Adversarial Cooperative Path-Finding: A First View

Marika Ivanová and **Pavel Surynek**
Charles University in Prague, Faculty of Mathematics and Physics

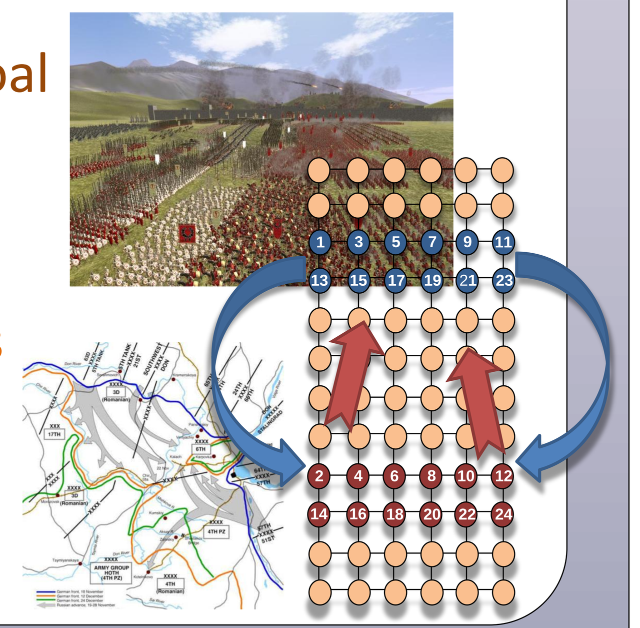
Introduction and Motivation

Adversarial Cooperative Path-Finding (ACPF)

- generalization of cooperative path-finding (CPF)
- teams of agents compete in reaching their goal
- **winner** = the first team to reach the goal

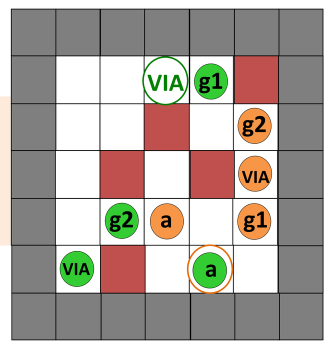
Motivation

- video games
- planning and simulations
- police interventions
- military actions
- security operations



Formal definition

The ACPF problem



Instance of ACPF problem is a 7-tuple
$\Sigma = (G, A, T, t^*, \lambda_0, \lambda_+, \alpha)$

Where

- $G = (V, E)$ — an undirected **graph**
- $A = \{a_1, a_2, \ldots, a_k\}$ — finite set of **agents**
- $T = \{T_1, T_2, \ldots, T_t\}$ — finite set of **teams**
- $\lambda_0: A \rightarrow V$ — **starting position** of each agent
- $\lambda_+: A \rightarrow P(V)$ — set of **target positions** of agents
- α — **next placement** of agents of teams of adversaries

Agent movement

- Agents move along edges or stay at a vertex.
- An agent can move to an unoccupied vertex or into vertex being left by other agent.
- Swapping along an edge is forbidden.
- Teams alternate in their moves.

Theoretical properites

Proposition. A question if there exist a solution for a selected team in ACPF is PSPACE-hard.

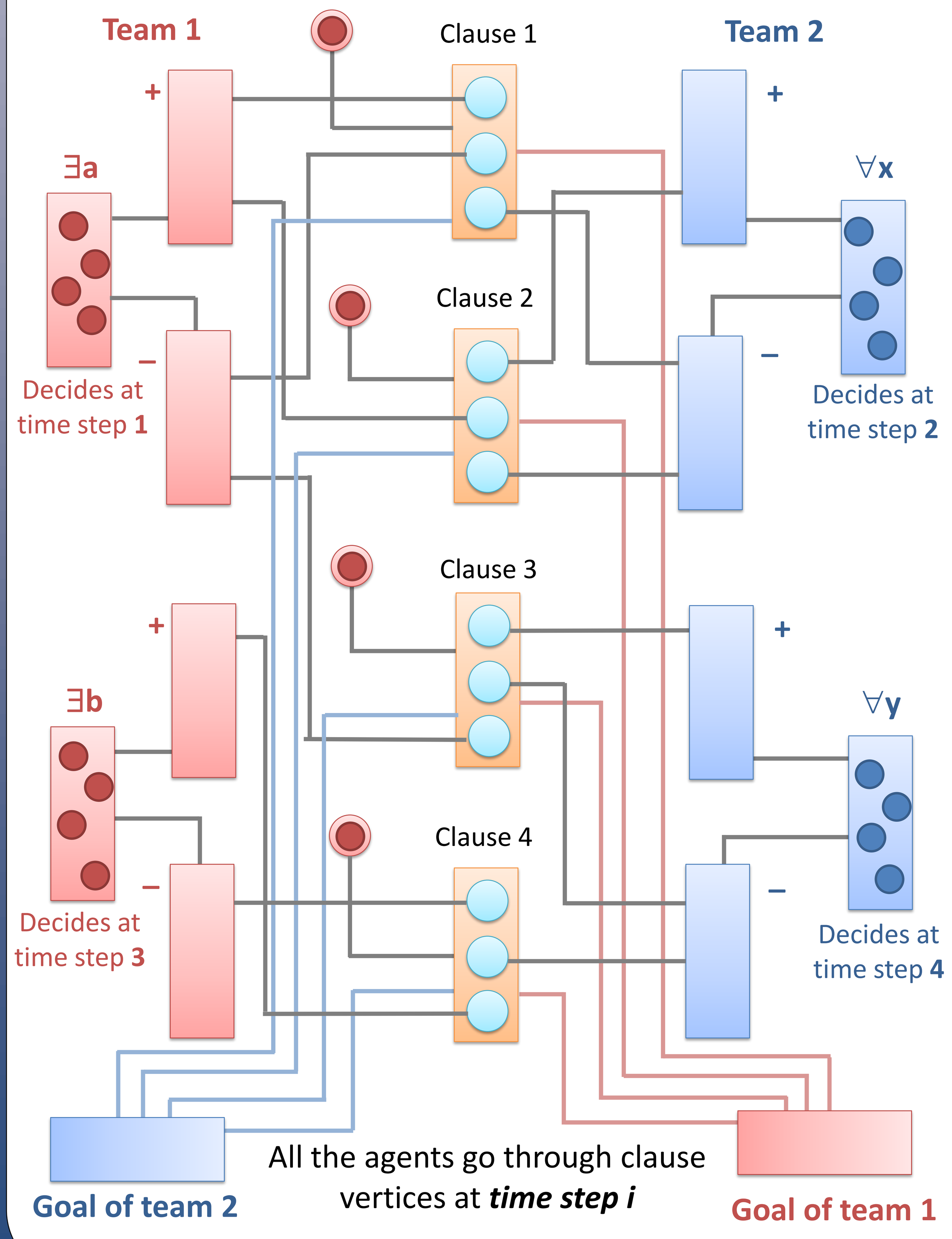
Reduction of QBF to ACPF

- QBF known to be PSPACE-complete
- construct an ACPF instance to simulate QBF

QBF – quantified Boolean formula

- propositional formula with quantification
- example: $\exists a \forall x \exists b \forall y\ [(a \lor b \lor \neg x) \land (\neg a \lor \neg b \lor y)]$
- question: is the given formula **valid**?

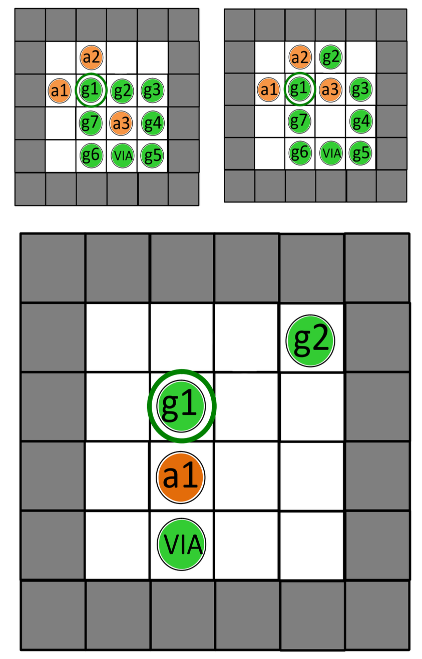
Can team T_1 chose moves to win whatever T_2 does?
(equivalently: is there a solution for T_1?)



Comments

Synchronizations and vertex locking

- agents are forced to follow paths leading to goal areas
- splitting between positive and negative branch need to be ensured
- vertex locking mechanism need to be employed



Even a small alternation of agent arrangement can violate target reachability.

Upper left: Green agents can lead the VIA to its target.

Upper right: Green team is not able to lead the VIA to its target .

Lower: Attacker *a1* blocks the opponent VIA, so it can never escape the bottom row. But when *g2* becomes involved, VIA's target is enforceable.

Practical Offensive and Defensive Tactics

Agent roles

Various tactics can be used when ACPF is solved in practice. Presented suggestion is motivated by a security operation.

Agents are divided into 3 roles, which are treated differently by the planning algorithm:

- VIA – Very Important Agent
- Guards
- Attackers

Agents with fewer targets should be treated as VIAs and can be protected by guards. Attackers are supposed to harm the opponent by blocking important vertices.

Target reachability

The idea is based on effort to find a position, in which it is possible to guide an agent to its target vertex no matter how the opponents behave.

Cooperation of agents of a particular team is important. Consider situations on following figures:

Conclusion and Future Work

- Presented problem is a generalization of well known cooperative path-finding problem.
- PSPACE-hardness was shown and several solving techniques were proposed.
- The ACPF problem offers new area for research:
  - Future study of the problem complexity
  - Finding a solving algorithm
  - Development of heuristics
  - Special cases (particular types of graph, bounded number of agents/teams, symmetric vs. asymmetric solutions and a lot more)

Bibliography

Silver, D., 2005. Cooperative Pathfinding. *Proceedings of the 1st Artificial Intelligence and Interactive Digital Entertainment Conference* (AIIDE 2005), pp. 117-122, AAAI Press.

Surynek, P., 2010. An Optimization Variant of Multi-Robot Path Planning is Intractable. *Proceedings of the 24th AAAI Conference on Artificial Intelligence* (AAAI 2010), pp. 1261-1263, AAAI Press.