Planning in Multiagent Systems

Mathijs de Weerdt
Cees Witteveen
Goals of this tutorial

• A bit background knowledge on AI planning
• Broad view of multiagent planning problems and
• multiagent planning techniques
• Details of some multiagent planning techniques
Tutorial Contents

1. Introduction & taxonomy (Mathijs)
2. Background single-agent planning (Mathijs)
3. Multi-agent planning techniques and illustrations (Cees)
Overview of first part of tutorial

- Introduction to multiagent planning
  - Relation with multiagent systems
  - Relation with planning
- Taxonomy of multiagent planning problems
- Taxonomy of multiagent planning techniques
- Discussion
Why planning in multiagent systems?

- More efficient system performance on run-time
  - Come prepared
  - Prevent deadlock
  - Lower costs
  - Accomplish task more quickly

- Useful assignment of resources, use of capabilities
Multiagent Planning (MAP) and Multiagent Systems (MAS)

- MAS: Coordination of autonomous entities
- MAP $\subseteq$ MAS (hence this tutorial)
- MAP: Focus on
  - Coordination of actions before execution
  - Finding correct actions to attain goals
- Strongly related to task allocation and auction/negotiation techniques
MAP and AI planning

- MAP $\supseteq$ AI Planning for multiple agents
  - Execution in parallel (instead of sequentially)
    $\rightarrow$ Parallel plans

- MAP $\supseteq$ Planning by multiple agents (distributed)
  - Incoherent plans: need for coordination; more difficult, less optimal
  - Why then?
    - Privacy & autonomy
    - Local $\rightarrow$ more efficient reaction on incidents (when communication limited) & no central point of failure
    - Speed-up: in parallel & smaller problems
Applications of Multiagent Planning

- Planetary explorations
- Multi-player video games
- Taxi companies
Planetary explorations

- More or less independent
- Communication difficult and costly
- Cooperative
Multi-player video games

- Self-interested players
- Independent
- Potential for coordinated behavior

Write your own agent(s) for Wargus (open source Warcraft 2 engine)
Taxi companies
Taxonomy of coordination

From: M. Huhns, L. Stephens, Ch.2 from G. Weiss (1999)
*Multiagent systems: A modern approach to Distributed Artificial Intelligence*
Taxonomy of MAP problems

Four ways to look at multiagent planning problems

- Strongly related → Independent
- Cooperative → Self-interested
- Resolving conflicts → Exploit efficiency
- No communication → Reliable communication
Strongly related $\rightarrow$ Loosely coupled $\rightarrow$ Independent

Strongly related because
- Joint actions
- Limited shared resources

Requires crisp coordination

Examples
- Lift a box together
- Car assembly
- Robocup
- Hospital
- PhD research
<table>
<thead>
<tr>
<th>Cooperative</th>
<th>Self-interested</th>
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<tbody>
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<td><strong>Independent</strong></td>
<td><strong>Self-Interested / Private</strong></td>
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<td>Rovers</td>
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**Cooperative**

- Rovers
- UN-operation
- Hospital
- Human soccer
- Lifting boxes
- Robocup

**Self-interested**

- PhD research
- Traffic
- Warcraft
- Taxi companies
- Supply chains
- Self-Interested / Private
Resolving conflicts → Exploit efficiency

Independent

Strongly related

Traffic

Warcraft

Hospital

Taxi companies

Lifting boxes

Robocup

Supply chains

Resolve conflicts

Both

Exploit efficiency
No communication → reliable communication

Examples:
- Rescue Robots
- Planetary explorations
- Military operations
Continuous planning and execution

- Any system that is used should deal with unexpected events
  - Plan adaption (repair) or
  - Start from scratch (replanning)
- Multi-agent planning can help here by locally replanning / plan repair
  - when no communication possible
  - to reduce the impact of incidents
Taxonomy of MAP techniques

- Where are plans created?
  - Centralized
  - Distributed

- When coordination in MAP process?
  - Before planning
  - During planning
  - Post-planning

- How are plans coordinated?
  - Dependency checks?
  - Task/resource allocation?
Where are plans created?

Centralized
- Optimal (potentially)
- Communication only twice (before & after)

Algorithm:
1. Label actions with agent names
2. Plan
3. Decompose into sub-plans
4. Add synchronization actions
Where are plans created?

Distributed
- Reduce computation time
- Keep privacy (potentially)
- Scalable
- Control as well

Examples:
- Ephrati (1995): by plan merging
- vd Krogt (2005): by plan repair
Where are plans created?

Partially distributed

- Share parts of your plan

Examples:

- Corkill (1979): Distributed NOAH (shared world model)

- Durfee, Decker, Lesser (1986-) Partial global planning (shared plan)
Where are plans created?

Distributed, for a centralized plan
- Specialized planning agents

Examples:
- Kambhampati (1991): Combining specialized reasoners and planning
- Wilkins (1998): Multiagent planning architecture
When coordination in MAP process?

1. Global task refinement  
   = AI planning
2. Task allocation
3. Coordination before planning
4. Individual planning
5. Coordination after planning
6. Plan execution
When coordination in MAP process? (pre)

3. Coordination before planning (pre-planning coordination)
   - Social laws (e.g. traffic rules): Shoham & Tennenholtz (1992)
   - Derive specific constraints for agents: Buzing, Valk et al. (2006)
When coordination in MAP process? (during)

4. Individual planning
   Coordination during planning
   • Distributed NOAH (Corkill)
   • Partial global planning (Decker, Lesser)
   • Through plan repair (vd Krogt)
When coordination in MAP process? (post)

5. Coordination after planning
   • Plan merging

6. Coordination during (plan) execution
   • “Normal” MAS/distributed systems solutions
     • FIFO-queues
     • Semaphores
When coordination in MAP process? (continual)

- Plans are being executed during planning and coordination
- May break and re-make commitments
  - unexpected event/failure
  - goal change

Distributed continual planning
Difficulties of continual planning

- Chain reactions of changes
- Cyclic dependencies
How are plans coordinated?

- Maintenance of dependencies?
  - Distributed check for cycles
  - Shared global plan
  - Afterwards: plan merging

- Distribution of tasks and resources?
  - Contract net protocol
  - Auctions (combinatorial?)
MAP Taxonomy Dimensions

- MAP problems:
  - Strongly related → Independent
  - Cooperative → Self-interested
  - Resolving conflicts → Exploit efficiency
  - No communication → Reliable communication

- MAP solutions:
  - Where (centralized, distributed)
  - When (pre, during, post)
  - How (dependencies/resources)
Recent focus

- Mixed initiative multiagent planning
  - Using domain knowledge (in task networks)
- More application-oriented work:
  - search & rescue
  - military operations (“Coordinators”)
  - logistics
Reasons for not doing multiagent planning

- Privacy & autonomy
  - First negotiating, then (optimal) planning

- No central point of failure
  - Just introduce redundancy

- Limited communication (on execution)
  - Contingent planning on forehand & with constraints on-line

- Speed-up: in parallel & smaller problems
  - Use a grid and parallel computing techniques
Recommended reading

- Durfee’s chapter (3) on Distributed Problem Solving and Planning in Weiss (1999), *Multiagent systems: A modern approach to Distributed Artificial Intelligence*


- (Links to) material can be found on: http://www.st.ewi.tudelft.nl/~mathijs/tutorial.php
Other references


