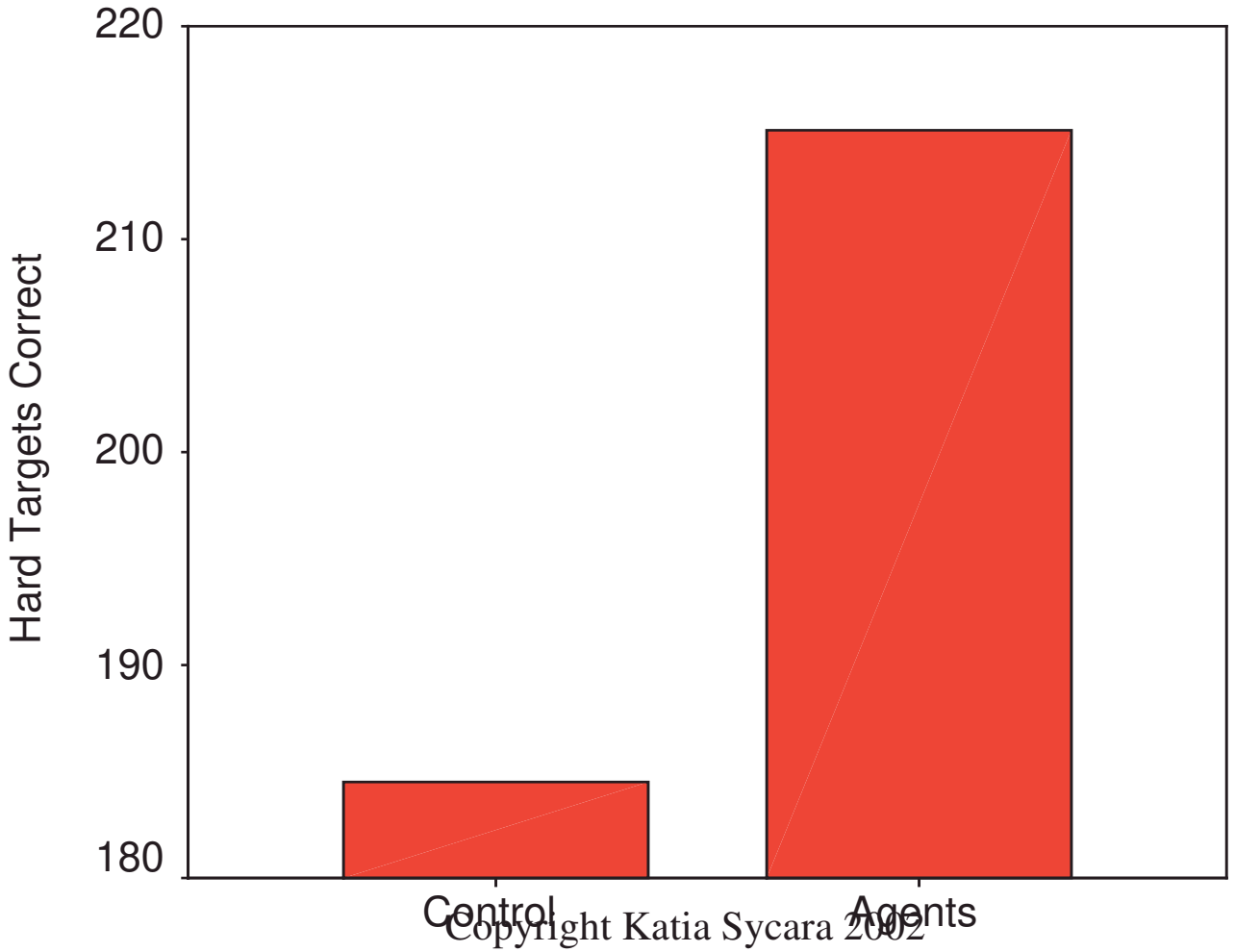
Registry Agent

Identification of Hard Targets



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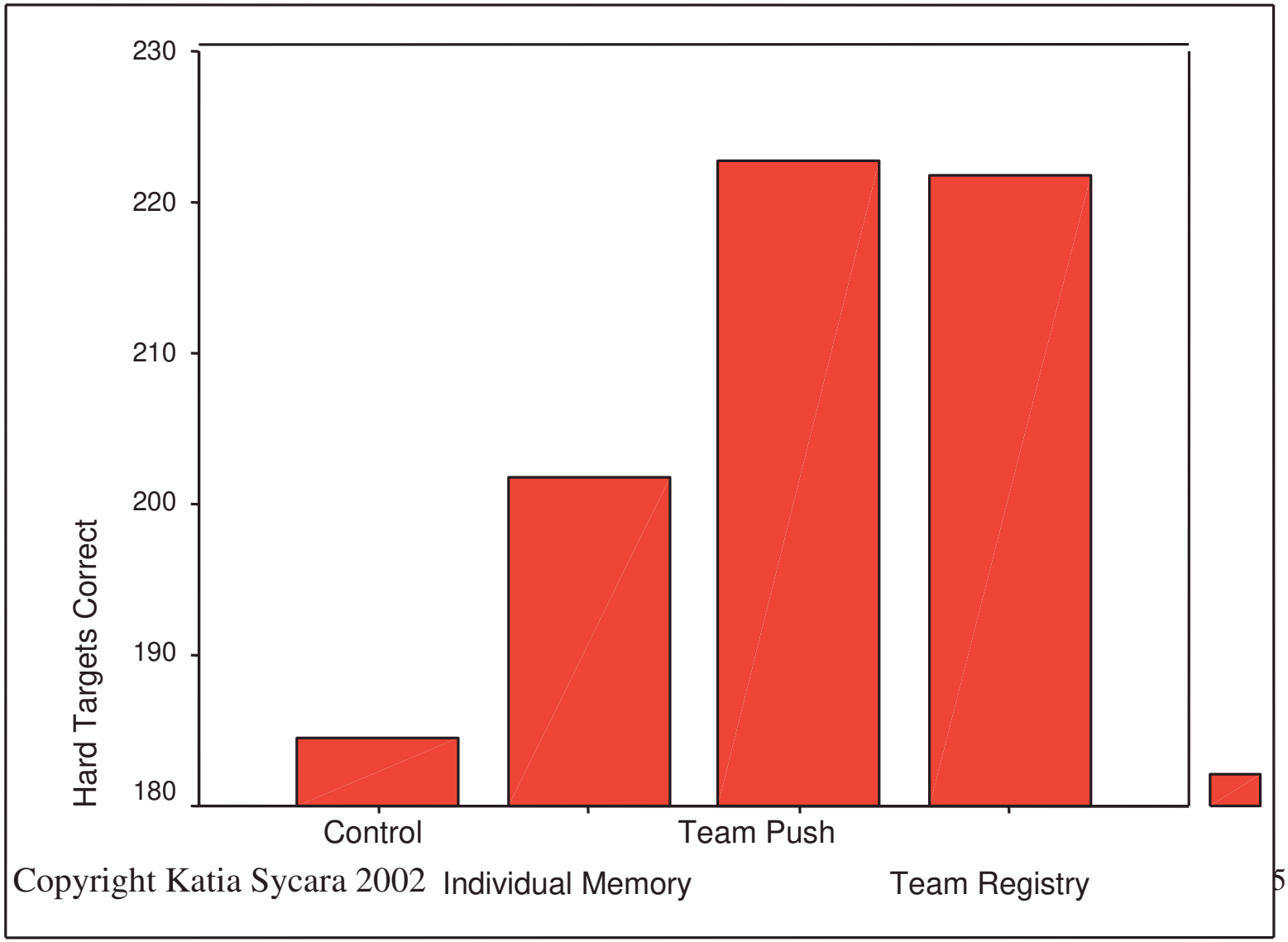
Aiding Teams Helps more than Aiding Individuals for Hard Targets



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MokSAF Collaborative Planning Task

- Lab Simulation : MokSAF lightweight agent-based planning environment using ModSAF terrain database and Retsina-like planner
- Characteristics : Deliberative, iterative & multiattribute
- Task : Self-Paced, Complex, Highly Dependent on Cooperation, Shared Information, Team Action
- Cognitive Demands: Complex problem-solving, requires multi-attribute negotiation among subjects
- Studies : Comparisons between autonomous, cooperative, and critiquing route planning agents

Payne, T., Sycara, K. and Lewis, M. "Varying the User Interaction within Multi-Agent Systems" , In Proceedings of the Fourth International Conference on Autono Agents, June 3-7, Barcelona, Spain, 2000. pp 412-418

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Humans & Agents

Agents:

- have access to digital information in the infosphere
- cannot consider intangible objectives which are not part of that digital infosphere

Humans:

- Understand Idiosyncratic and situation-specific factors
  - local politics, non-quantified information, complex or vaguely specified mission objectives
- Dynamically changing situations
  - Information, obstacles, enemy actions

Problem:

- To share and combine human and agent information and resources

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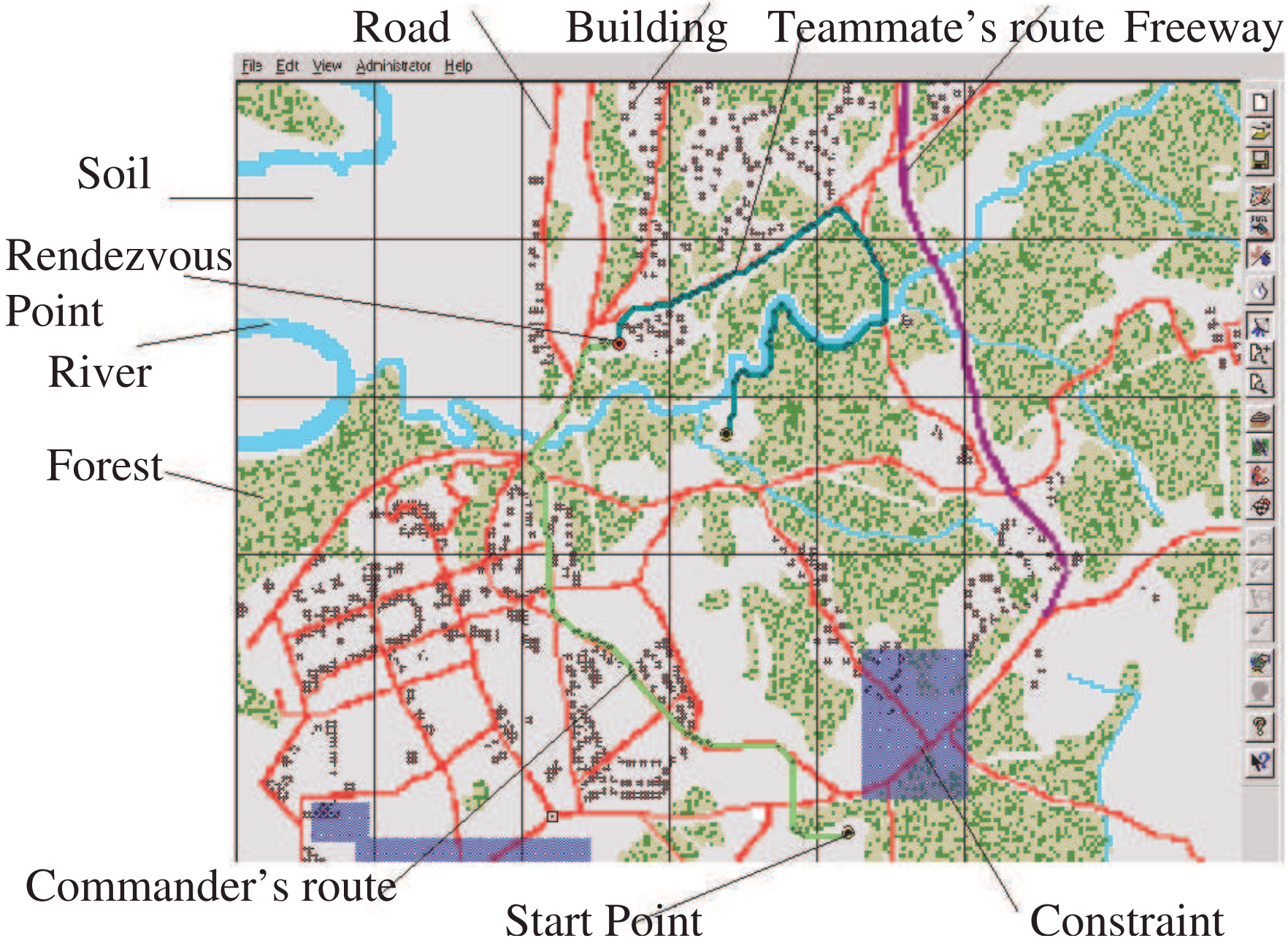
MokSAF Display



Experiments

- Map planning environment
- Teams of three subjects
- Three conditions
  - Control (route critic) Agent
  - Autonomous Planning Agent
  - Cooperative Planning Agent
- Capability to express intangible constraints via physical artifacts on the map

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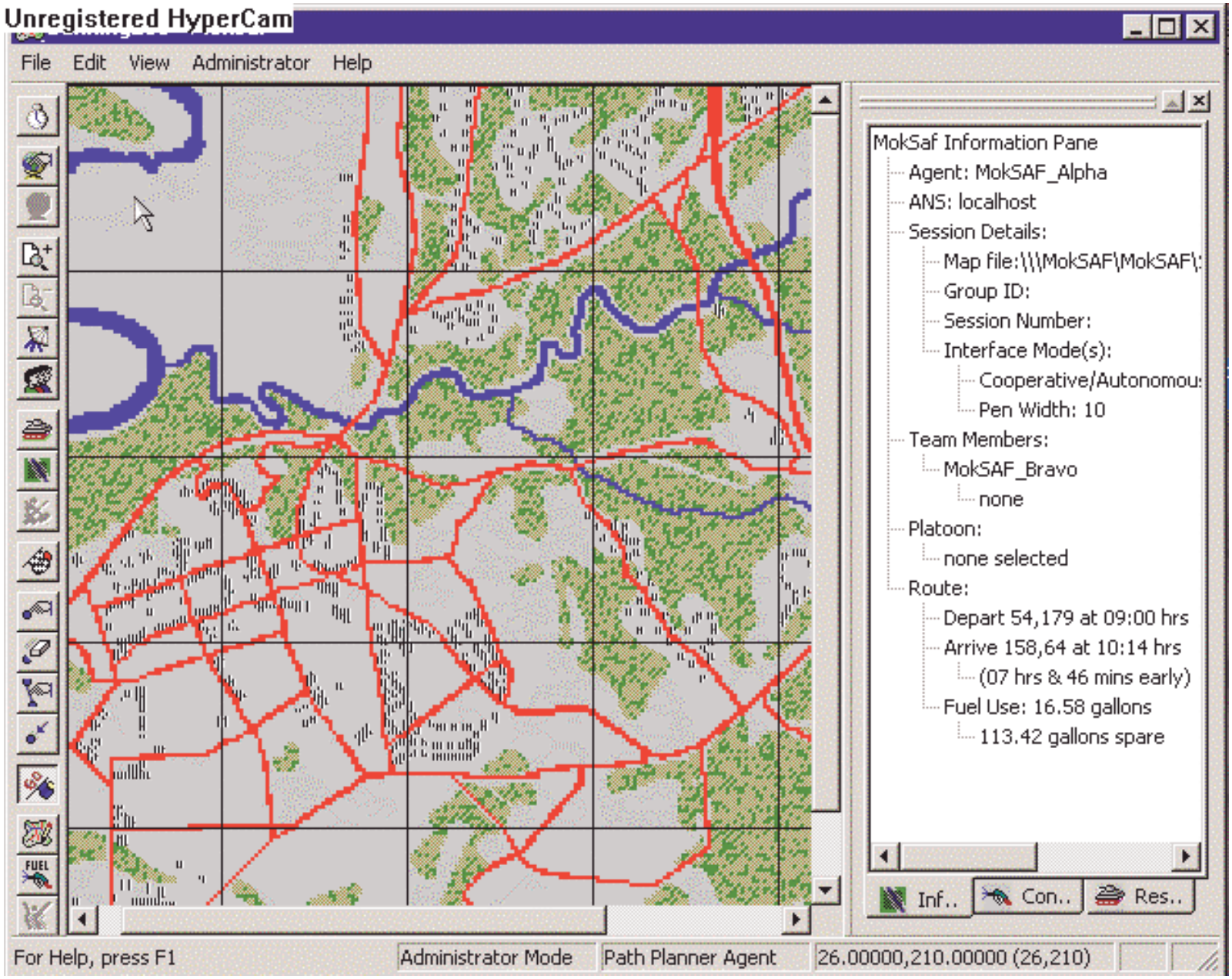
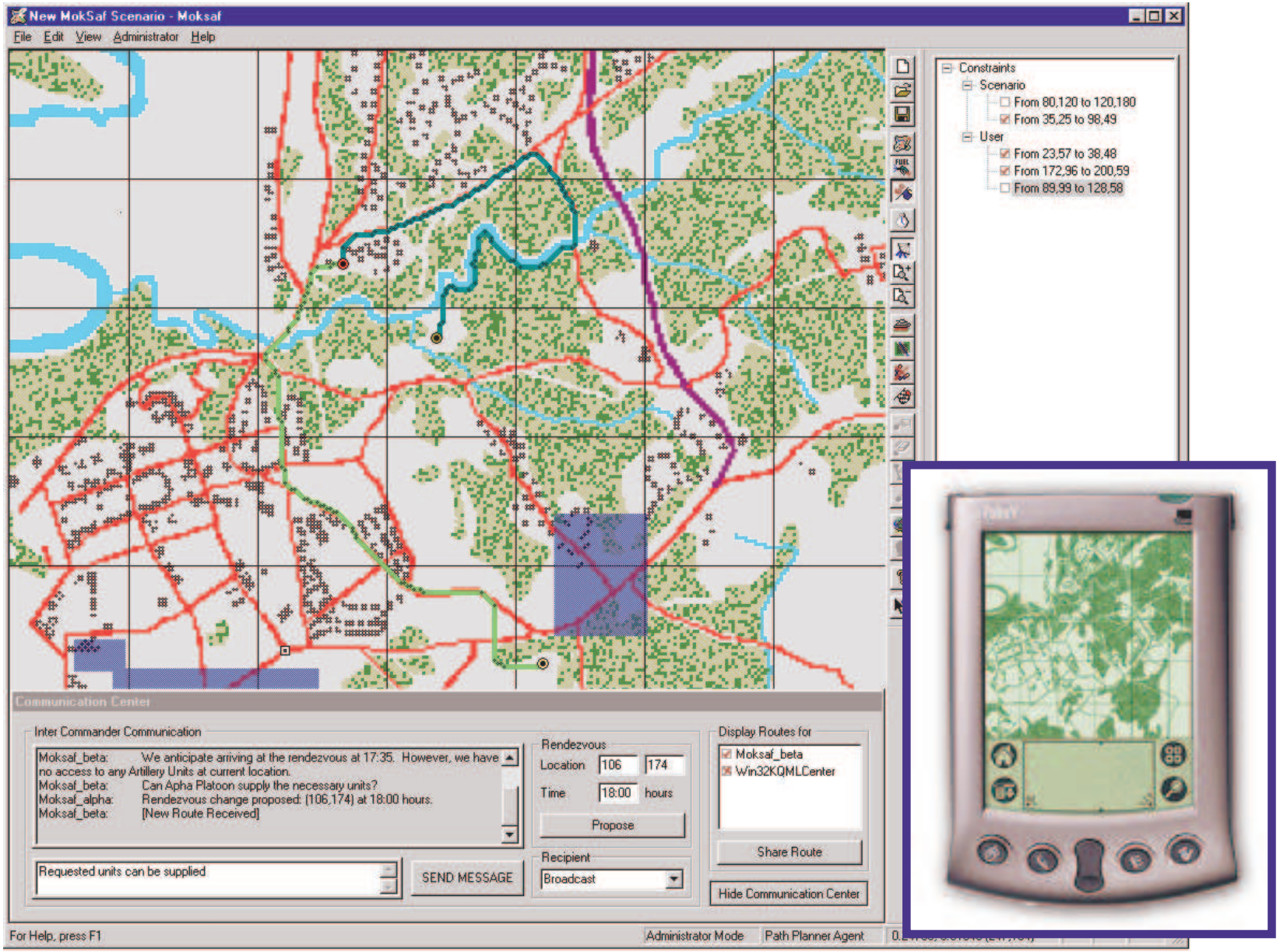
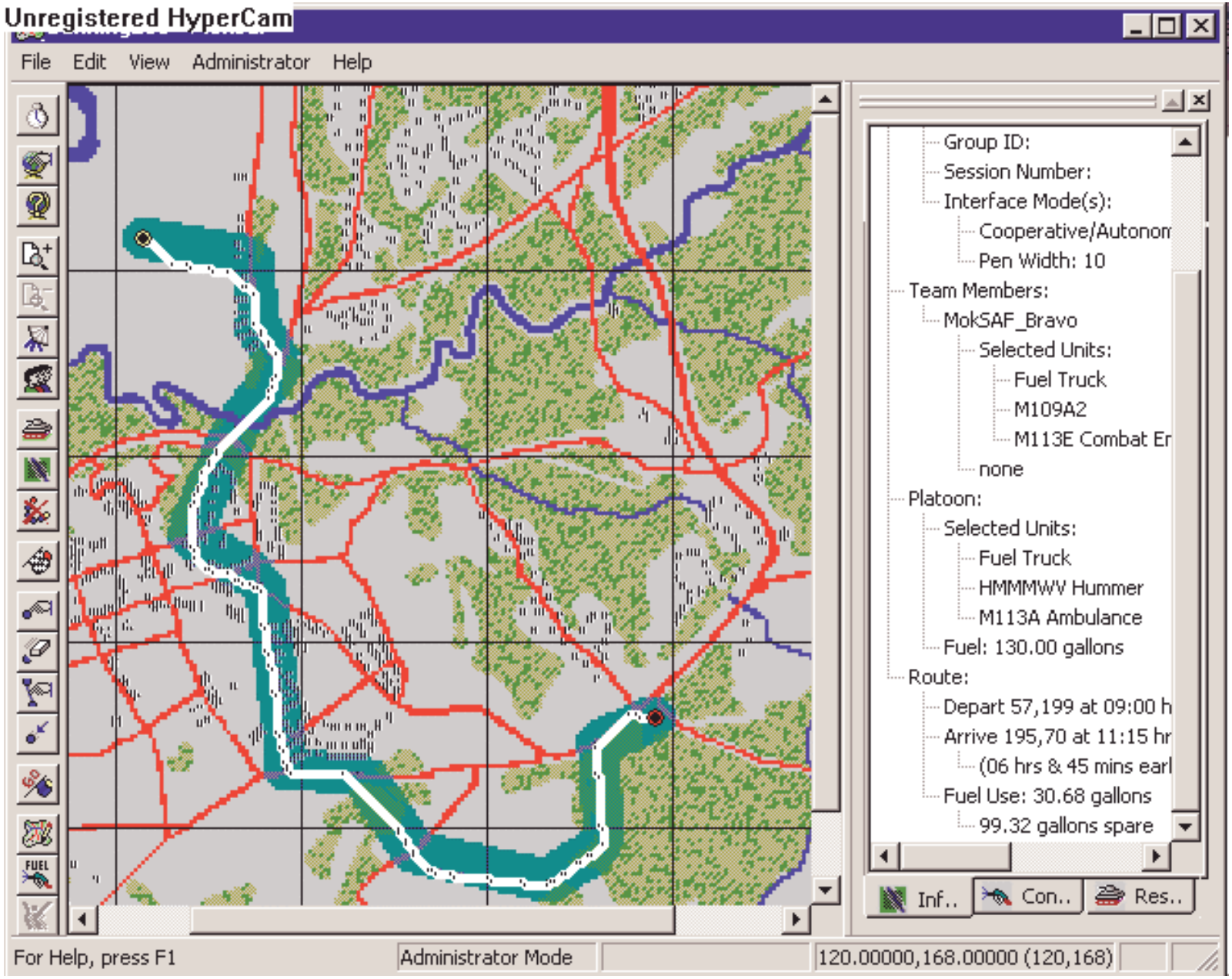
Planning Routes



MokSAF: Autonomous Agent with user supplied constraints



Cooperative Agent/hilighter mode



Sharing Plans

- Subjects create individual routes to rendezvous point by
  - drawing them
  - asking agent to draw them
- When ready, subjects can share plans with other commanders
  - all routes will appear on screen
- Can communicate with each other via typing into a comm program
  - messages go to one commander or all commanders
  - categorized by subject

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Mission Objectives (Performance Measures)

- All platoons arrive at the specified rendezvous point within a some agreed time frame
- Create an optimal route in terms of path length
- The route should not violate any physical constraints
- The route should not violate any social constraints (e.g., avoid this area because the roads are under construction)
- The route should pass through areas designated as “go-bys”
- Minimize sharing paths with other teammates
- The team should take the total number and types of units specified by the mission briefing.
  - Too few units is worse than too many units.
  - An exact match is best.

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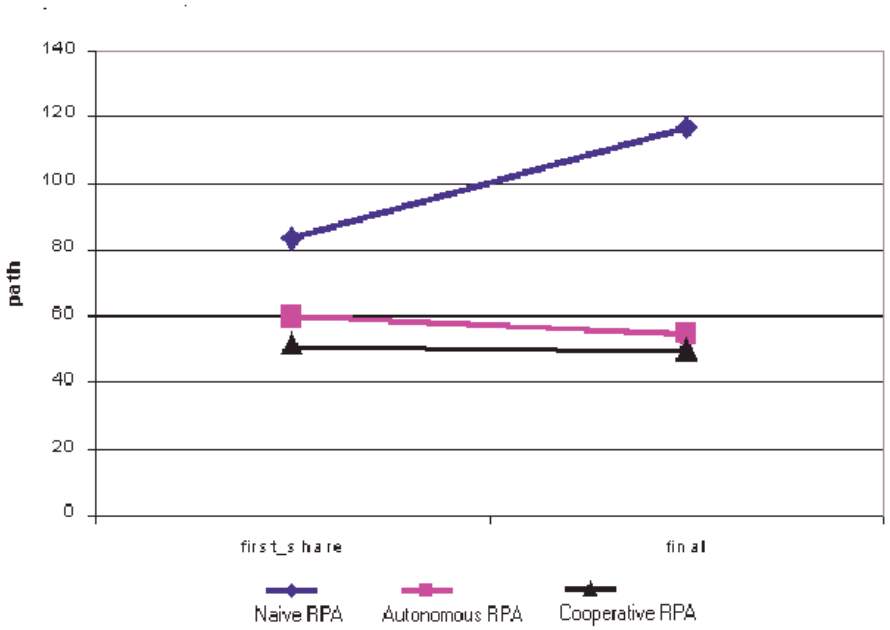
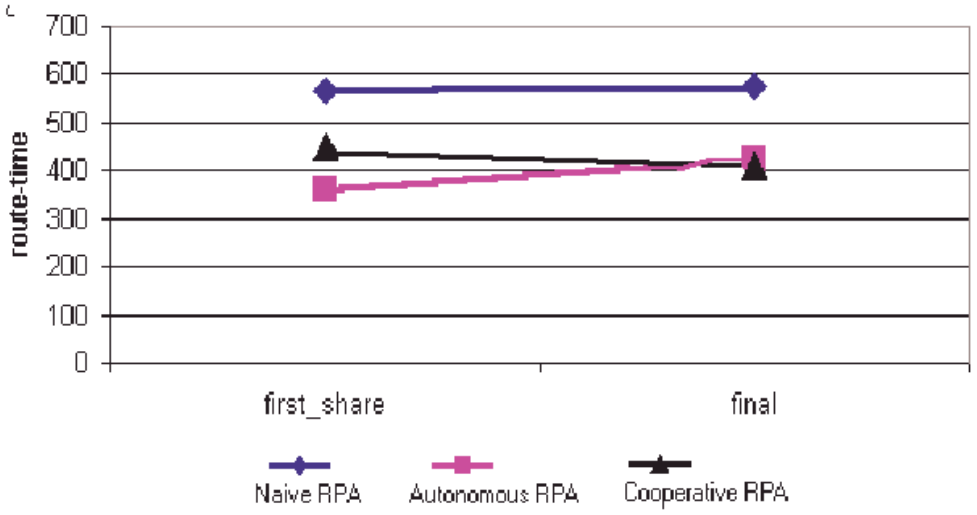
Path Length, Route Times, and Fuel Usage were uniformly better for Aided Teams



Path Length



Route Times

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Results Vehicle Selection & Successful Rendezvous

On the more difficult Session 2 Rendezvous:

- Teams using the Cooperative RPA most closely approximated reference performance
- Teams using the Autonomous RPA made slightly less appropriate decisions
- Teams using the Route Critic Control performed poorly sometimes failing to rendezvous

For the less difficult Session 3 Rendezvous:

- Performance retains ordering although differences are not significant

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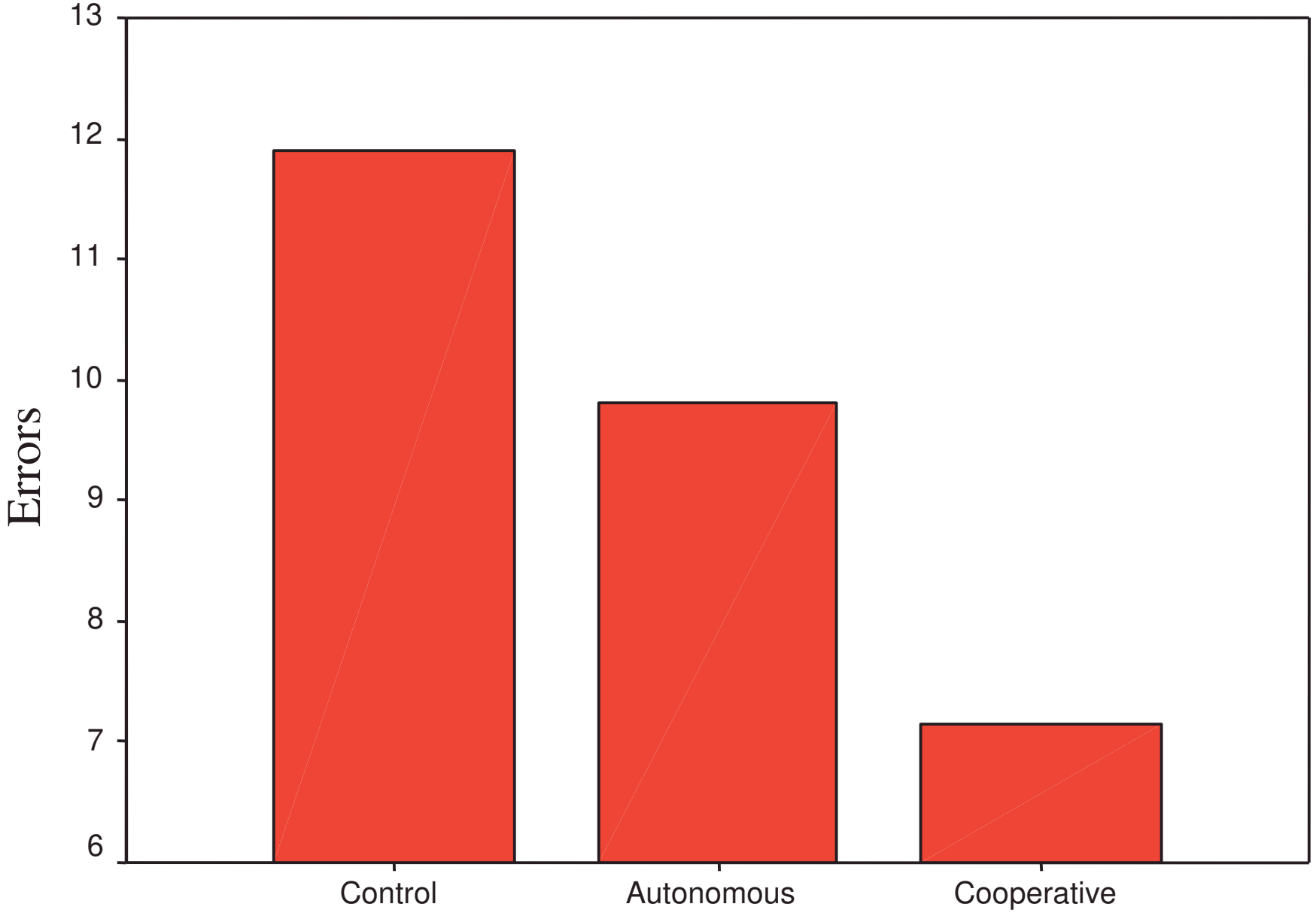
Errors in Vehicle Choice session 2



Shuttle Launch

Several distributed range operators must collaborate to achieve a successful launch within the launch window or abort the mission in minimal time

- Responsible for monitoring a particular area in the launch zone
- Negotiate with other range operators

Monitoring of several conditions, such as

- There should be no civilian or military vehicles in the path of the shuttle, in case of falling debris
- The weather conditions need to be such that the exhaust plumage does not fall on inhabited areas
- …

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Shuttle Launch

Work environment is

- distributed
- time-critical
- information-rich
- communication-intensive

Increasingly, bottleneck on team performance is not availability of information, but limits on human capabilities: perception, cognition, attention

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Supporting Human-Agent Teams in Shuttle Mission Launch

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Approach

- Develop task models appropriate to the distributed workflow
- Develop cognitive models of key team members
- Develop software agents to support the team members and the team
- Evaluate the approach and resulting system

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Evaluation

- Verification of task and cognitive models with human performance data
- Evaluate effectiveness of software agents using models and then through empirical testing in the laboratory and field settings
- Develop evaluation metrics to assess team performance

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Range Operations & Space Launch Safety

Space Launch is an **inherently risky business**

- Many factors exist that could result in accidents
- However, US Ranges have an **outstanding safety record due to:**
  - **Safety systems** designed to minimized risk and to validate protocol
  - **Protecting civilians** by restricting access to areas of potential risk
  - **Monitoring environmental factors** to determine safe launch parameters

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Range Operations & Space Launch Safety

However,

- Existing systems are highly resource & expertise intensive
  - Want to improve operations, maintain quality of service, but reduce cost.

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Assisting Range Operations

Agents could assist Range Operations Teams

- Monitor team behavior/coordination to highlight emergent risk factors
- Provide assistance during range operations execution

To provide assistance, **a model of the team task** is required. Team-based Launch Scenario where team members:

- Assume responsibility for different cognitive tasks
- Are responsible for negotiating and managing shared resources
- Have to respond to unexpected events in a dynamic environment

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MORSE Simulation Environment

- MORSE is a simulation environment designed to reproduce a time critical team based task that provides a variable cognitive load to a human team
  - Simulates the team-based task of launching a space vehicle
  - Logs interaction between team members for the duration of the task
  - Provides interfaces to setup and run experiments with various scenarios
  - Provides interfaces for team members to focus attention to areas relevant to their responsibilities
- Network communication driven architecture can be extended to allow communication with external systems

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Simulation Scenario for MORSE

Synopsis

- During the hours leading up to a space launch, three Range operators located at three different monitoring stations have to prepare for the launch. This involves:
  - **Monitoring environmental conditions** such as the weather to determine it's effect on the launch and the surrounding inhabited areas (monitor winds to determine plume dispersion)
  - **Monitoring the area** within the anticipated flight path (Impact Lines)

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Simulation Scenario for MORSE

  - **Allocating resources** to prohibit incursions into the areas demarked by Impact Lines
  - **Determining if the launch should be aborted** based on conditions at the time of launch
- The Range operators have access to shared, limited resources, and have to negotiate their allocation to maximize utility while minimizing cost

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Team Objectives

Maximize safety, guarantee launch, yet minimize redundancy. Launch will be aborted if:

- Weather conditions are severe
- There is insufficient radar coverage of the launch path
- Civilian vehicles (air or water based) are within the IILs or African Gates
- Incursions are expected but interceptors are not in position

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MORSE Stations

Three stations (each with a different coverage area):

- Cape Canaveral *(area around launch site & coastline)*
- Antigua *(area around Caribbean and South American Coastline)*
- Ascension *(area over Atlantic Ocean)*

Decision Making

- Each station is responsible for:
  - Ensuring complete coverage of their area of responsibility
  - Monitoring weather within their domain
  - Negotiating with team members to acquire resources
  - Communicating with team members to share gathered data in order to reduce mission cost

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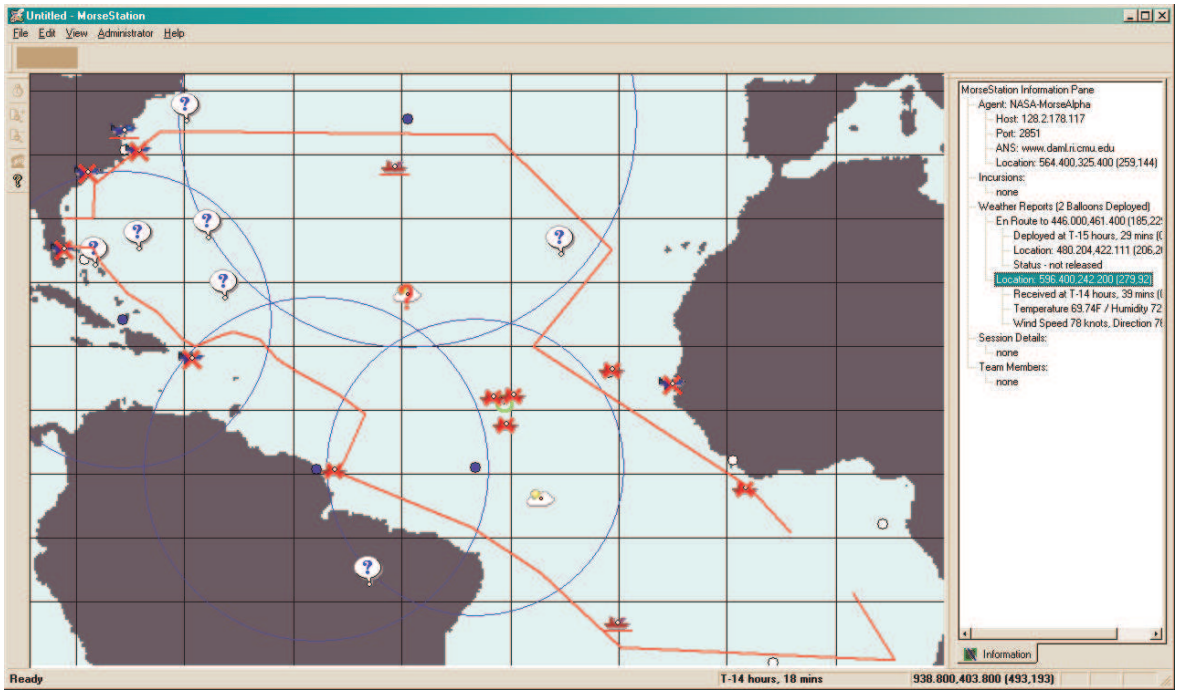
MORSE Station *(Ascension Islands)*

The MORSE Station Interface supports communication between team members, resource allocation, planning, etc

This example illustrates the interface (showing the Instantaneous Impact Lines of the current launch) for the Range operator stationed at the Ascension Islands.



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Factors affecting the Scenario

- **Wind (strength and direction)**
  - Wind Strength and Direction may change throughout scenario
  - Wind Strength and Direction affects the dispersion of the plume.
  - High temperatures can be a cause for aborting launch
- **Space Launch Vehicle**
  - Determines the position of the Impact Lines and hence the area that must be covered

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Factors affecting the Scenario

- **Radar Stations**
  - Positions of Radar Stations ensures that maximum coverage is obtained by the users.
  - Fewer radar stations make the scenario more difficult because incursions are harder to detect
- **Incursions**
  - Initial incursions may be harmless – sea or air traffic that may clear zones by launch time
  - Slow incursions on a course that will stay within the IIL zone till the launch will require escorting by interceptor units.
  - Probability of incursions between scenarios is variable

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Factors affecting the Scenario

- **Interceptors**
  - Positions of available interceptor units
  - Speeds of different units is variable and affects the ability of that unit to intercept incursions
  - Fewer interceptors will make the mission harder
- **Plume Dispersion**
  - Plume lines demark the anticipated dispersion of the plume and are affected with the wind speed and direction
  - Subjects will need to carefully determine expected dispersion of plume by launch time

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Units and Deployment

- Units are available at different locations
- Each unit can be deployed from its current position to a new position by a user that controls that unit
- Deployment of a unit entails:
  - Acquiring that unit (by request if it is controlled by another user)
  - Cost, dependent on unit
  - Calculation of time required to reach destination

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Units and Deployment

- **Units include:**
  - Weather Balloons – unlimited
  - Air Vehicles – several sizes
  - Sea Vessels – several sizes
  - Radar Stations (stationary) – user determines which of these are manned to obtain information

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Tasks available to the Subjects (1)

- **Deploy Weather Balloons**
  - Weather balloons return the following information about the sector at which they are deployed
    - Temperature
    - Pressure
    - Wind Speed
    - Wind Direction
    - Humidity
  - Balloons take a finite amount to time to be deployed and hence there is a delay before data is returned
  - Weather data returned by a balloon is available for 4 minutes (4 hours) after deployment

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Tasks available to the Subjects (2)

- **Deploy Interceptors**
  - A number of different Ocean-going vessels and aircraft are available.
    - Positions of these are established before the simulation starts
  - Parameters of an interceptor include
    - Max Speed: Interceptors always travel at this speed
    - Position: This is position of an interceptor and changes as it is deployed
    - Range: This is the maximum distance that the vehicle can travel
    - Scope: This is the scope of coverage (i.e. sea or air)

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Tasks available to the Subjects (3)

- **Control Radar Stations**
  - Select appropriate radar stations
    - If a radar station is located at a non-critical area then there may be no need to activate it
    - If a radar is inactivated then it may be activated immediately.
    - If a radar is in use by another station then it may be requested

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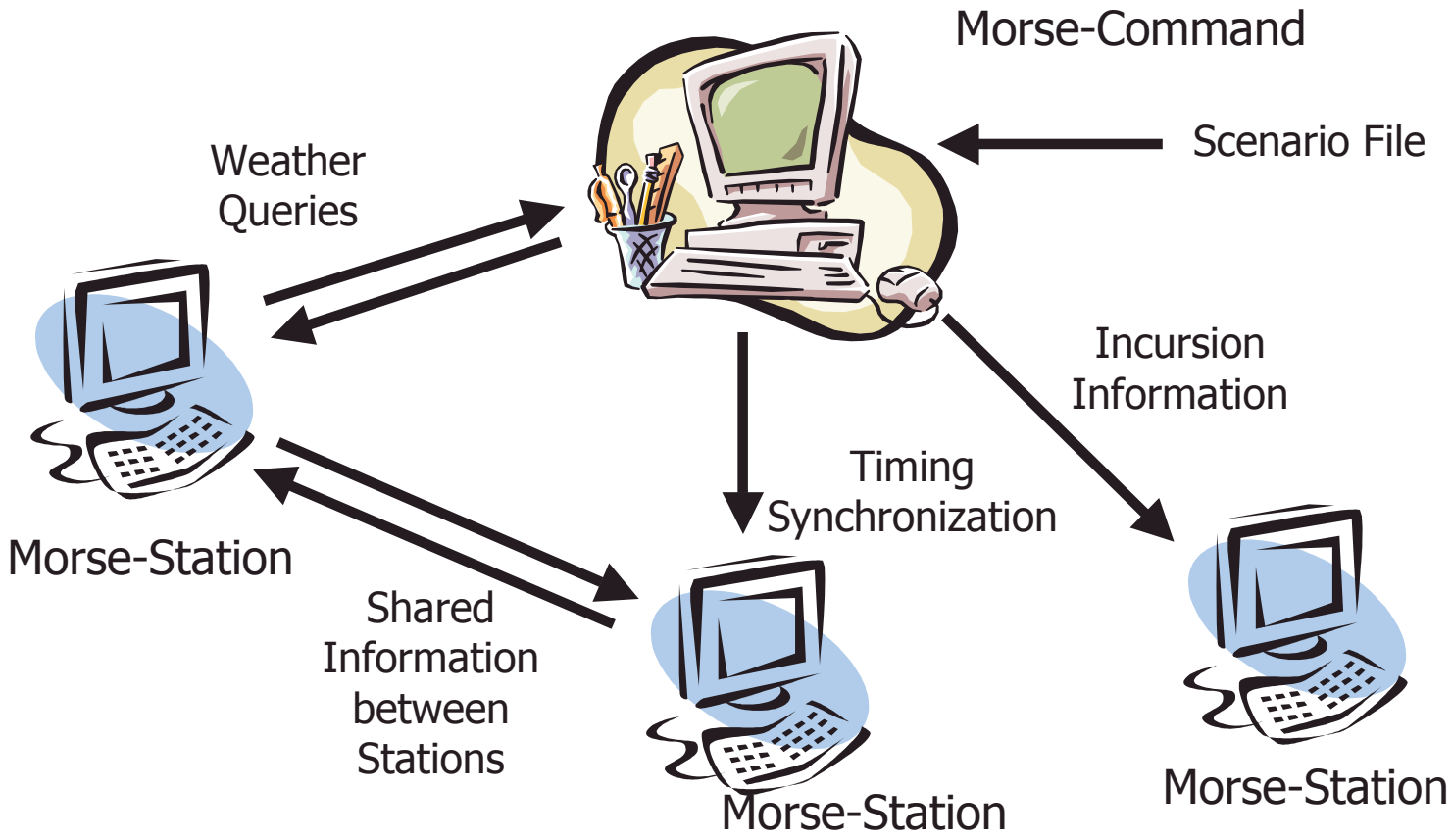
Morse Architecture

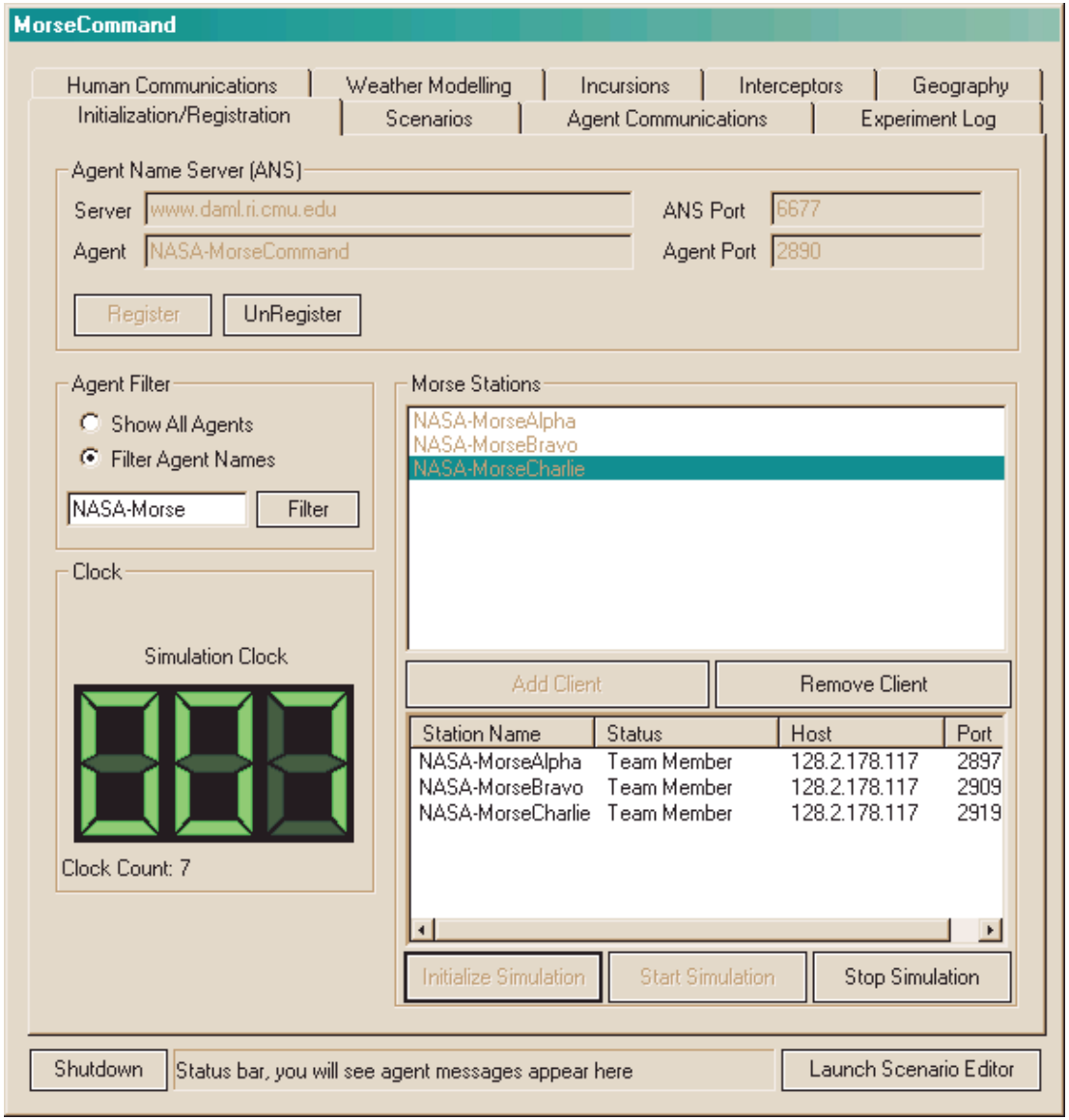


- Flow of the experiment is controlled by the MORSECommand
- MORSECommand models entire mission and simulation world
- If MORSEStation displays focused subset of simulation world to each user

Morse Command Station – Team Formation

This is the Initialization Page of the Morse Command Window.

Functions:
- Agent Registration
- Simulation Setup
- Team Setup
- Clock Initialization
- Simulation Control

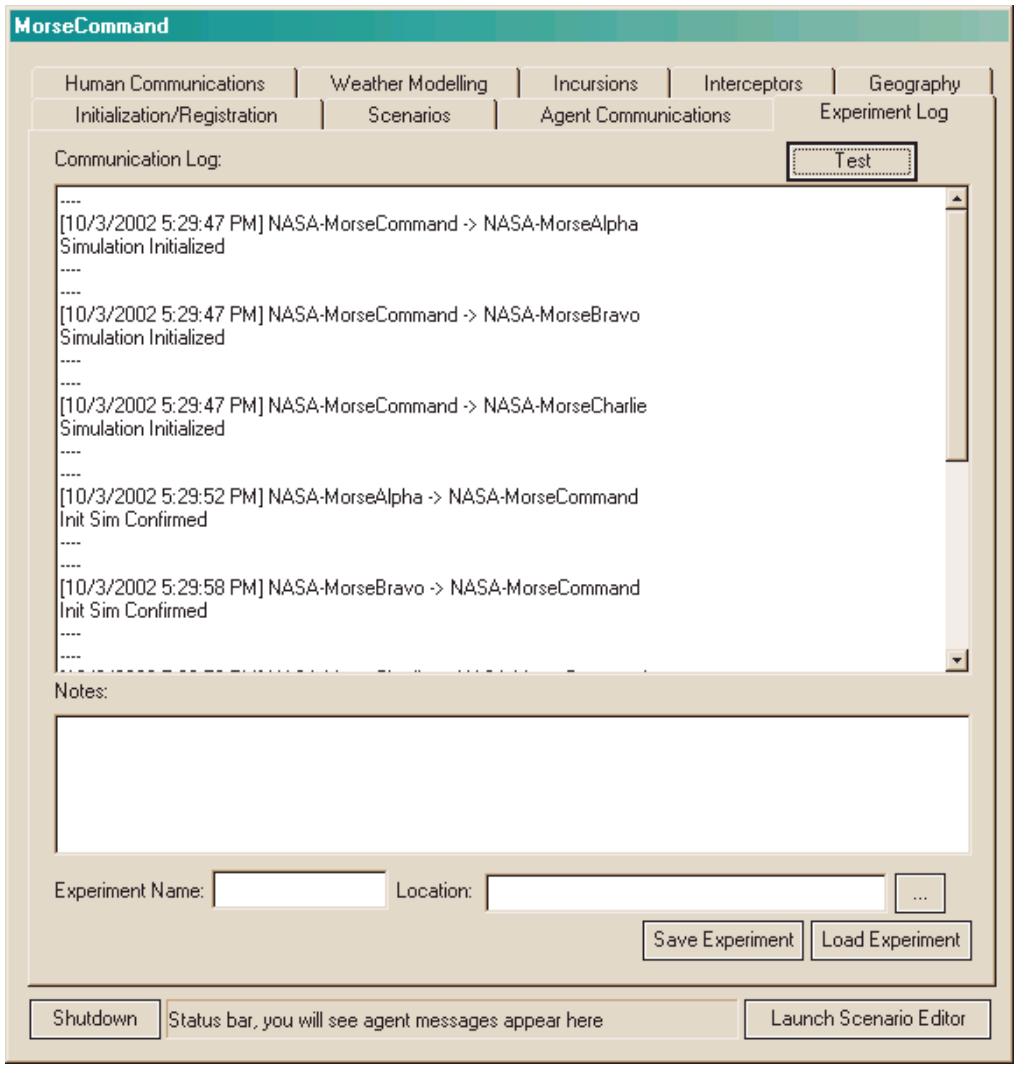


Morse Command – Experiment Logging

This page in the MORSE Command logs the experiment events as they occur

Functions:

- Logs events such as activation of interceptors, radars, deployment of balloons etc
- Logs can be saved to a file.



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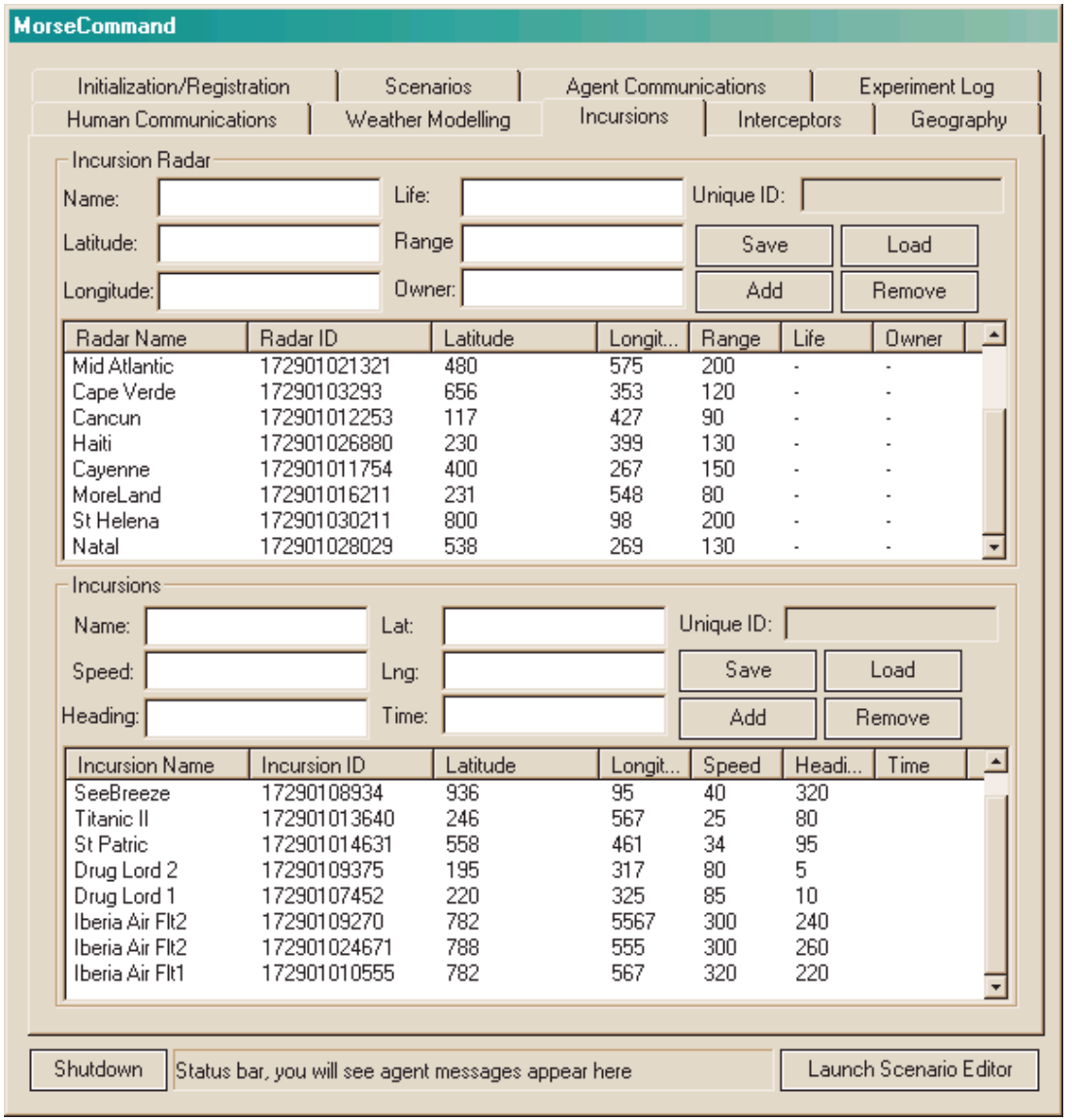
Morse Command – Incursion Generation

This is the Incursion Information page.

Functions:
- Maintains model of incursions in the simulation world
- Maintains current position/status of radars



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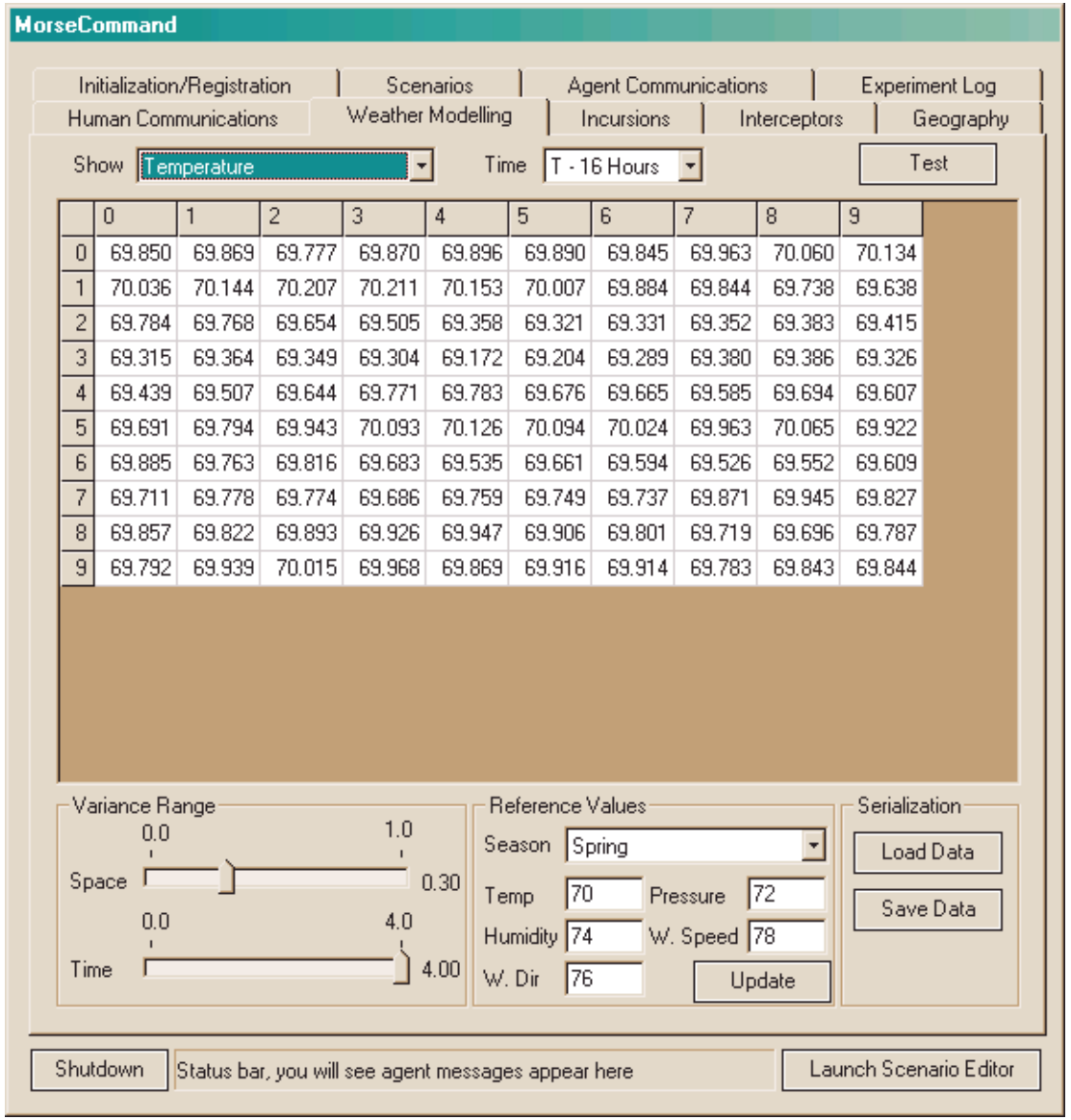
Morse Command – Weather Modeling

This is the Weather Modeling Page of the Morse Command Window.

Functions:

- Models the Weather as a simple random variance around a pivot (Reference Value)
- Variance is parameterized and pivots can be specified



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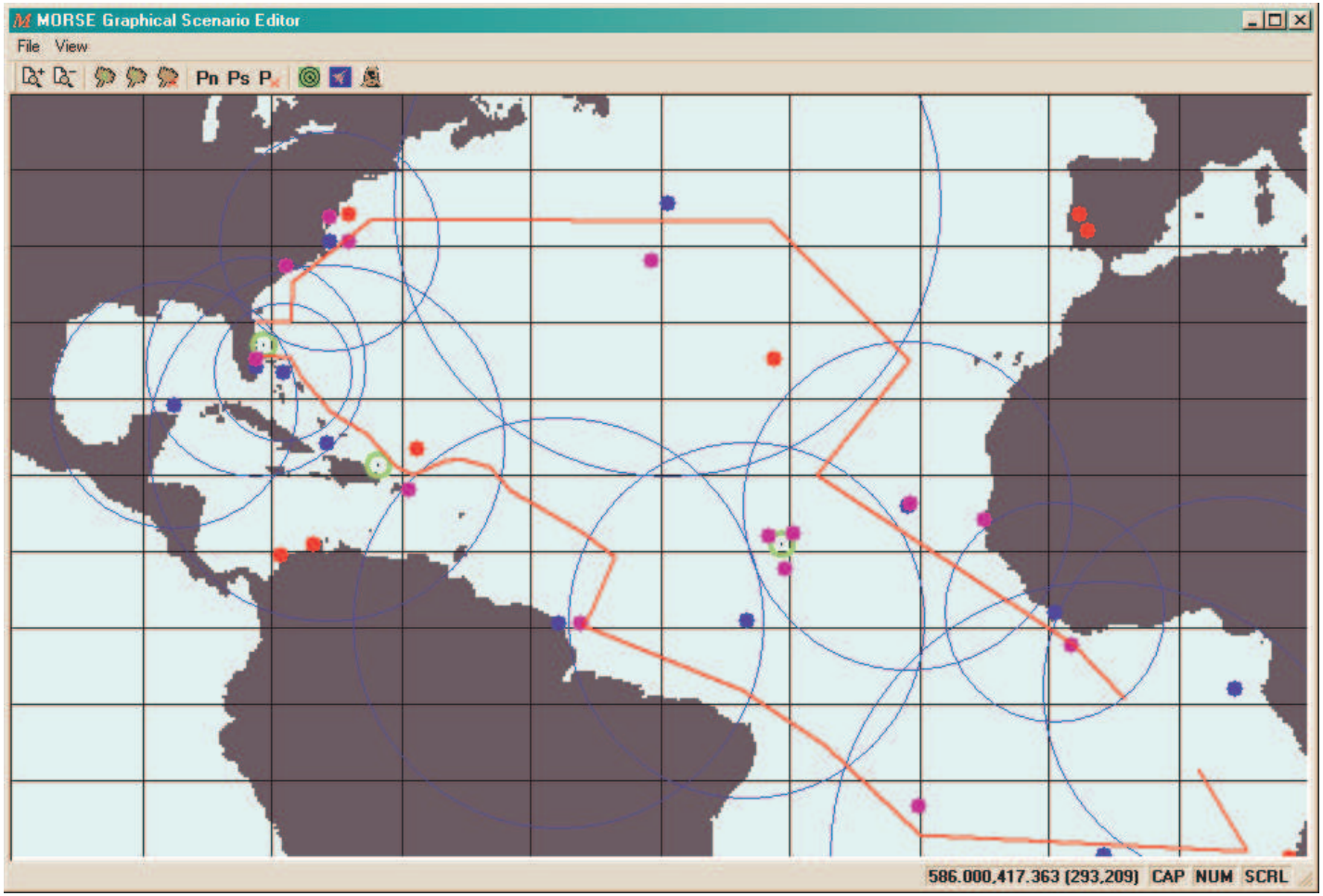
MORSE Command – Scenario Editor

The Graphical Scenario Editor can be used to design scenarios. Allows easy placement of units before the simulation starts



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Performance Evaluation

Introduce score-keeping mechanism to provide team performance feedback for individual team members and team itself during the simulation

Based on:

- how efficiently resources are being used
- how team members coordinate activities
- how quickly the infeasibility of launch is recognised and the mission aborted

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Project Status

Currently:

developing the simulation environment based on task knowledge provided by NASA

Next:

evaluate simulation environment

develop cognitive models

develop agents

study their effectiveness

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Conclusions: How Agents might support human teams

- Leverage implementation & testing by supporting domain independent aspects of teamwork in a variety of contexts
- Acting as bridge between stove-piped systems (currently done by humans e.g. Tandem)
- Acting to reduce the friction of HCI (cooperative RPA engaged participants in problem solving in the domain rather than in operating the system as the autonomous RPA did)

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Multiagent Negotiation

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A General Negotiation Model

- Communicate (offers & counter-offers)
- Compute (based on prior knowledge & negotiation history)
- Repeat / Quit

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Literature Review

- Game theory
  - Profit dividing model (Rubinstein & Stahl)
    - Complete information
    - Unique equilibrium
  - K-double auction (Chatterjee & Samuelson)
    - Incomplete information (buyer and seller know each other's reservation price distribution)
    - Bayesian belief update
    - If the buyer's offer b is greater than or equal to the seller's offer s, then trade is possible
    - But they may not make a deal even if they could

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Literature Review

- Most multi-agent negotiation models belong to K-double auction framework
  - Personality model (Bazzan & Bordini)
  - mental emotion model(Sen et. al.)
  - Bayesian Learning (Zeng & Sycara)
- AI-based models
  - Argumentation-based negotiation
  - Experience-based negotiation

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Desired characteristics of a Negotiation Model

- Support representation of negotiation context
- Be prescriptive
- Incur moderate computational cost
- Model the dynamics of negotiation
- Support learning from feedback in negotiation

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The Bazaar Model

- Uses sequential decision making framework
- Players have knowledge about the environment and other players
- History of negotiation is also taken into account
- At each stage in the negotiation and for each non-terminal history, each player has a subjective probability distribution that represents the player's knowledge at this stage

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The Bazaar Model (cnt)

In response to the most recent action taken by others, a player will:

1. Update his subjective evaluation of the environment and other players, using Bayesian rules (posterior probability calculation)
2. Select the action that maximizes his expected payoff, given the information available at the current stage

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A Simple Example

Suppose that the buyer has two hypotheses about supplier's reservation price:

H1= $100

H2=$130

Suppose the buyer has no other knowledge about the supplier. Then, P(H1)=0.5 and P(H2)=0.5

Suppose the buyer also has domain knowledge that "The suppliers will typically ask a price above their reservation price by 17%" So, P(e/H1)=0.95

and P(e/H2)=0.75, where e denotes the event that the supplier asks $117

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A Simple Example

Now, suppose that the supplier does ask 117.00

Then the buyer uses Bayes rule to calculate P(H1/e) = 55.9 and P(H2/e)= 44.1

Suppose the buyer adopts a simple strategy "Propose a price that is 10% less than the estimated reservation price of the supplier".

Prior to receiving the supplier's offer the buyer would have offered 115.00 (the mean of the RP of supplier's distribution).

After receiving the offer and updating his beliefs, the buyer now offers 113.25.

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Experimental Design

- A buyer, and a supplier
- RP private information
- The agents try to estimate the other player's RP
- Range of possible actions is integer within [0, 100]
- Each player's utility is linear in the final price
- Each agent proposes strictly monotonically.
- Each agent has different initial subjective belied functions

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Experimental Design

Three conditions:

- Neither one learns
- Both learn
- Buyer learns, supplier does not (game is symmetric)
- For each condition, we ran 500 randomly generated negotiation scenarios
- Evaluation criterion the normalized joint Nash solution (max is o.25)

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Average Performance of Three Experimental Configurations in Bazaar

- ***A non-learning agent makes decisions based solely on his own reservation price***
- ***A learning agents makes decisions based on both the agent's own and the opponent's reservation price***

Zeng D. and Sycara, K. "Bayesian Learning in Negotiation", *International Journal of Human Computer Systems*, Vol 48, pp.125-141, 1998.

Configuration	Joint Utility	Buyer's Utility	Supplier's Utility	# of Proposals Exchanged
Both Learn	0.22	0.49	.051	24
Neither Learn	0.18	0.49	0.51	34
Only Buyer Learns	0.15	0.59	0.41	28

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Evaluating Belief Updating Methods

- A variant of K-double auction model
- No Bayesian update
- Take finite bargaining time into consideration
- Provide a set of belief updating methods for agents' human master to choose
- Easy implementation

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Evaluating Belief Updating Methods

- Finite bargaining time T
- DP like offering strategy

$$f_t(x^*) = \max_a \{\Pr(a) f_{t+1}(x)\}$$

$$x^* = \arg \max_a \{\Pr(a) f_{t+1}(x)\}$$

x: Agent's offer

$f_t(x)$: Expected profit at time t if offer x

$\Pr(a)$: Agent's belief that his opponent will offer a

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Belief Updating Methods

- Negotiation range: $[\min P, \max P]$
- Buyer and seller's offer at time t: b_t, S_t
- Buyer's updating method (Seller's is similar)

Uniform	Exp (1)	Exp (2)
$[\min P, S_t]$	$[\min P, S_t]$	$[\min P, S_t]$
$[b_t, S_t]$	$[b_t, S_t]$	$[b_t, S_t]$

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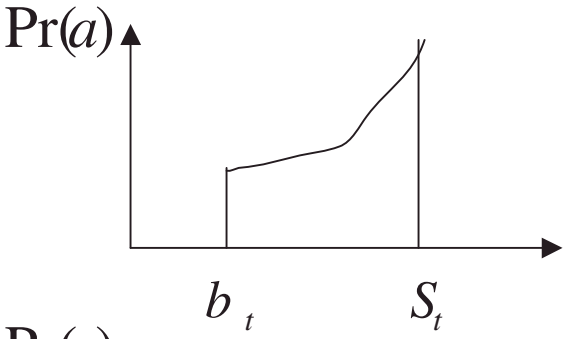
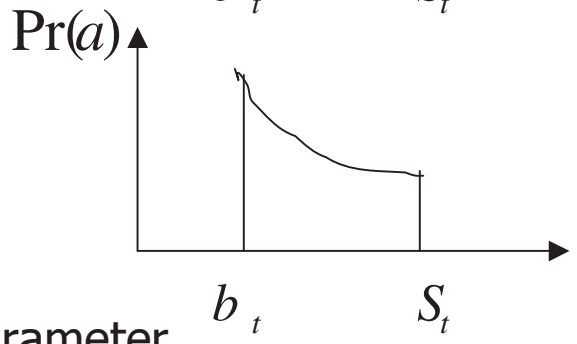
Belief Updating Methods

- Two exponential updating (over $[b_t, S_t]$

$$\Pr(a) = \frac{1}{Z}\exp\{\frac{a - S_t}{\beta(T-t)}\} \quad (1)$$



$$\Pr(a) = \frac{1}{Z}\exp\{\frac{a - b_t}{\beta(T-t)}\} \quad (2)$$



T: Finite bargaining time β: Control parameter

Z: Normalization factor

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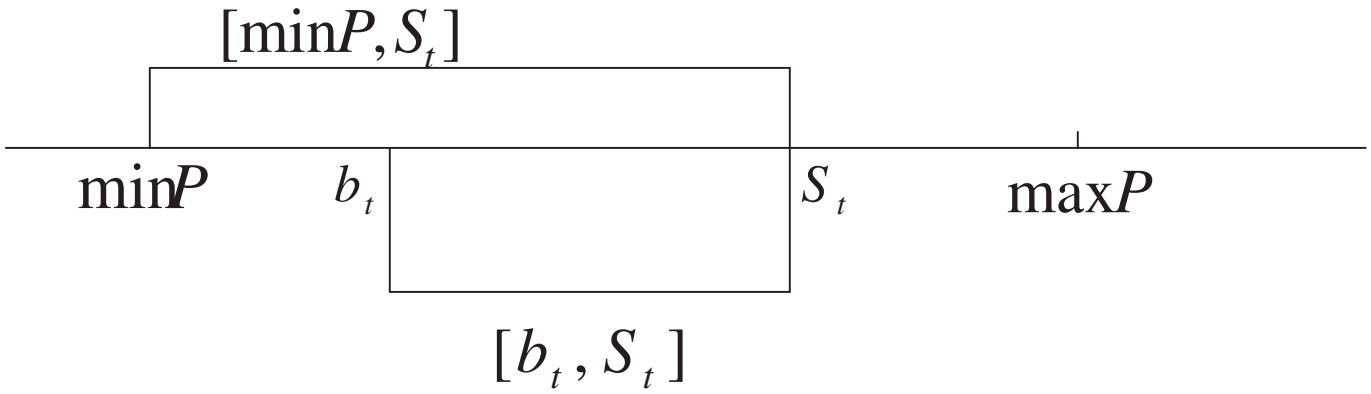
Intuition (buyer's viewpoint)

- Seller's value is higher than my current offer b_t, update over interval $[b_t, S_t]$
- I may have over-bided, update belief over interval $[\min P, S_t]$



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Intuition (buyer's viewpoint)

- I belief the seller is not likely to move back from his current offer exp method (2) s_t,
- There is still enough negotiation space, exp method (1) (does not trust the seller)

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Numerical Experiments

- Negotiation range [0, 100]
- Fix buyers' reservation price to 100
- In different experiments, increase seller's reservation price from 0 to 100

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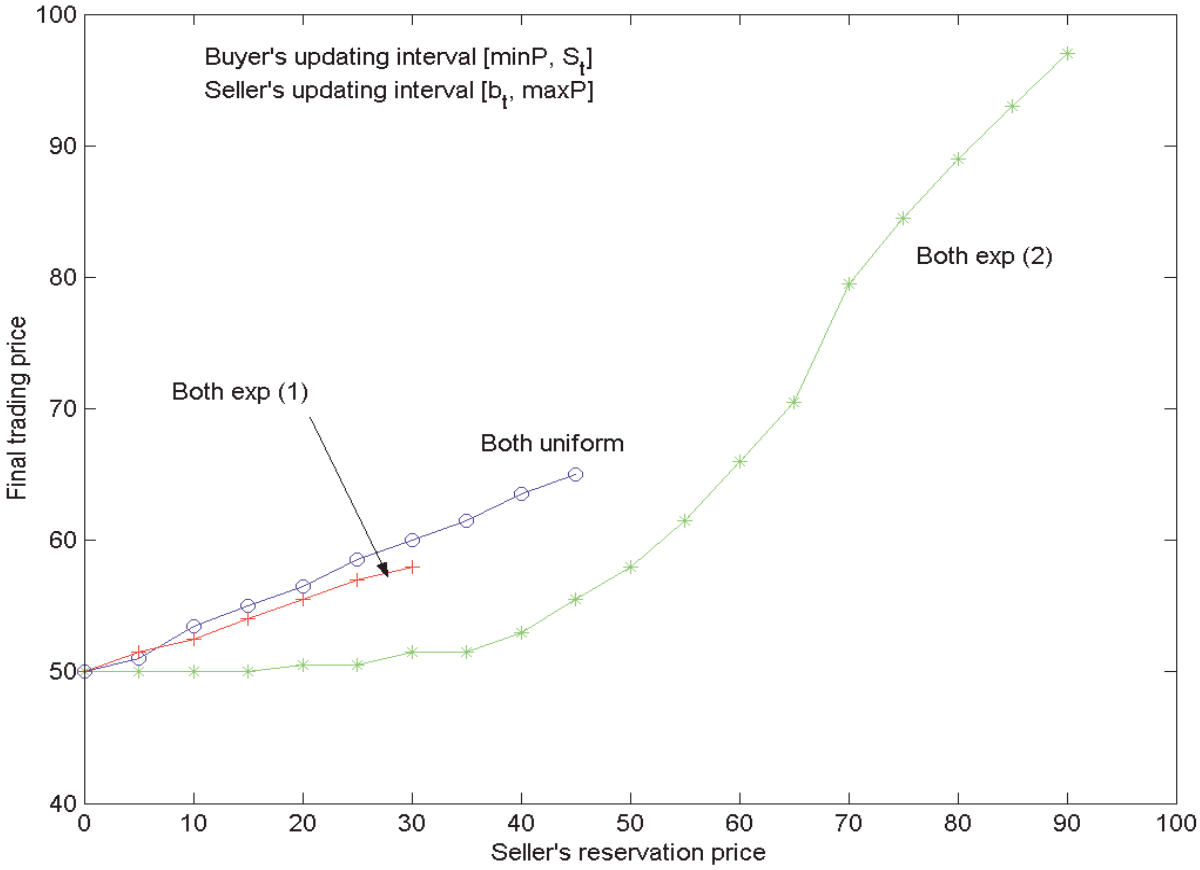
Some Results (1)



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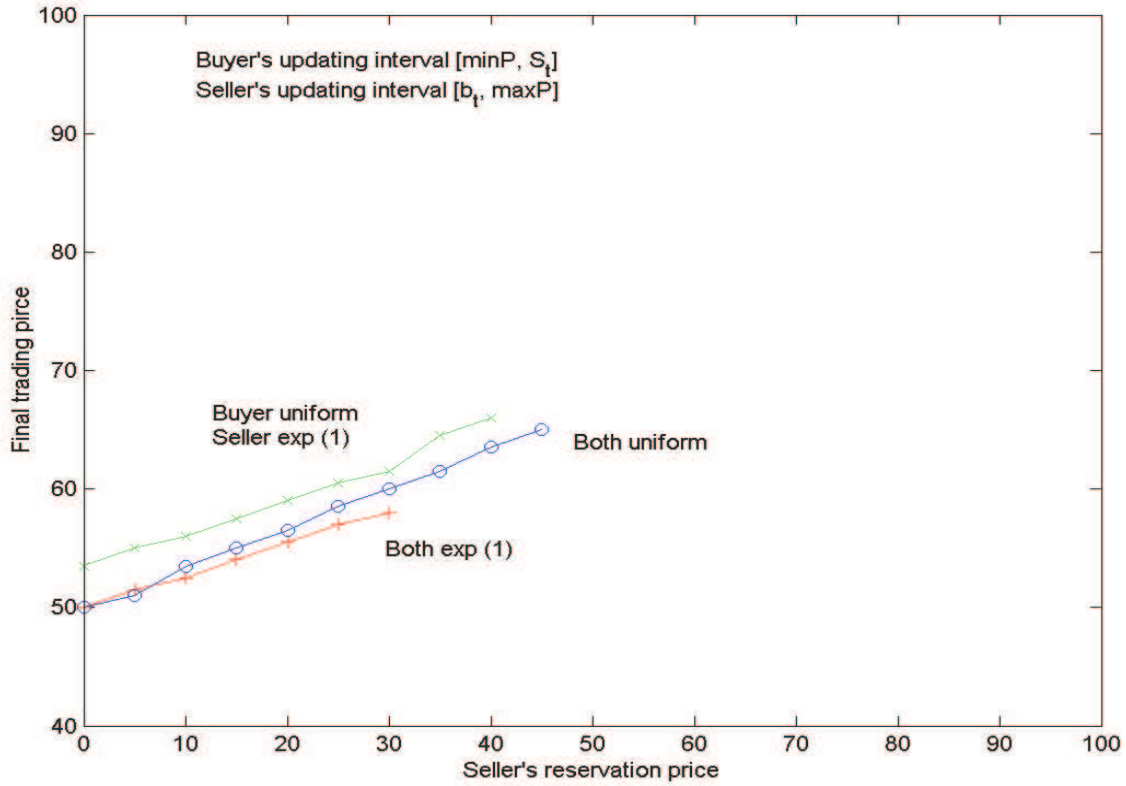
Some Results (2)



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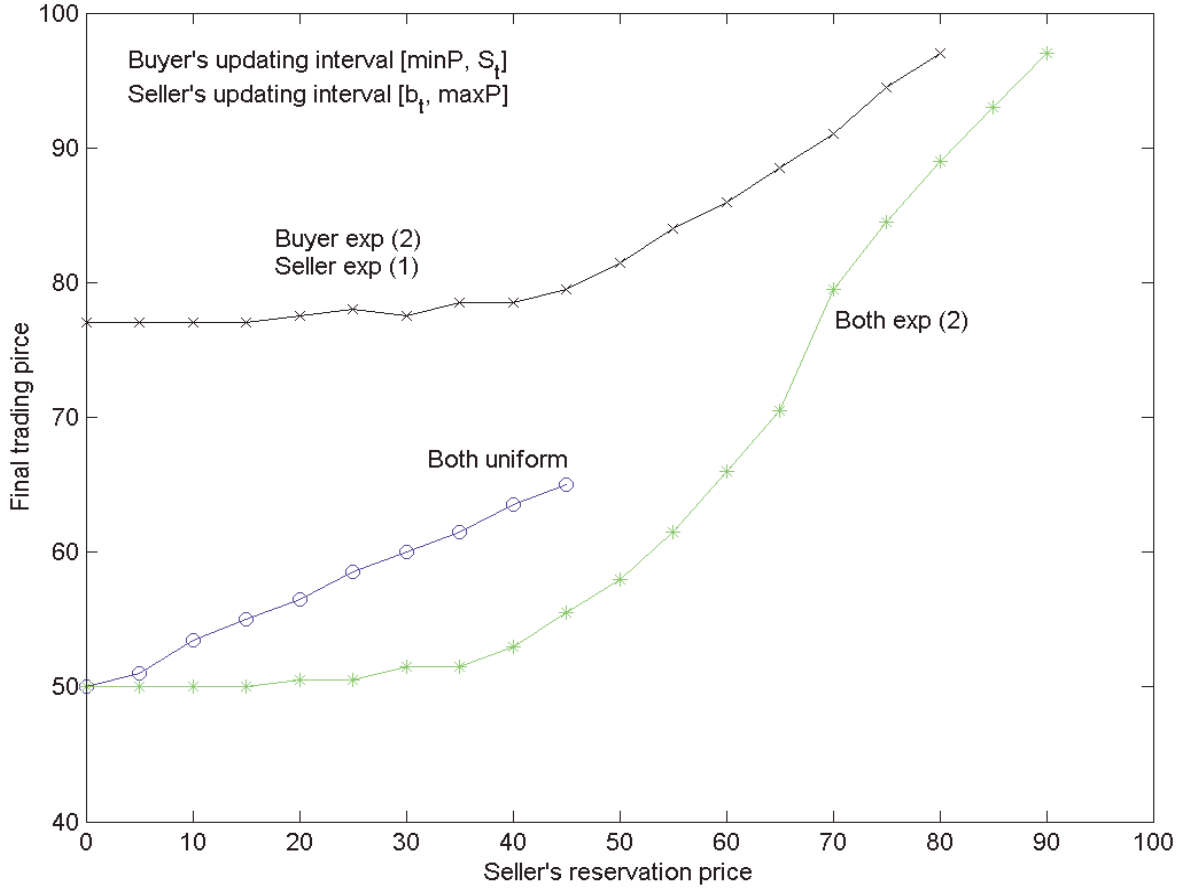
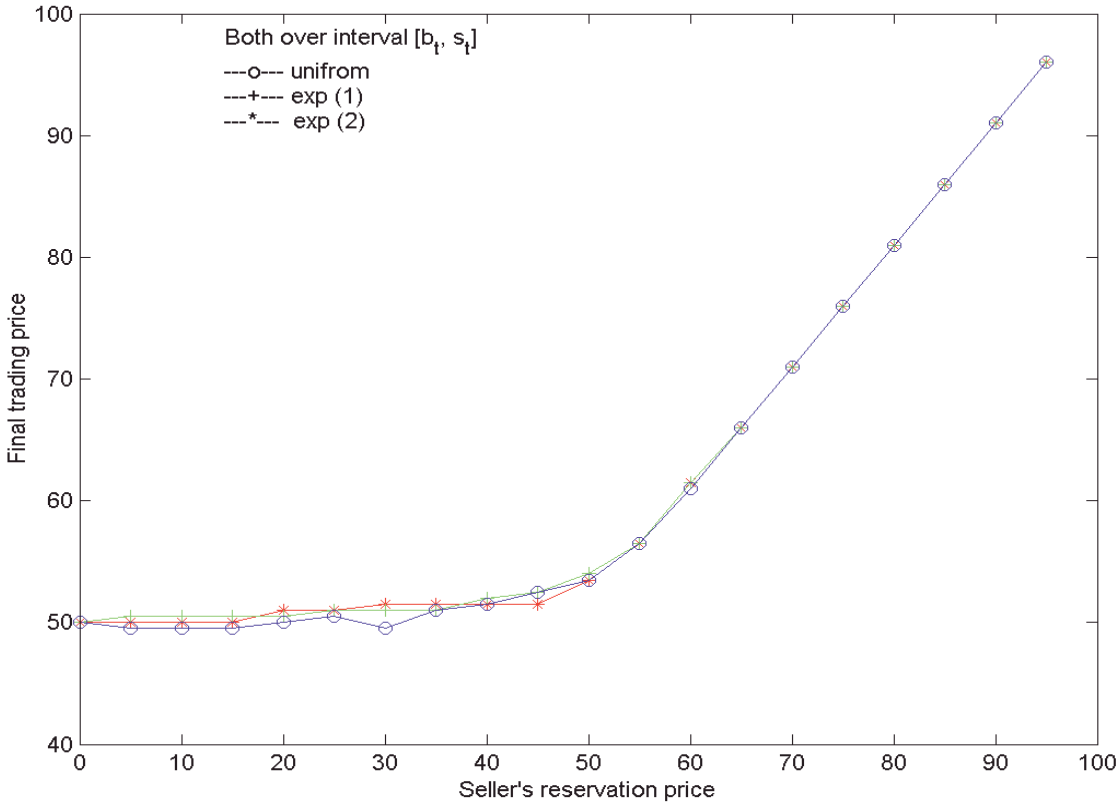
Some Results (3)



Some Results (4)



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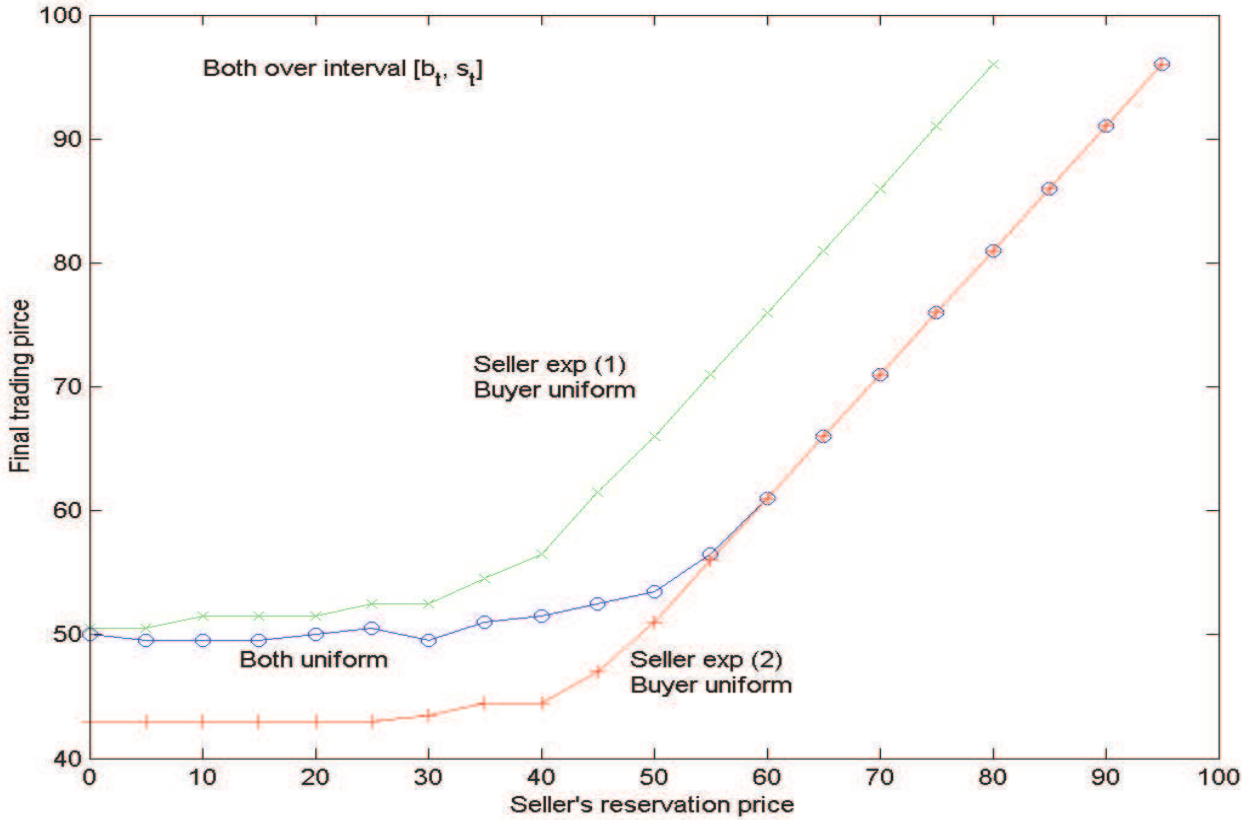
Some Results (5)



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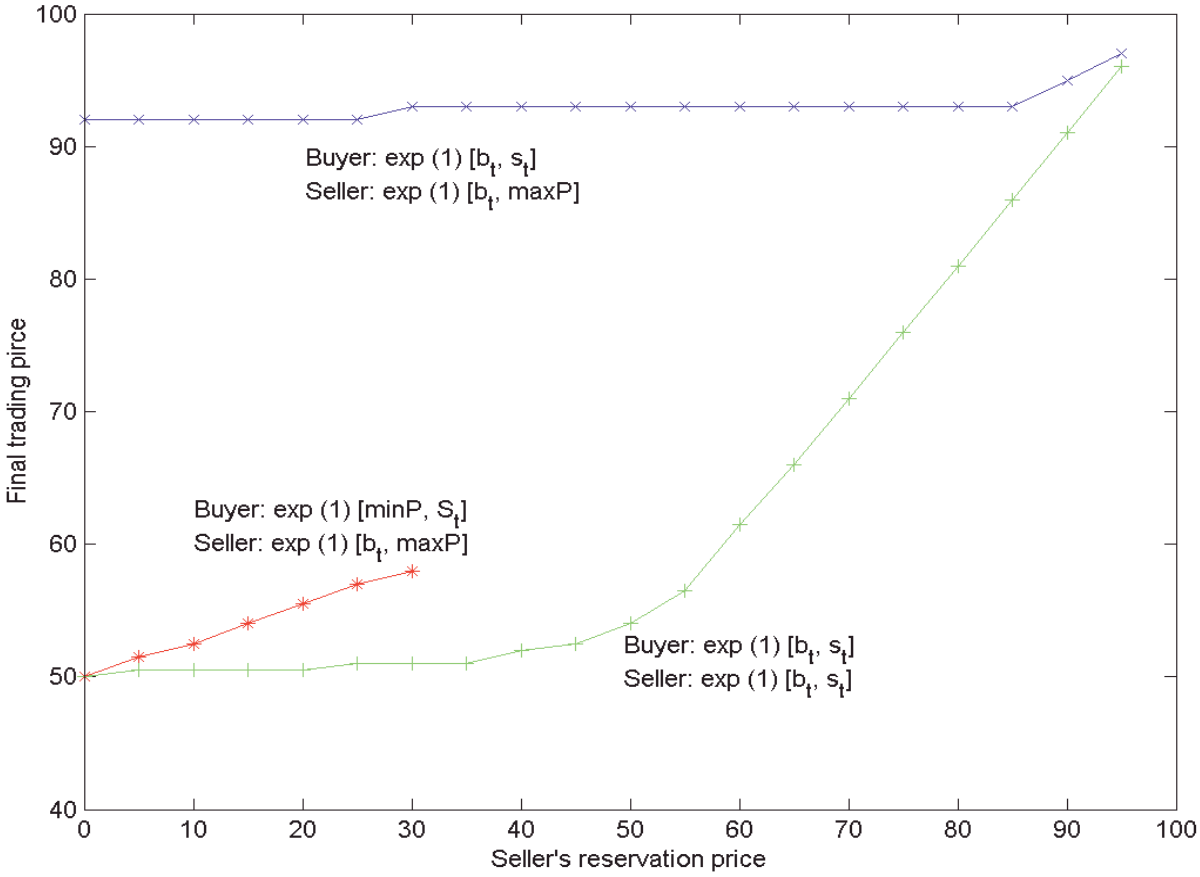
Some Results (6)



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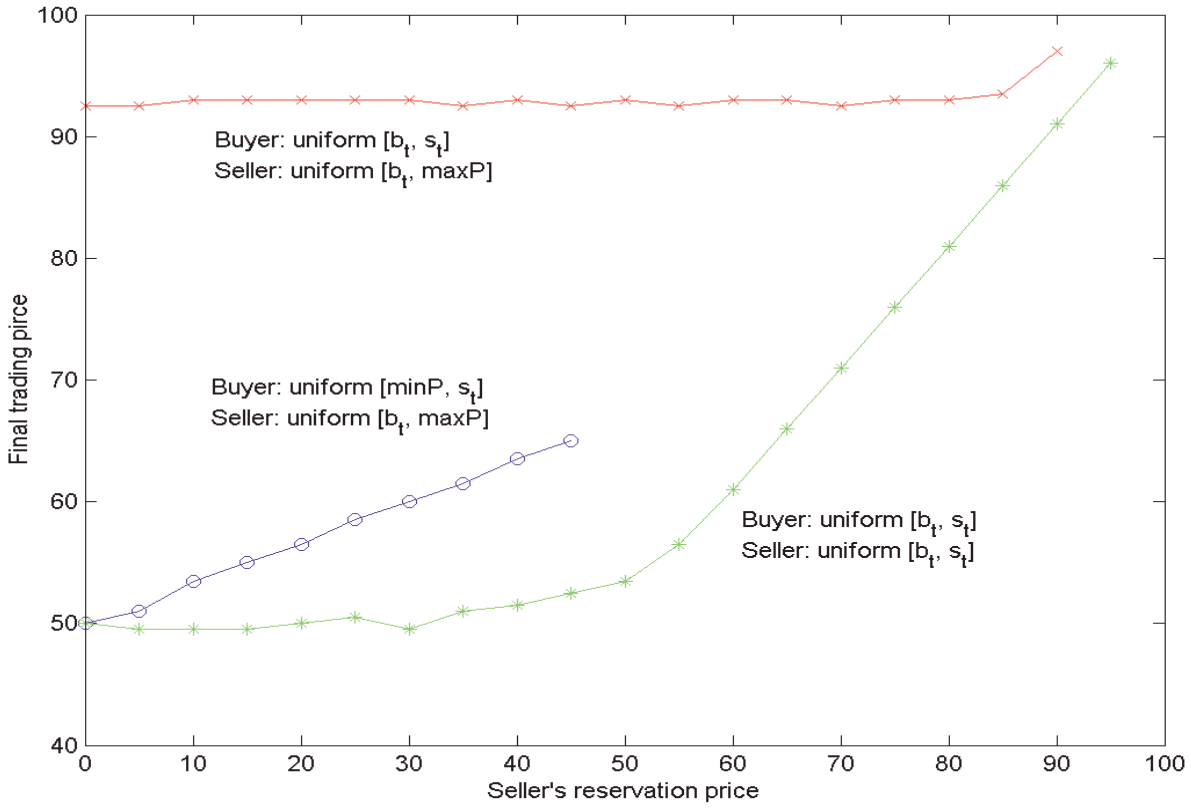
Some Results (7)



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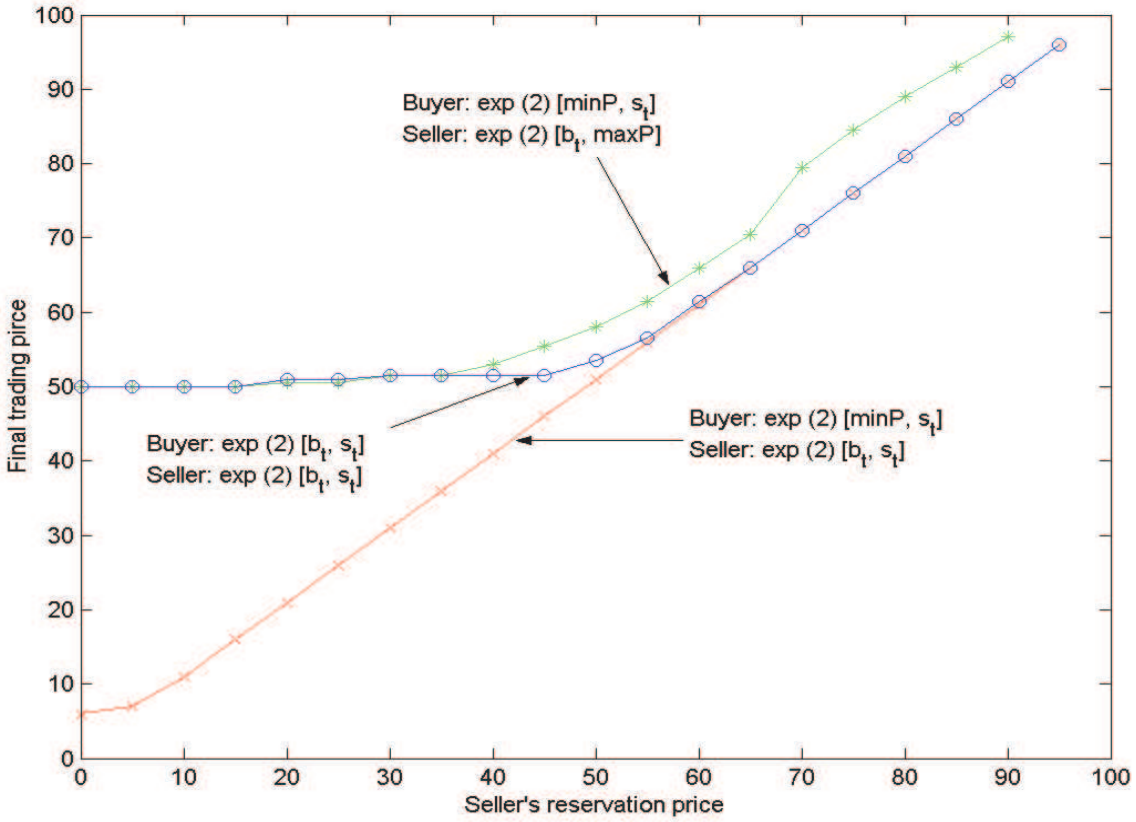
Some Results (8)



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Conclusion

- It is hard to interpret your opponent's behavior in bargaining
  - general knowledge about the environment
  - specific knowledge about your opponent
- We leave task to the agent's human master
- We provide a computational model for human to control their agents' negotiation behavior

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Work on Coalitions

Yamamoto, J, and Sycara, K. "A Stable and Efficient Buyer Coalition Scheme for e-Marketplaces" ***Proceedings of the Fifth International Conference on Autonomous Agents*****, May 28-June 1, Montreal, CA. 2001.**

Li, C. and Sycara, K. "Algorithms for Coalition Formation and Payoff Division in e-Marketplace", ***Proceedings of the International Conference on Autonomous Agents and Multiagent Systems*****, Bologna, Italy, July 15-19, 2002.**

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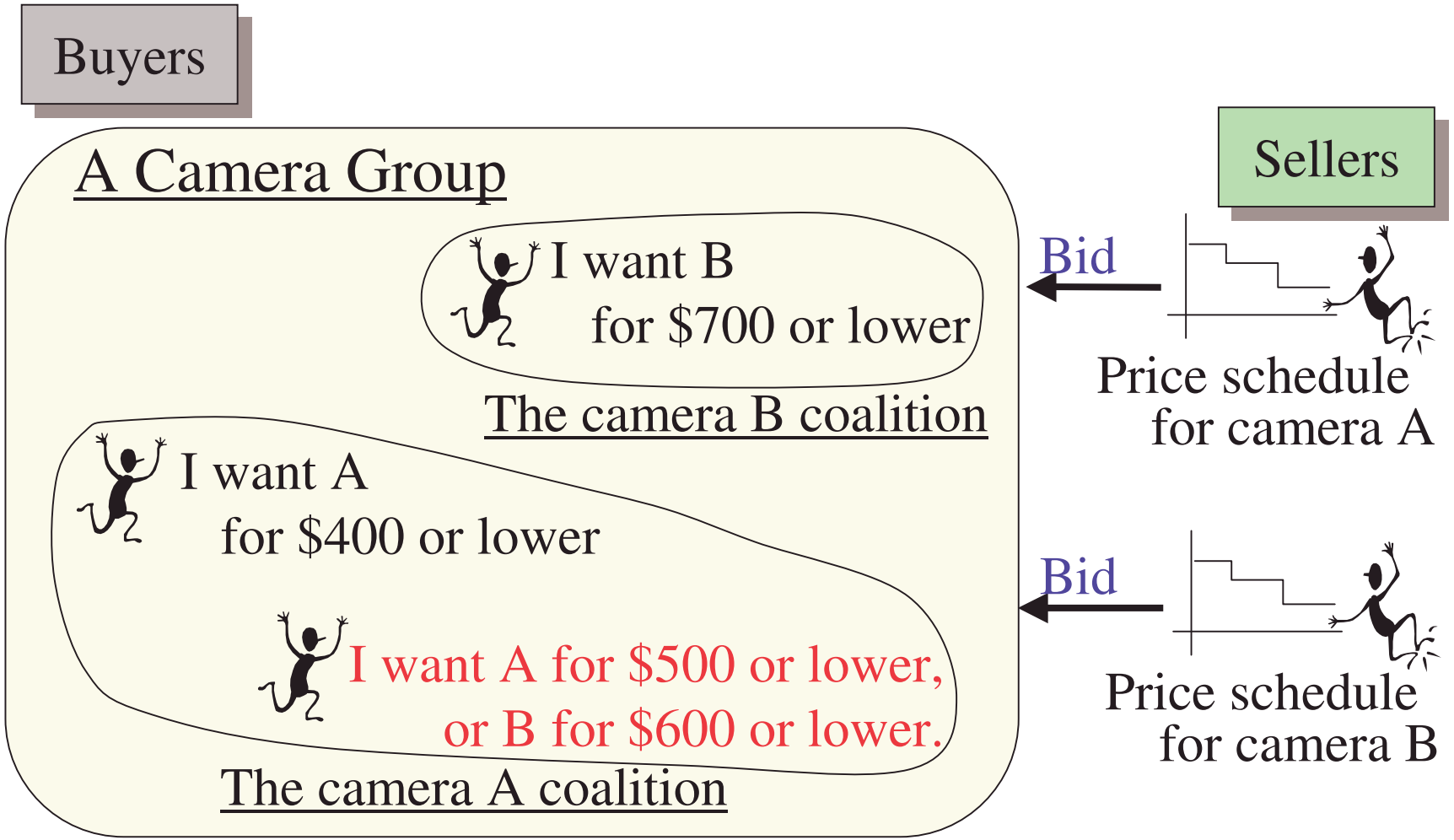
Outline of the GourpBuyAuction scheme



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Coalitions

A buyers' coalition is a group of buyers that want to buy the same item.

- Buyers in a coalition may pay different prices for the same item depending on their reservation prices

- Desired goals for the coalition are:
  - Increase the number of buyers who can purchase items
  - Increase group utility and individual buyers utility
  - Divide the total utility among buyers in a fair and stable way.

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An Example

Buyers: b0, {(item0, 100), (item2, 70)}
b1, {(item0, 80), (item1, 95), item2,95)}
b2, {(item1, 95)}
b3, {(item1,65)}
b4, {(item1, 85), (item2, 95)}

Price schedule (assume all 3 items have same price schedule, for the example)
One unit: 100, two units 95, three units 90, etc

Possible coalitions: item0 ({b0})
item1: ({b1,b2},{b1,b2,b4},{b1,b2,b3,b4})
Item2: ({b1,b4})
Our scheme derives: item0 ({b0)}: b0 pays 100
Item1 ({b1,b2,b4}) : b1 pays 92.5; b2 pays 92.5, b4 pays 85

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Approach to Coalition Formation

Principle 1:

Maximize the utility of the most valuable coalition, then maximize the utility of the second valuable one, and continue recursively.

Principle 2:

Distribute the surplus of each coalition within the coalition in a stable way.

•Our coalition formation algorithm is a variant of the weighted set packing problem O (2**n) (n is the number of buyers)
•If we assume that the number of items in a category is bounded above by an integer K, independent of n, then O(n*log*n)

Buyers' Utility

b_k: a buyer,
g_i: an item,
r_{ki}: the reservation price of a buyer b_k for g_i,
Ci : a buyer coalition to purchase g_i.

$v_i(k) = r_{ki} - p_k$

The utility of buyer b_k
gained from buying g_i at the price p_k,

$v_i(Ci) =$ Sum of $v_i(k)$ where b_k in Ci

The utility of a buyer coalition
gained from buying g_i.

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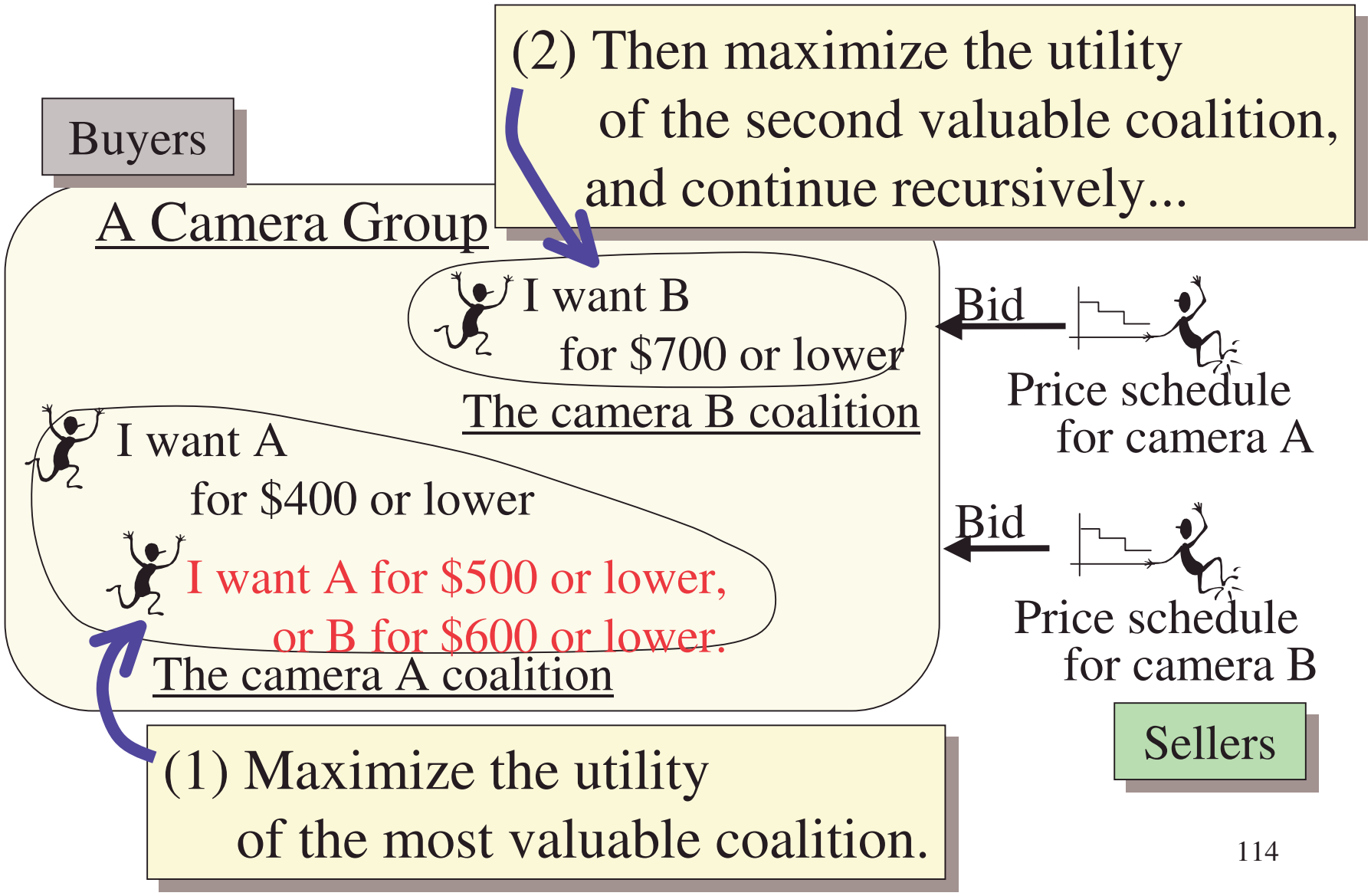
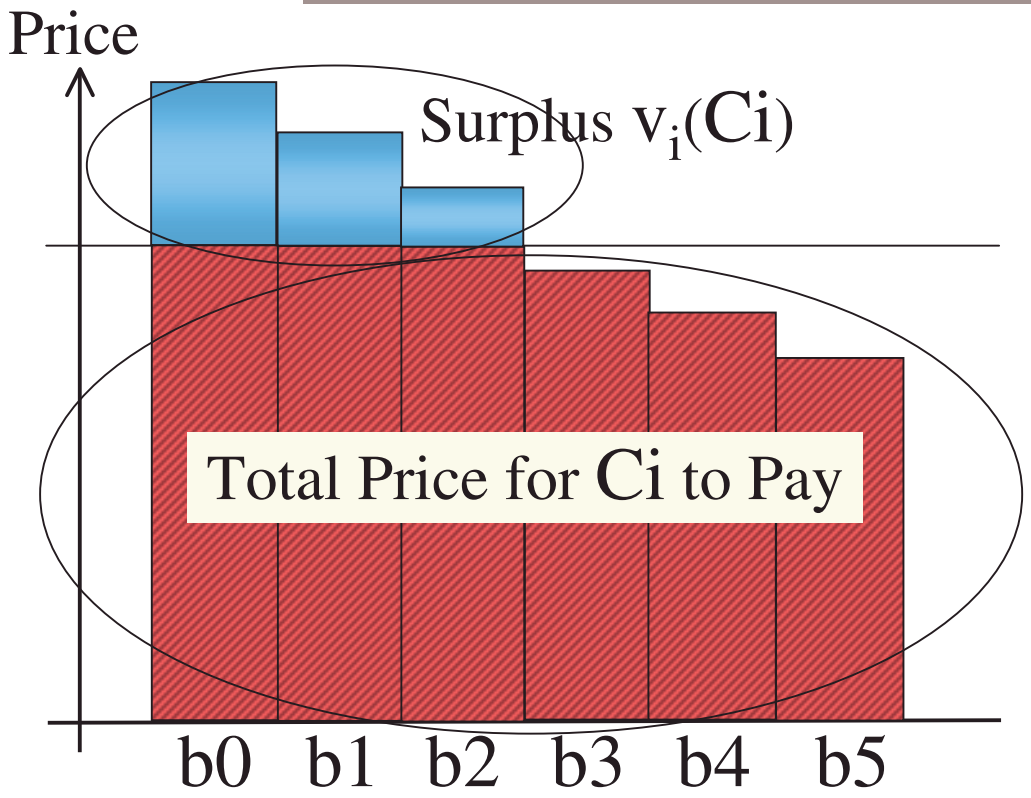
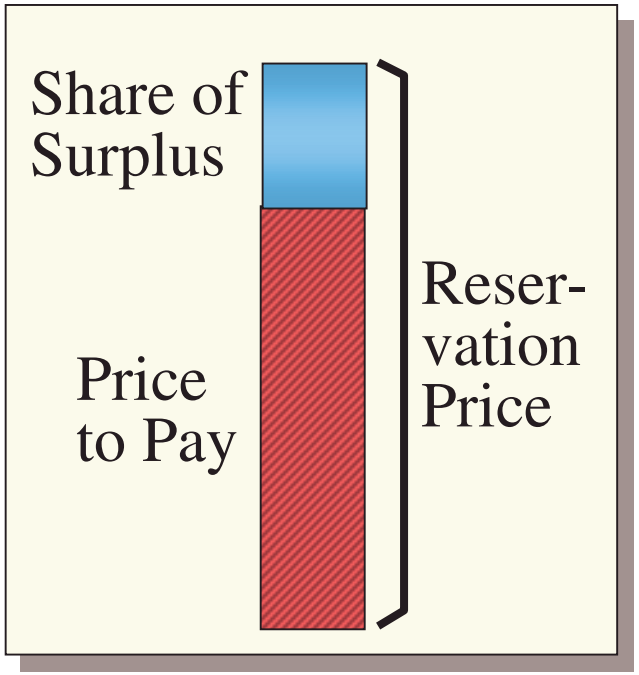
Coalition Configuration Algorithm



Surplus Sharing Rule in a Coalition

Distribute the surplus of each coalition within the coalition.





Coalition $Ci = \{b0, b1, \ldots, b5\}$

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Stability of the Surplus Sharing Rule

Proposition

For any coalition Ci ,
the surplus distribution is in the *core* of coalitional game with transferable payoff < Ci, v_i>

No subset of buyers in a coalition can obtain utility that exceeds the sum of the current utility of the members in the subset.

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Effectiveness in Increasing Buyers' Benefits

- Simulate buyers' behaviors under several conditions at three group buying schemes:
  (1) our scheme,
  (2) a traditional scheme,
  (3) an optimal scheme.

- Compare the three schemes using the evaluation criteria:
  (a) group's total utility,
  (b) the number of buyers who can obtain items.

- Assume that a buyer randomly selects preferred items and reservation prices; they are not affected by others.

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Simulation Results

Summary of Simulation Results

(1) Our scheme performed
better than the traditional scheme
under most conditions,

(2) Our scheme performed well
close to the optimal scheme under most conditions
which the optimal scheme could handle.

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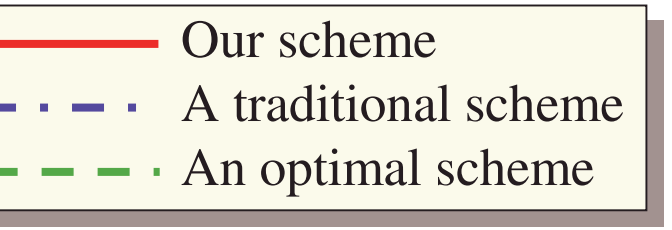
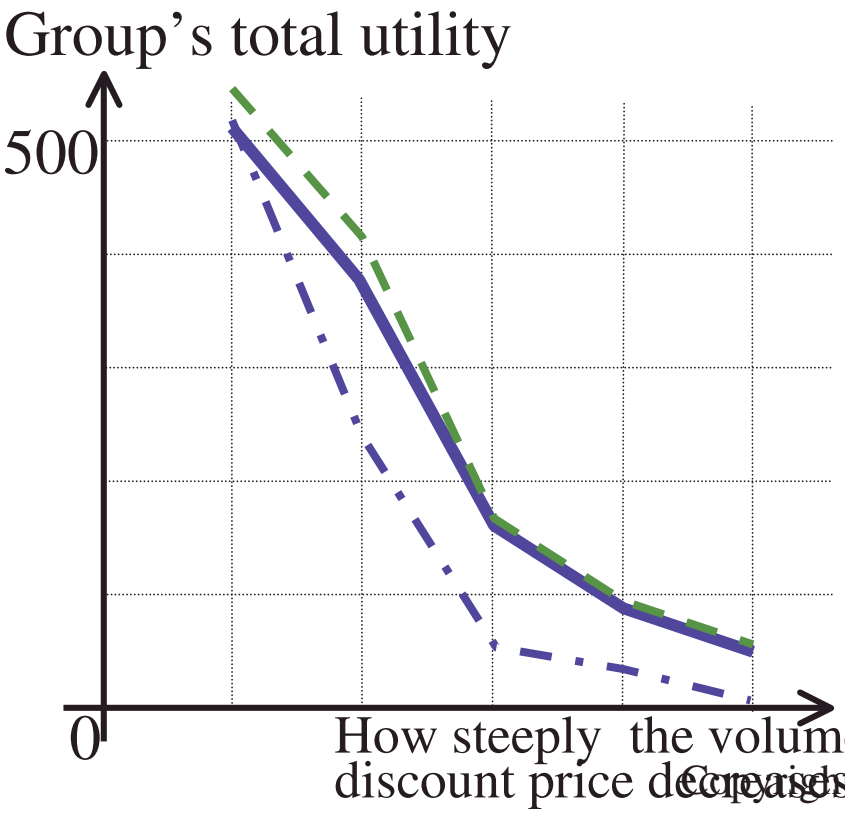
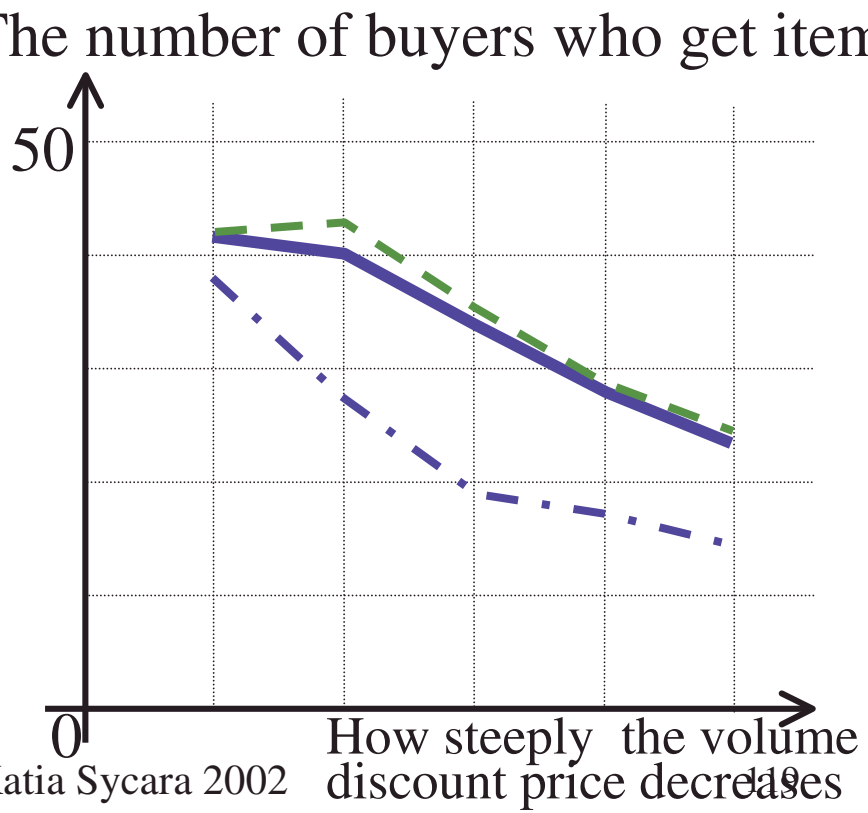
Simulation Results

Examples of simulation results.

Parameters: The number of items = 3
The number of buyers = 50
…….







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Optimal coalition formation in Combinatorial Auctions

- Coalition formation allows buyers to enjoy volume discounts
- In combinatorial auctions buyers place bids for bundles of items.
- How to form an "optimal" combinatorial coalition of buyers?
- What is a "fair" mechanism to distribute the profit among members of the coalition?

Li, C. and Sycara, K. "Algorithms for Coalition Formation and Payoff Division in e-Marketplace", *Proceedings of the International Conference on Autonomous Agents and Multiagent Systems*, Bologna, Italy, July 15-19, 2002.

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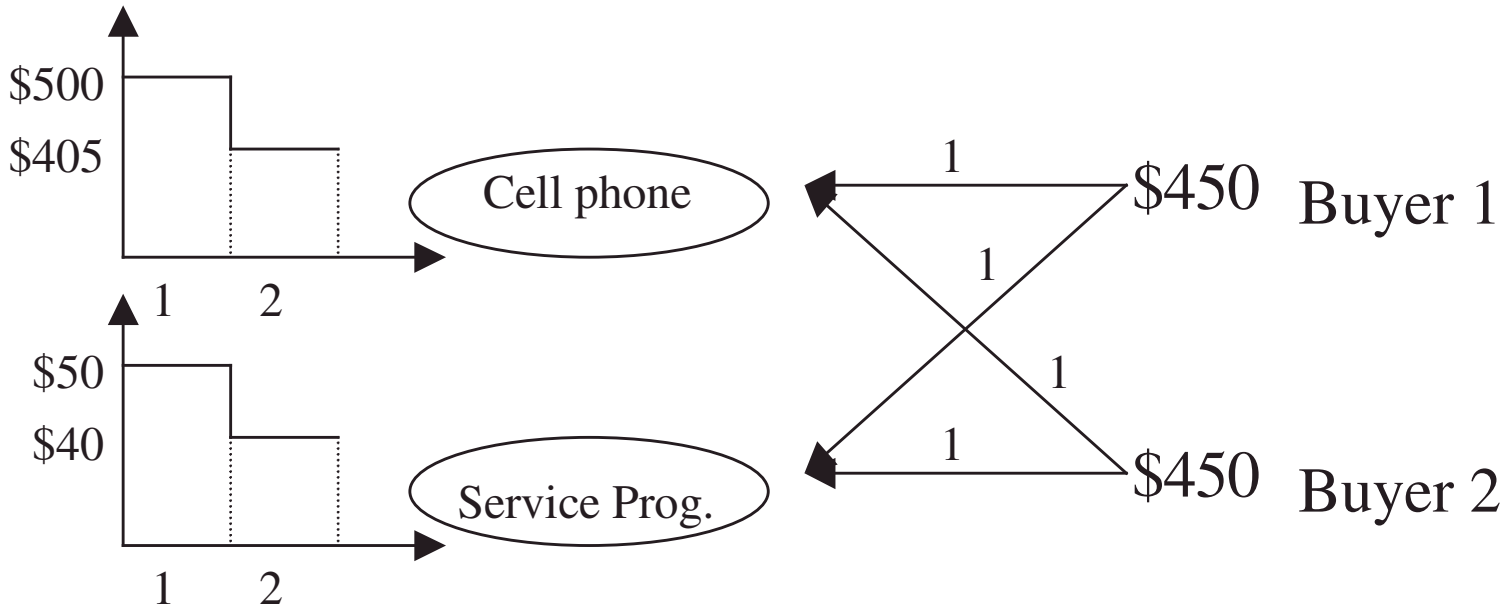
Let's see an example



Buyers: Only a cell phone or service program means nothing to me !

Sellers: I'm happy to sell more goods with a lower price.

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Coalition formation

Let's take advantage of the price discounts…

	Cell phone	Service program
Buyer 1	$405	$45
Buyer 2	$400	$50
Sum	$805 < $405*2	$95 > $40*2

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Combinatorial bidding

I want all of *m* units of *a* and *n* units of *b* (and …) for no more than *r*.

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Combinatorial coalition formation

Combinatorial bidding + Coalition formation

Sum: $900 > $($405+$40)*2

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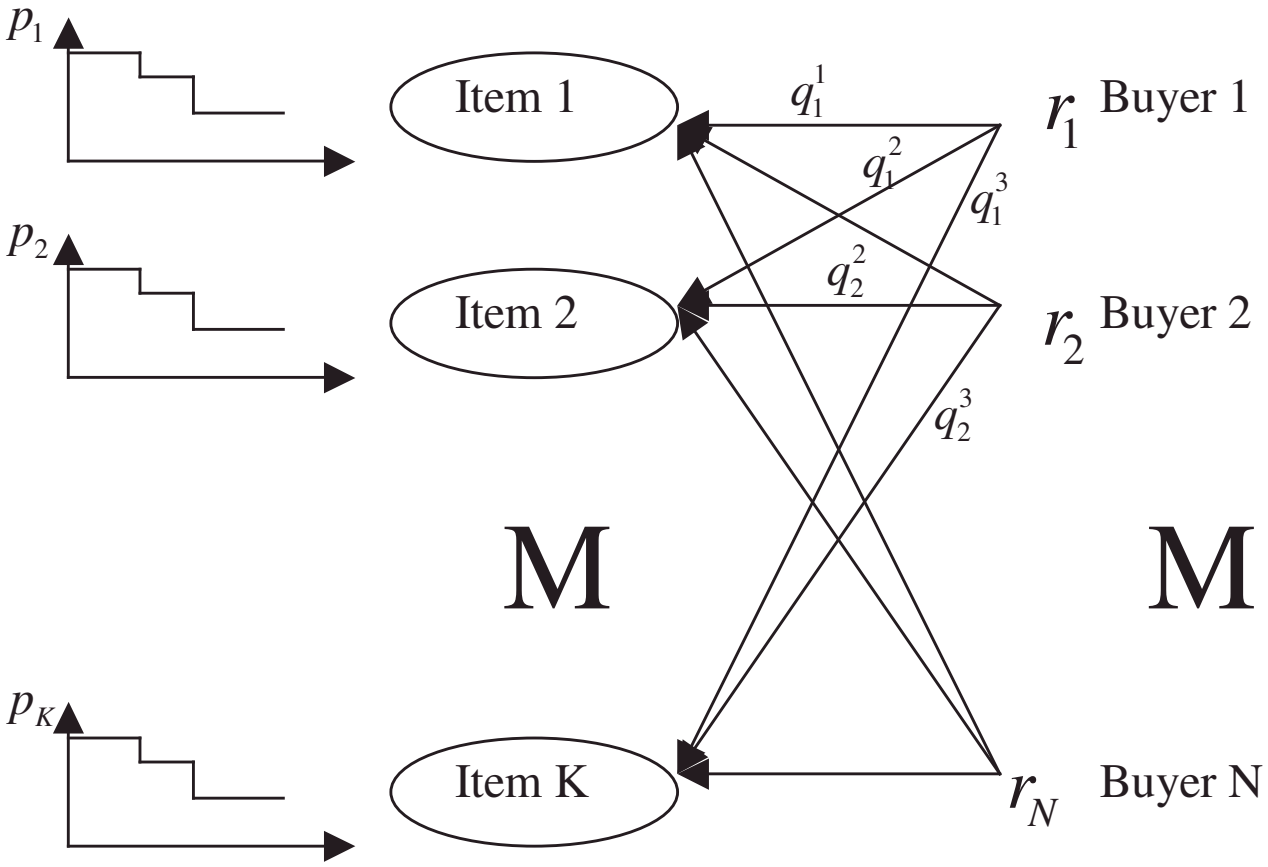
Combinatorial Coalition Formation(CCF)



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Questions

- How to form an “optimal” coalition of buyers?

- What is a “fair” mechanism to distribute the profit among members of the coalition?

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Literature review

- Economics
  - ➢ Payoff division of coalitions

    Osborne and Rubinstein[94]
  - ➢ Mech. design of comb. Auctions

    Bykowsky[95], Rassenti[82]
- Computer science
  - ➢ Coalition formation: Yamamoto and Sycara (01), Lerman[00], Sen[00], Shehory[99], Sandholm[97]
  - ➢ Winner determination: Sandholm[99], Fujishima[99], Andersson[00], Wurman[00], etc.

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Problem formulation

- Maximize the value of the coalition:

$$C^* = \max_{C \subset B} v(C) \qquad v(C) = \sum_{b_n \in C} (r_n - \sum_{k=1}^{K} q_n^k \cdot p_k(q_C^k))$$

  - Divide the payoff in the core:

(no members can get better payoff by deviating from the coalition)

$$v_{C'} \leq x_C(C'), \forall C' \subset C$$

$$\sum_{b \in C} x_C(b) = v(C) \qquad x_C(C') = \sum_{b \in C'} x_C(b)$$

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Assumptions

- Items are sold in fixed price schedules
- Buyers tell the truth about their reservation costs
- A partial bundle has value zero
- One-shot winner determination

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Main Idea

- Price dominates the decision for coalition formation
- Use divide and conquer to search for the optimal coalition
  - For each item, find its optimal sub-coalition
  - Apply transfer of reservation cost/price between optimal sub-coalitions to get the optimal coalition
- Approximate algorithm for optimal coalition by considering only greedy transfer of reservation costs

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Some concepts

- Reservation cost division $r_n = \sum_{k=1}^{K} r_n^k$

	r_n	r_n^1	r_n^2
Buyer 1	450	405	45
Buyer 2	450	400	50

- Subcoalition $v_k(C) = \sum_{b_n \in C} (r_n^k - q_n^k \cdot p_k(q_C^k))$

$C_1^* = \Phi$ $C_2^* = \{b_1, b_2\}$

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Some concepts(ctd.)

- Compatible

$C_1^* = \{b_1, b_2\}$ and $C_2^* = \{b_1, b_2\}$ YES

$C_1^* = \{b_1\}$ and $C_2^* = \{b_1\}$ YES

$C_1^* = \Phi$ and $C_2^* = \Phi$ YES

$C_1^* = \{b_1, b_2\}$ and $C_2^* = \{b_2\}$ NO

$C_1^* = \{b_1\}$ and $C_2^* = \{b_2\}$ NO

$C_1^* = \Phi$ and $C_2^* = \{b_1, b_2\}$ NO

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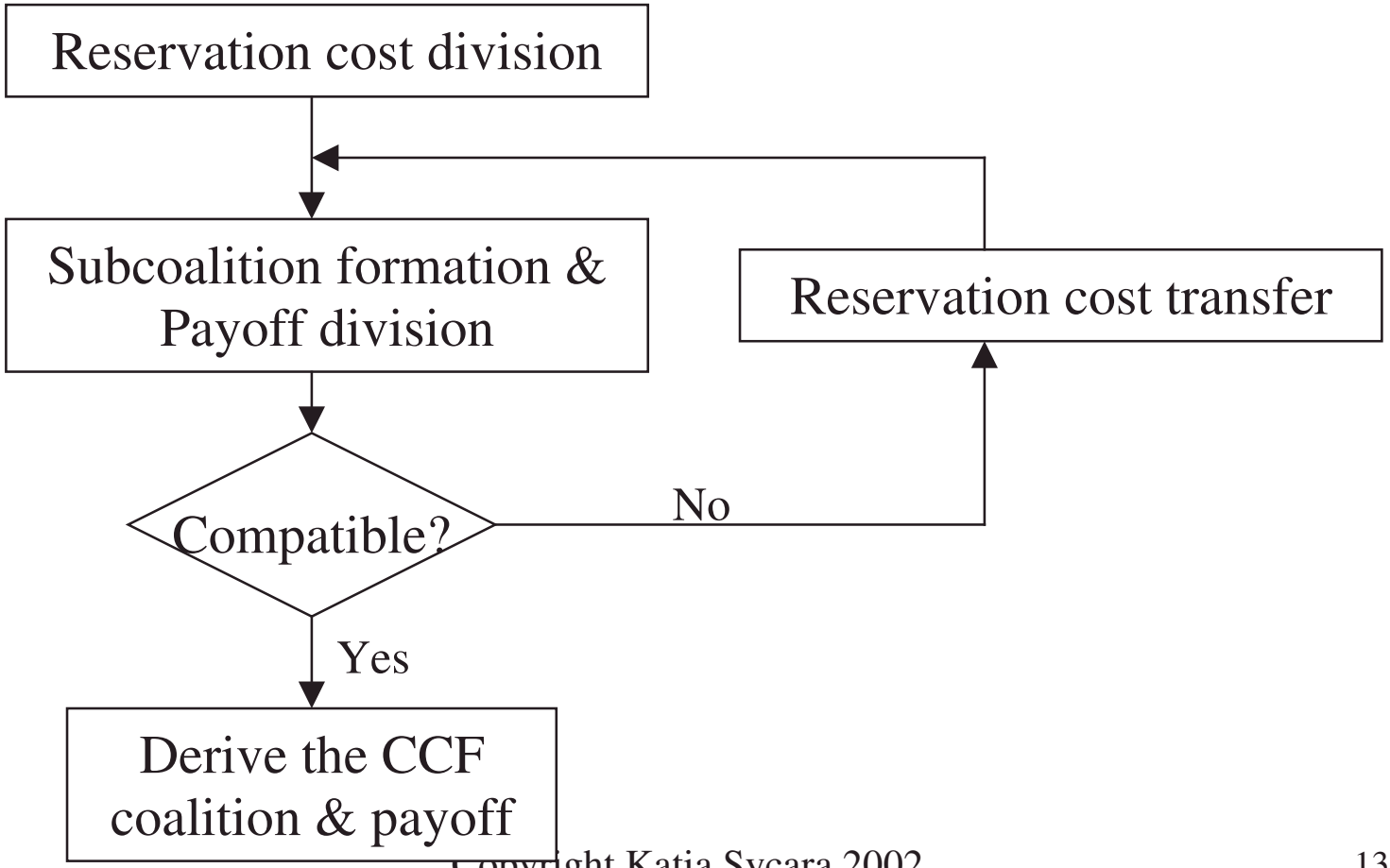
Approach



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Why subcoalitions?

Claim 2: *If the optimal subcoalitions are compatible, then the derived coalition is optimal.*

If each subcoalition distribute the payoff in the core, then the payoff division obtained by summing up the payoff in the subcoalitions for each buyer is in the core of the derived coalition.

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Go back to the example…

	r_n	r_n^1	r_n^2
Buyer 1	450	403	47
Buyer 2	450	411	39

$$\left.\begin{array}{l} C_1^* = \{b_1, b_2\} \\ C_2^* = \{b_1, b_2\} \end{array}\right\} \text{ comp. } \Rightarrow \quad C^* = \{b_1, b_2\}$$

$$\left.\begin{array}{l} x_1(C_1^*) = \{0,4\} \\ x_2(C_2^*) = \{6,0\} \end{array}\right\} \Rightarrow \quad x(C^*) = \{6,4\} \in Core(C^*)$$

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Existence of compatible optimal subcoalitions

Linear price function:

$$p_k(m) = -d_k \cdot m + a_k$$

Claim 3: *Suppose the price functions are linear price functions, then there exists a reservation cost division such that the optimal subcoalitions are compatible.*

From now on, the focus will be put on the systems with linear price functions…

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Need to solve …

- Q1: How to efficiently form an optimal subcoalition
- Q2: How to distribute the payoff in the core of the subcoalitions
- Q3: How to transfer the virtual reservation cost among items to make the optimal subcoalitions compatible
- Q4: How to construct an approximation algorithm in polynomial time

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Q1: Optimal Subcoalition Formation…

- In Yamamoto and Sycara, we showed efficient and accurate algorithm for coalition formation for single unit items. This algorithm was extended to coalition formation for multiple units.

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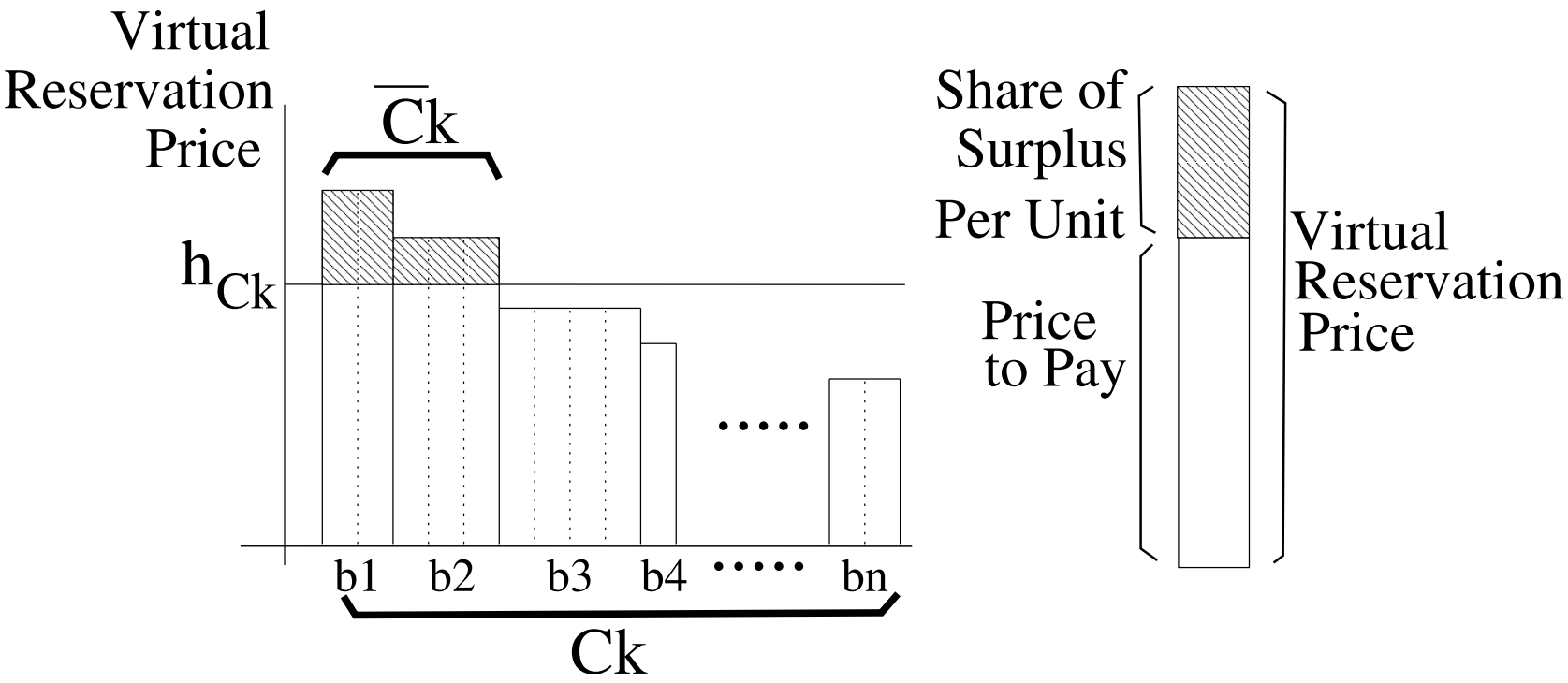
Q2: Subcoalition payoff division



Can be realized in $O(K \cdot N \log N)$

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Q3: Reservation cost transfer scheme

- Check the buyers one by one. If a sub-coalition is not compatible with respect to buyer b, then redistribute the reservation cost of b.
- Converges to a set of compatible optimal subcoalitions

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Q4: Approximation Algorithm

- Use the heuristic: Once a buyer has been excluded from all sub coalitions, there is a very small possibility that he will be included in the optimal coalition.
- Therefore, discard the buyer from the buyer set.
- This results in a polynomial time algorithm

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Experiment: instance generation

- System scale:

  number of buyers and items
- System characteristics:
  - DS(Discount Slope)
  - RBMI(the Ratio of Buyers preferring Multiple Items)
  - RBBR(the Ratio of Buyers Bidding at the Retail Prices)

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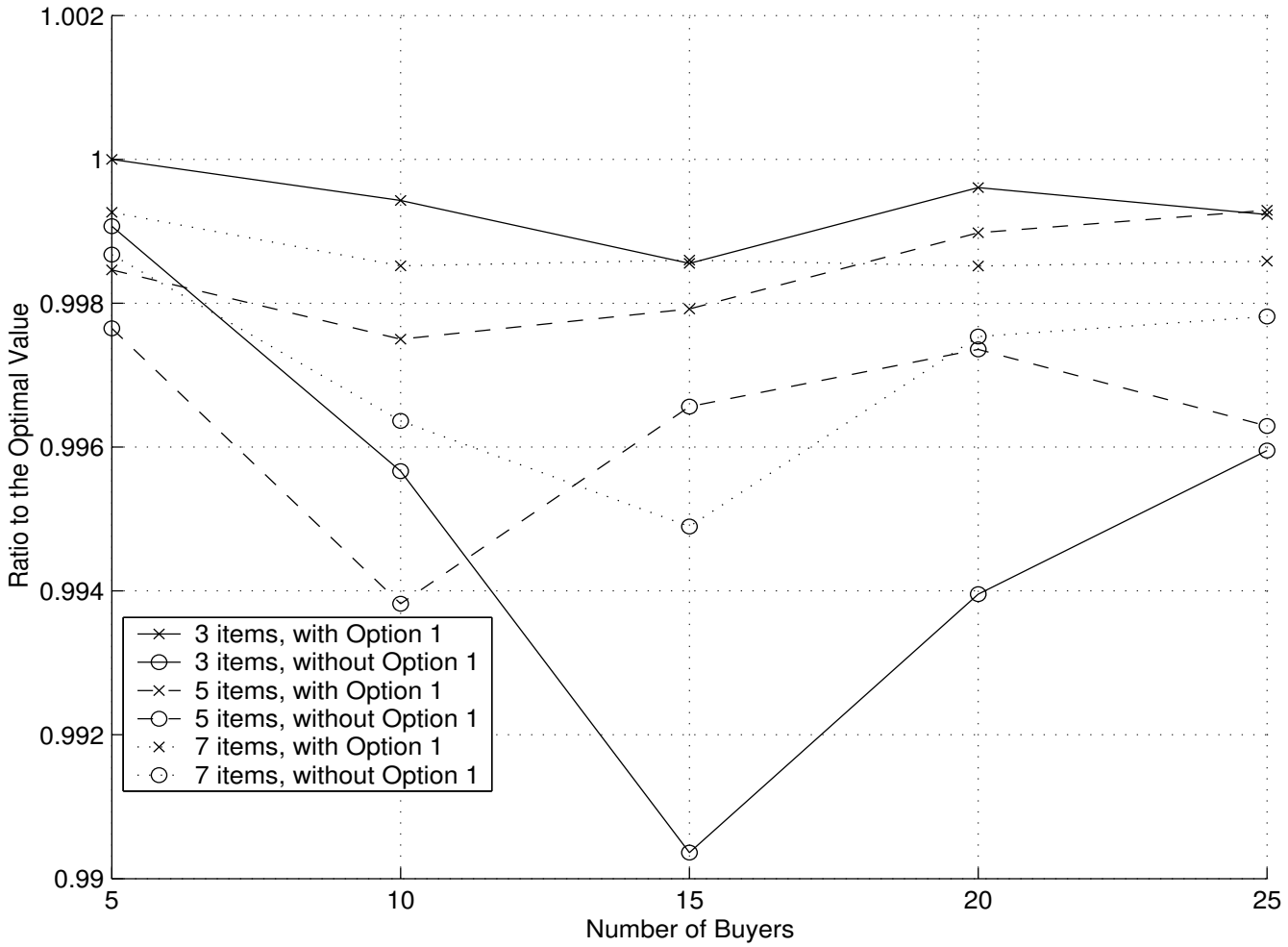
Experiment: numerical result



Research Results

- Developed a polynomial time approximation algorithm for formation of ccf (coalition formation is NP-complete)
- Good ratio to the optimal value by experimental results
- Payoff division scheme in the core of the coalition, guaranteeing coalition stability

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Multiunit Double Auctions: Design goals

- Efficient
  - Maximizes the collective profit of all the participating agents
- Strategy-proof
  - Induce agents to honestly report their private information
- Budget-balanced
  - The market does not need to be subsidized by outside sources
- Individual rational
  - Agents will voluntarily attend the market because of expected positive profit

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Design goals (cont)

- We can not achieve all four goals at the same time
- For MDAs, we also need to consider the volume issues
- Trade-offs
  - Asymptotically efficient
  - Strategy-proof in price
  - Weakly budget-balanced
  - Individual rational
  - Hard for sellers to influence market price by misreporting volumes

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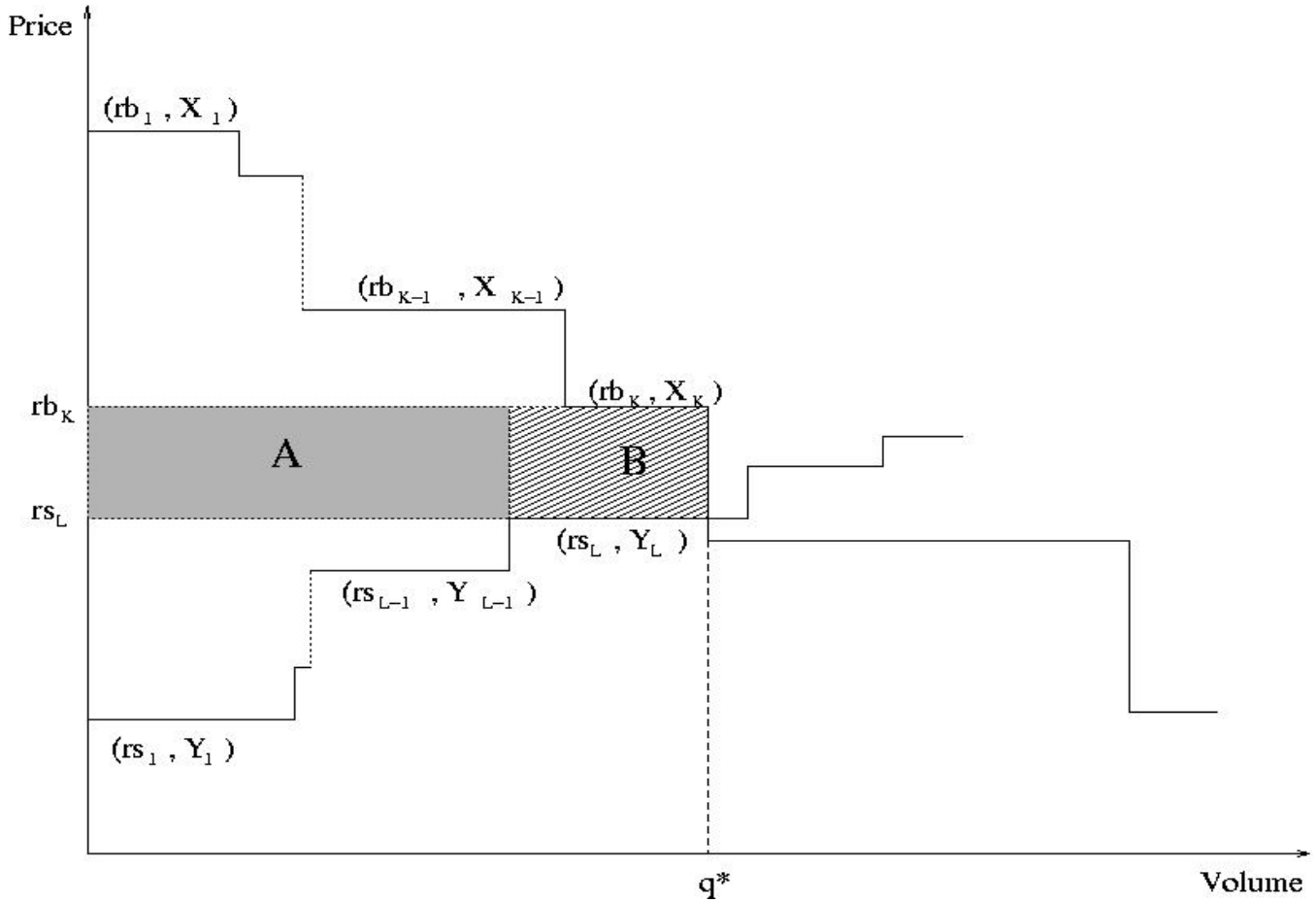
The Mechanism



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The Mechanism

- Two-side Vickrey-like auction
- Balance the supply volume and the demand volume
- Main result
  - If the buyers and sellers' volumes are public information, the above mechanism is strategy-proof with respect to reservation price, weakly budget-balanced, and individually rational.

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Sellers' volume strategy

- Sellers may drive the market price up by tightening the supply volume
- Though possible, it is hard to for sellers to do so because the information disclosure rule of our market
  - Only sellers with index j<L can do so
  - Sellers do not how much to under-report
    - Lack of information of the whole market
    - Gaming between sellers

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Efficiency

- Market loss
  - Market values loss between buyer K and seller L (part A and part B in the figure)
  - Market values loss in order to balance the supply and demand volume

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Efficiency

- Main results
  - Given the number of agents who successfully trade is large, the market is asymptotically efficient
  - Under some weak assumptions, given the number of agents, trade or not, is large, the market is asymptotically efficient

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Conclusions

- Agents are becoming a reality
- One of the killer applications is going to be the deployment of agents as the future generation of Web Services
- Remaining open issues
  - Scalability of coordination
  - Predictability of overall results of a MAS
  - Agent trust
  - Semantic interoperation
  - Human delegation
  - Agent customization

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