Distributed Deliberative Planning with Partial Observability: Heuristic Approaches

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Outline

- Motivation
- Legal Agreement Protocol (LAP)
- Deliberative Planning & Partial Observability
- Heuristics
- Results

Characteristics of Military Operations

- Decentralised:
  - cooperation among distributed autonomous organisations
  - make their own self-interested decisions (not controlled)
  - may keep information/capabilities private
- Dynamic
  - organisation's capabilities, information & goals may change
  - the environment in which they interact may change
- Open
  - organisations with indeterminate capabilities may come and go at any time
- Agreements
  - formation of "legal" agreements for services/capabilities
  - contract law to establish commitment and agreements

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Legal Agreement Protocol (LAP)

- LAP facilitates cooperation and coordination among organisations (or agents)
  - Enables planning, task allocation and agreements among agents in a decentralised, dynamic and open environment
- Extension of the Contract Net Protocol (CNP)
- Comprises an iterative interaction process:
  - *Customer* agents extract, match and negotiate capabilities from *supplier* agents
  - Distributed assembly of capabilities (e.g. using A*)
  - Adapt via updating, withdrawing & backtracking mechanisms (not discussed)

LAP Components

- Messaging component
  - Describes the sequence of messages (speech acts & semantics) and events that can occur at various stages of the protocol
- Reasoning component
  - Drives the protocol (messaging component)
    - e.g. when to offer, update, backtrack, negotiate, etc.
  - Highly domain dependent
  - Require heuristics to facilitate effective reasoning and planning within the complex environments that LAP is applied

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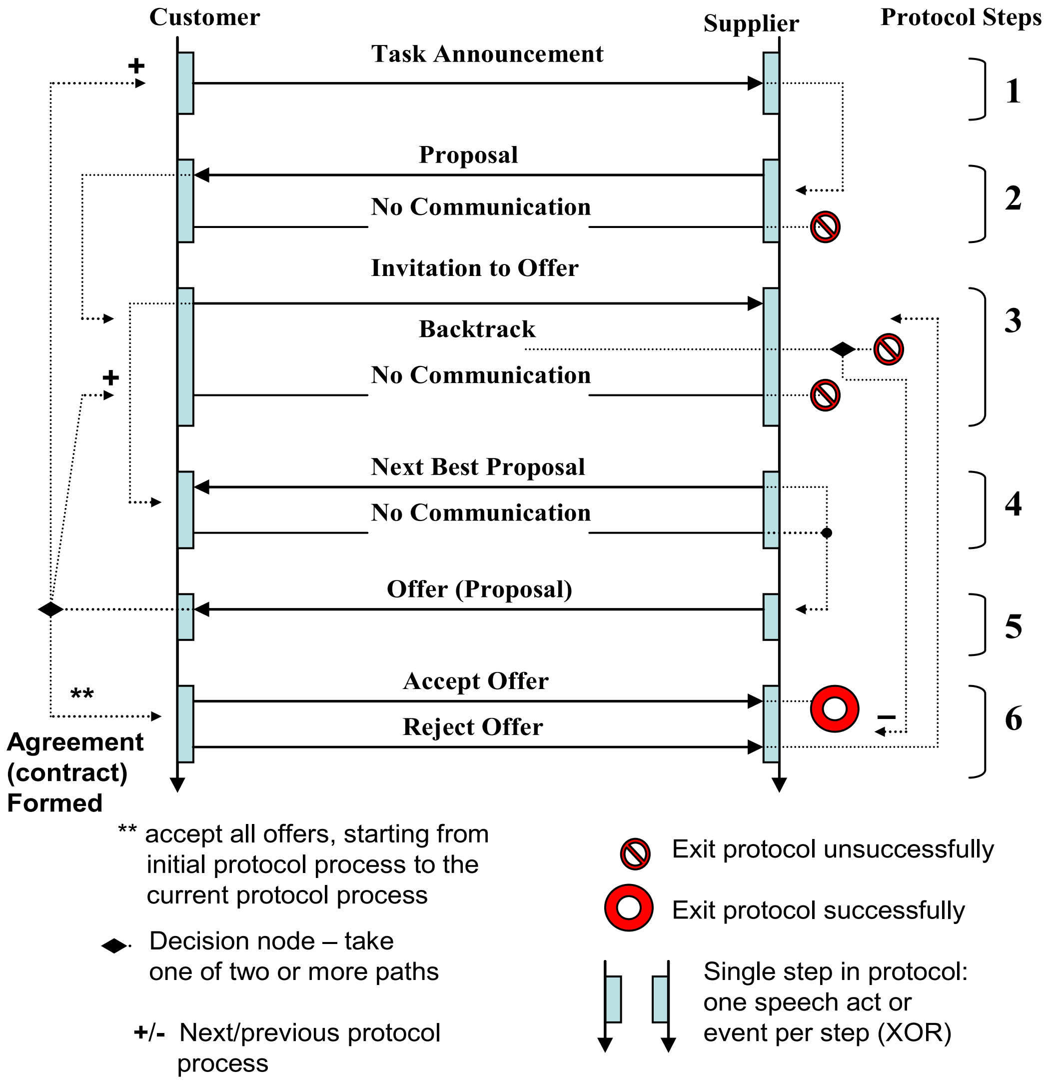
LAP Messaging Component



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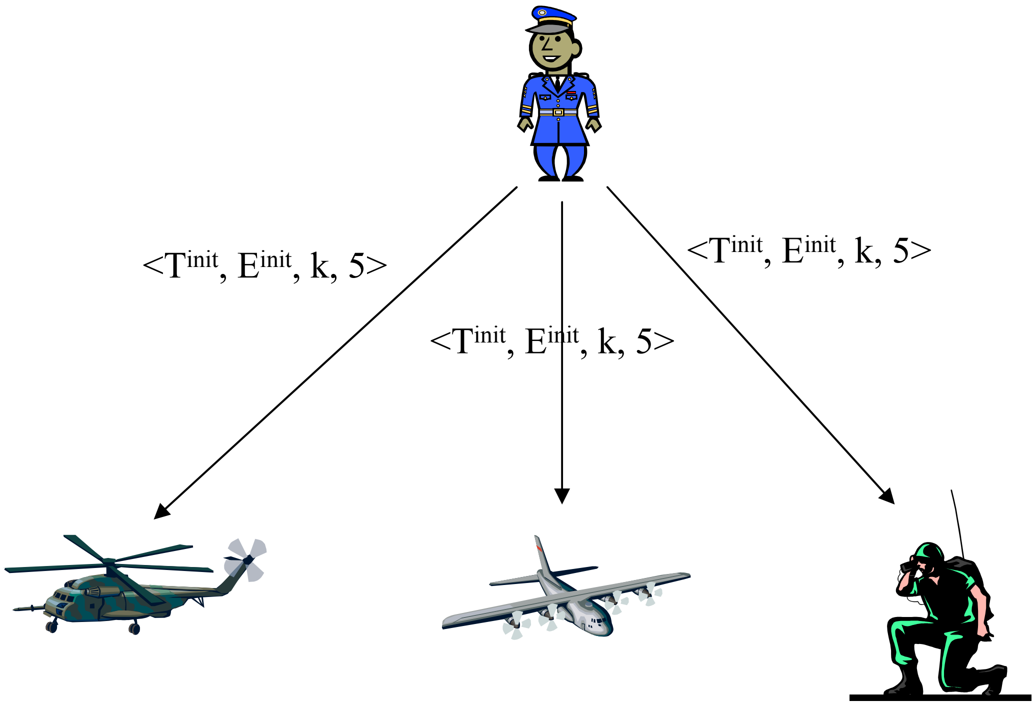
LAP Example (Distributed A*)

Customer:
Goal: $T^{init} = <t_1, t_2, t_3, t_4, t_5>$
Expected costs: $E^{init} = <e_1, e_2, e_3, e_4, e_5>$
Current path cost: $k = 0$
Deadline for responses = 5 mins

A* search, branches evaluated by:
$f = g + h$
g = current path cost
h = expected cost to achieve remaining tasks
h must be an underestimate to guarantee optimality

Search Tree

T^{init}



Suppliers

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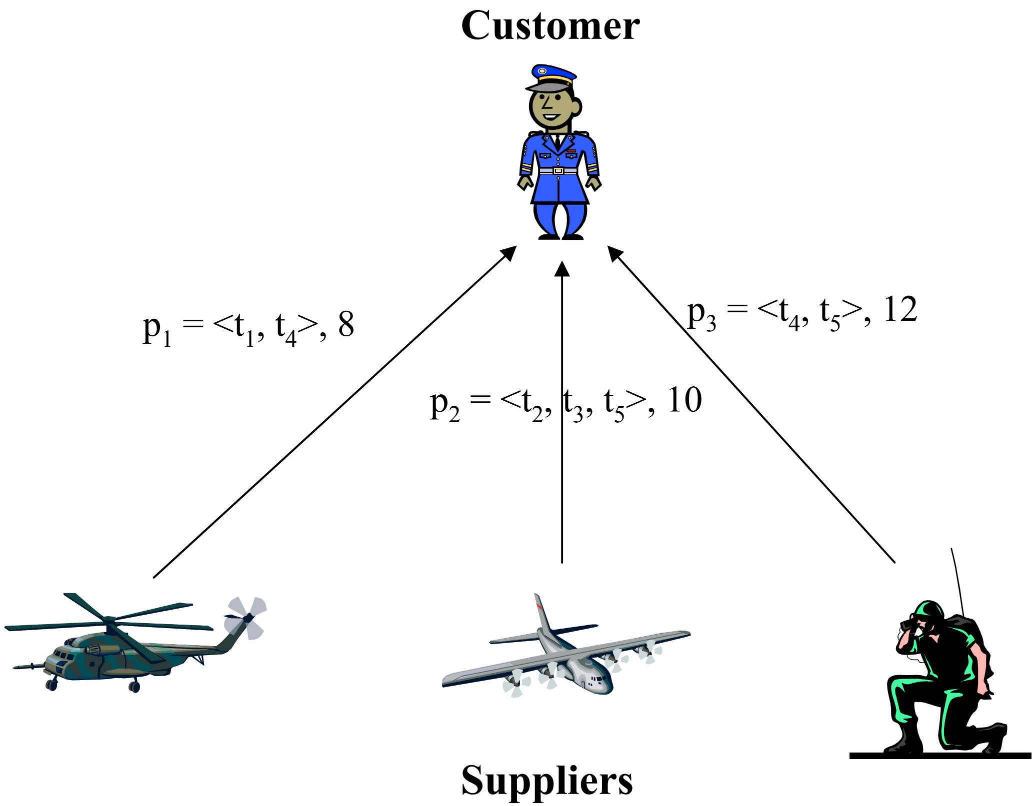
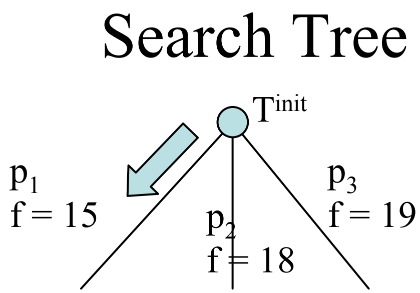
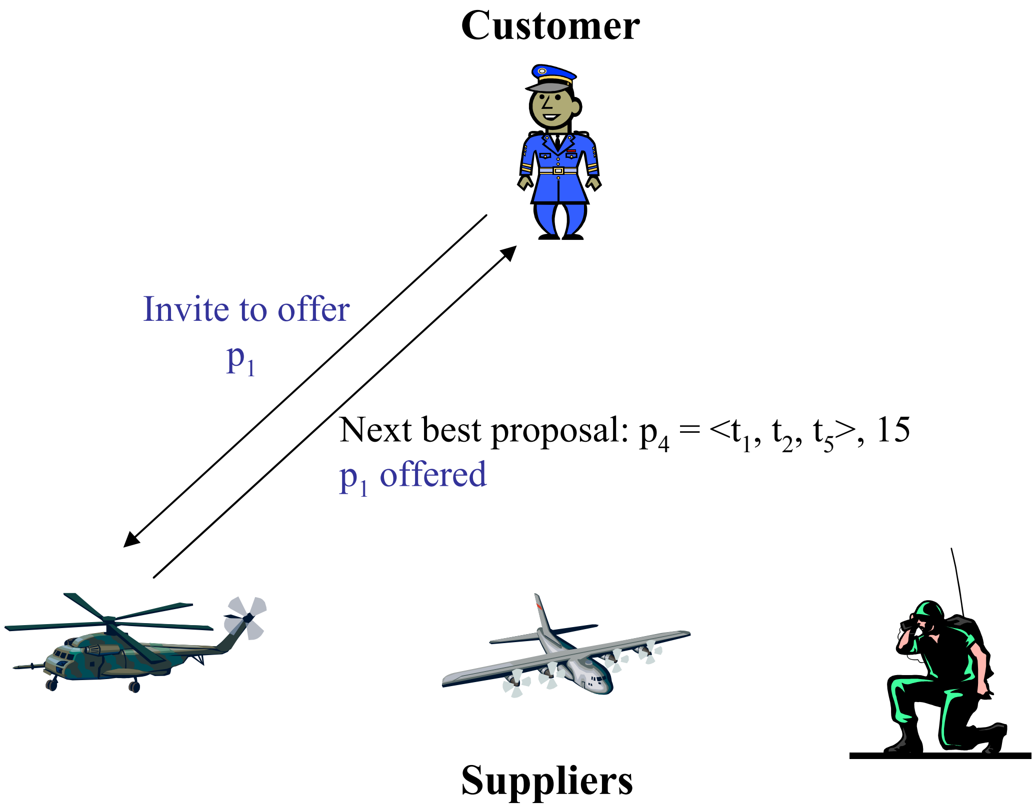
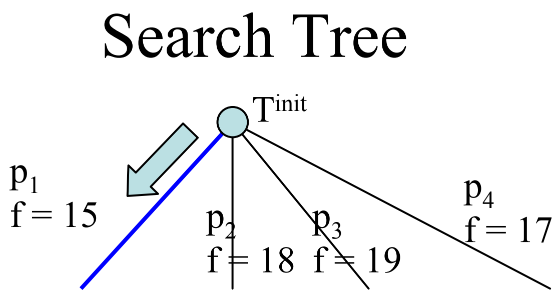
LAP Example (Distributed A*)





LAP Example (Distributed A*)





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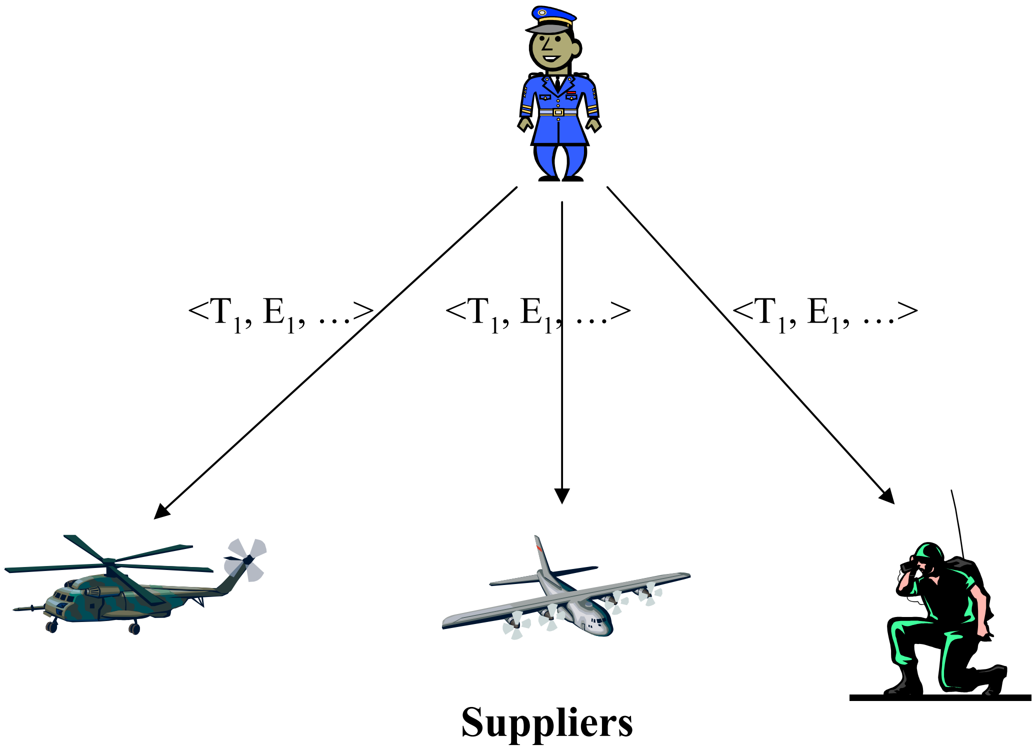
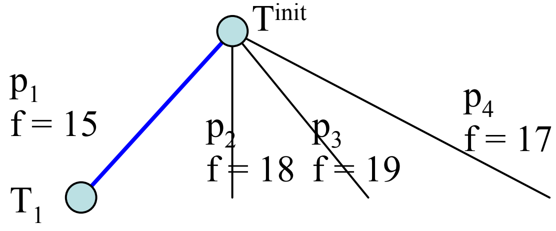
LAP Example (Distributed A*)

Customer:
Tasks left to achieve:
$T_1 = T^{init} \backslash p_1 = <t_2, t_3, t_5>$
$E_1 = <e_2, e_3, e_5>$, $k = 8$ (cost of p_1)



Search Tree



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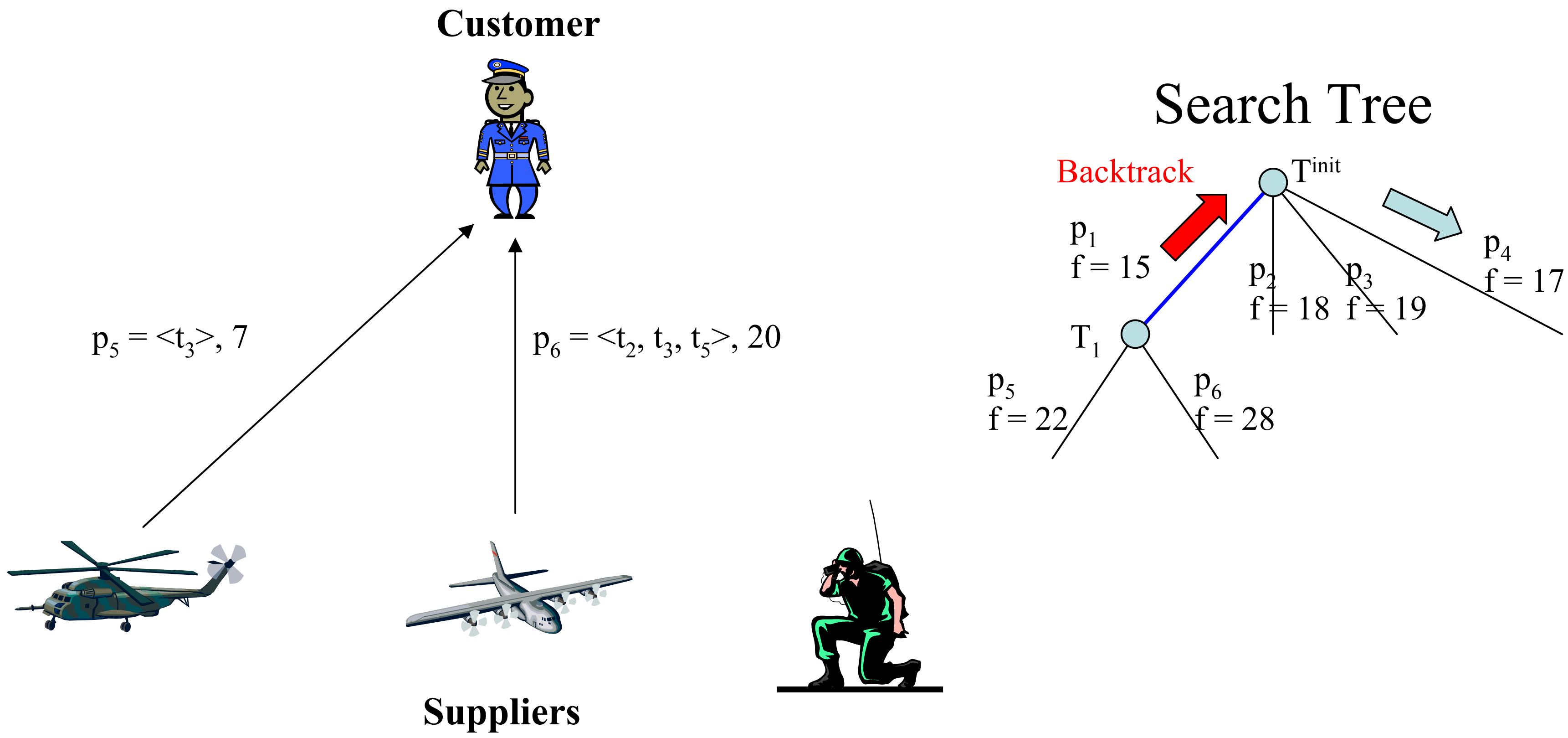
LAP Example (Distributed A*)



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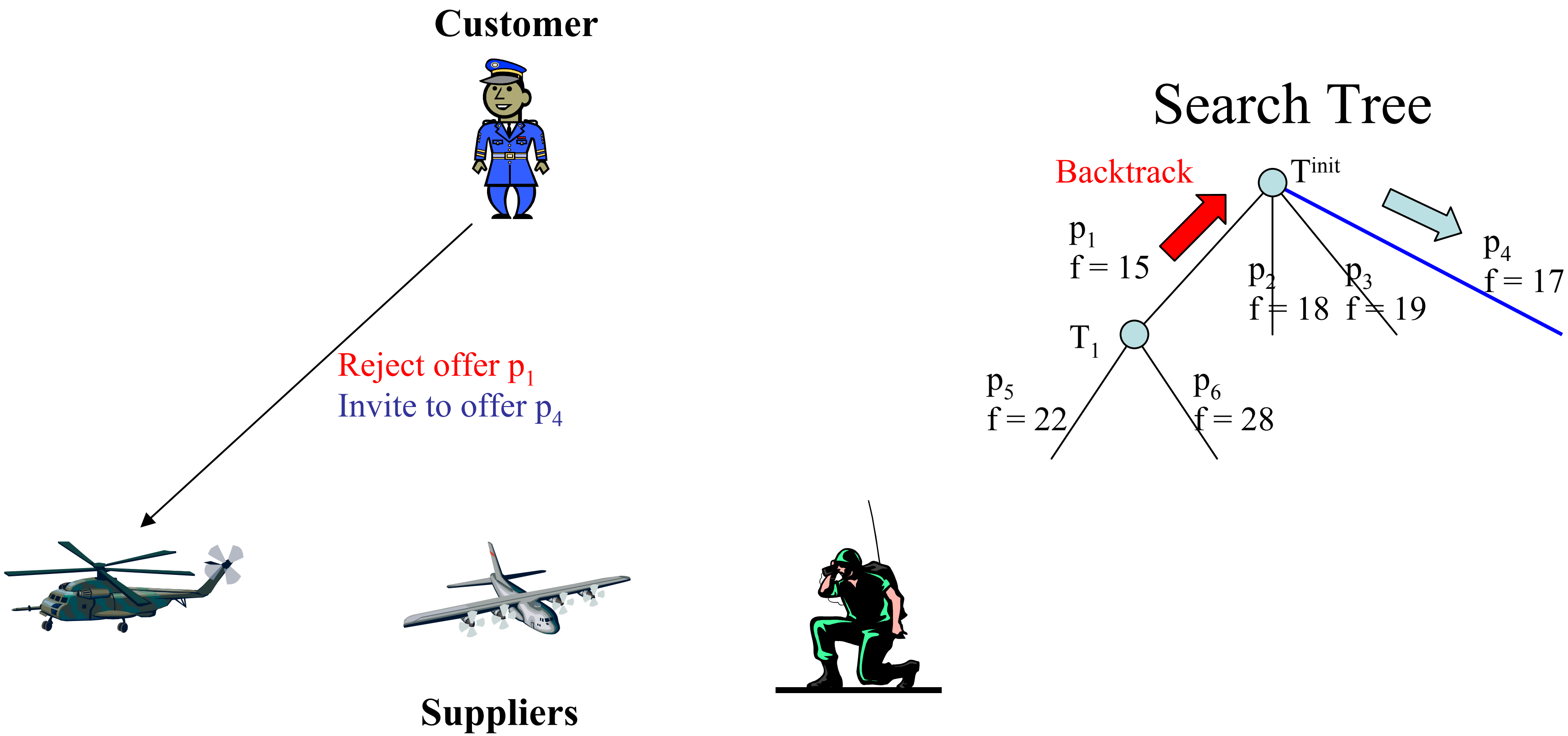
LAP Example (Distributed A*)



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Partial Observability

- With centralised search approaches, the expected cost e_i for each sub-task can be determined naïvely using $$\min_{j \mid i \in p_j} \frac{c_j}{\left| p_j \right|}$$
- Requires visibility of all proposals
- In a decentralised environment, and with LAP, the customer does not have access to all other agent's capabilities (proposals)
- Makes finding e_i difficult
- Solution: *the expected cost e_i is determined dynamically during planning as the customer receives information about other agents' capabilities*

Heuristic Approaches

Commence with $e_i = 0$

1. **Minimum cost heuristic**
   - e_i is the minimum cost observed so far
2. **Alpha factor on difference, limited**
   - Increase e_i slowly to prevent over-estimation
   - s is a newly observed sub-task cost
   - If $s < e_i$, set $e_i = s$, use minimum cost heuristic
   - Otherwise, $e_i = e_i + \alpha \cdot \Delta$, where $\Delta = e_i - s$
3. **Average over all sub-tasks**
   - e_i is the average over all observed sub-task costs
4. **Average of current average**
   - $e_i = (e_i + s)/2$, where s is a newly observed sub-task cost

Experiments

- Used set partitioning problem datasets
  - Set of tasks T = {1, 2, …, m} need to be achieved using a set of package propoals $B = \{B_1, B_2, \ldots, B_n\}$, where $B_j = \langle p_j, c_j \rangle$, $p_j \subseteq T$ is a set of achieving capabilities at cost c_j
  - Aim: achieve all sub-tasks in T once, at minimum cost
- 90 scenarios
  - 18 datasets
  - 1, 2, 5, 10, 100 suppliers
  - α values of 0.2, 0.4, 0.6, 0.8
- Evaluated on: solution quality, number of nodes traversed, number of branches received

Results

Heuristic	Quality (% *above* optimal)	Nodes Normalized	Branches Normalized	# Opt
Minimum Cost	2.7 ± 6.9	33.0 ± 26.7	28.7 ± 30.7	57
Alpha Factor (α=0.2)	0.07 ± 0.52	77.5 ± 22.5	62.2 ± 30.0	85
Alpha Factor (α=0.4)	0.36 ± 1.4	58.5 ± 23.8	46.3 ± 28.5	76
Alpha Factor (α=0.6)	0.51 ± 1.7	50.1 ± 25.9	41.1 ± 29.3	69
Alpha Factor (α=0.8)	0.71 ± 1.9	44.2 ± 25.0	36.6 ± 29.2	63
Average Cost	22.5 ± 20.5	1.0 ± 2.6	0.54 ± 0.83	5
Average of Average	30.9 ± 27.3	0.65 ± 1.8	0.41 ± 0.69	4

- Average cost heuristics find a solution with less branches & nodes (i.e. less time and communication) than other heuristics, but at the cost of the quality of solution
- Minimum cost heuristic is 280% worse than the worst alpha factor heuristic (α = 0.8), but the reduction in effort was only 25% for nodes and 22% for branches

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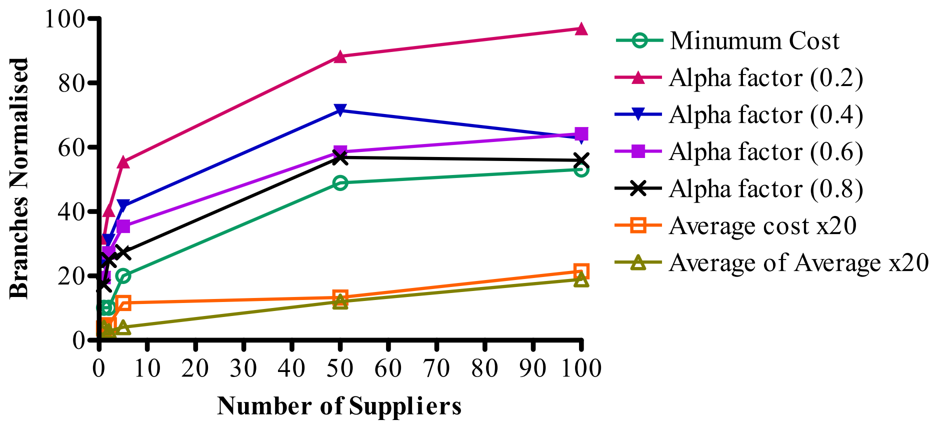
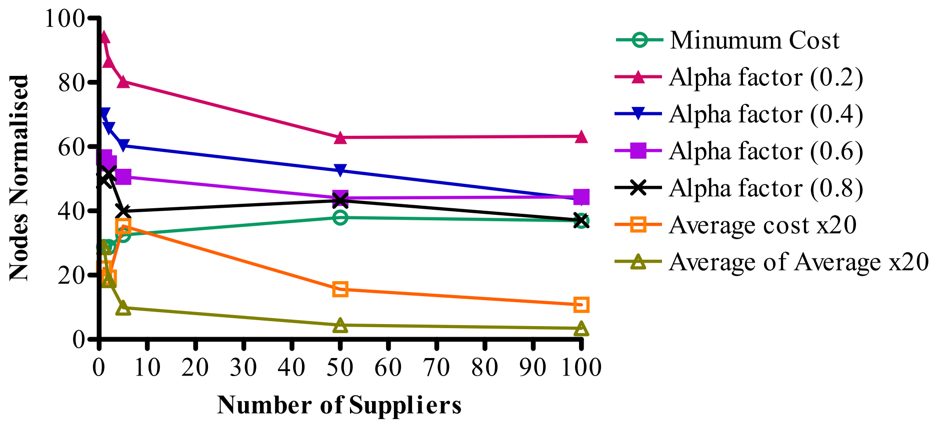
Results





- Number of branches increases with the number of suppliers since more suppliers can submit proposals for each task announcement
- Number of nodes traversed decreases (more efficient search) as suppliers increase for all but minimum cost heuristic due to increase in submitted proposals
  - Alpha factor: expected cost increases quickly to the min cost at the start of the search
  - Average: stable, accurate and larger expected cost
  - Min cost: minimum cost of many proposals is lower than the minimum cost of a few proposals

Conclusion

- Investigated four heuristics to dynamically determine the expected cost during planning using LAP in the presence of partial observability
- Heuristics have tradeoffs: quality of solution vs effort required to search (nodes & branches)
  - Average cost heuristics required less effort, but at the cost of the quality of solution
  - The quality by using the alpha factor heuristic is much greater than the minimum cost heuristic, with little extra effort
- Number of supplier influences search effort
  - Number of branches increase with the number of suppliers
  - Number of nodes traversed decreased with all heuristics except the minimum cost heuristic

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QUESTIONS?