Leveraging FOND Planning Technology to Solve Multi-Agent Planning Problems

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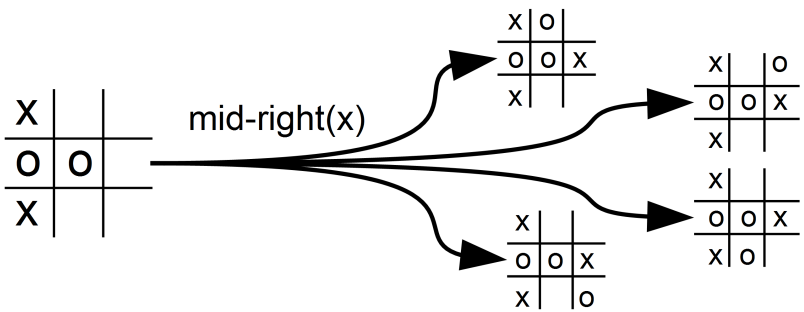
Multi-agent Planning as FOND: Key Points



- Perspectival view on multi-agent planning
- Leverage the power of modern FOND planning
- Seamlessly handle a mix of agnostic, collaborative, and combative agents

Outline

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FOND Planning

Planning Task: $\langle \mathcal{F}, \mathcal{G}, \mathcal{I}, \mathcal{A} \rangle$

- $\mathcal{F}$: Finite set of fluents.
- $\mathcal{G}$: Conjunction of atoms over $\mathcal{F}$ that determines the goal.
- $\mathcal{I}$: Complete setting of the fluents for the initial state.
- $\mathcal{A}$: Set of (possibly non-deterministic) actions.

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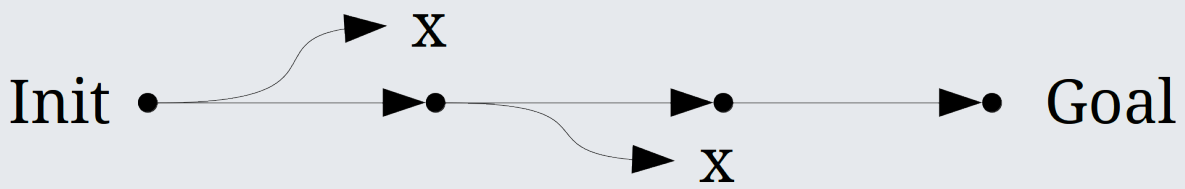
Actions

- Pre_a is the set of fluents that must be true to execute a.
- Eff_a is a finite set of *non-deterministic effects*.
- A non-deterministic effect consists of a set of fluents.

FOND Solutions and Representation

Weak Plan



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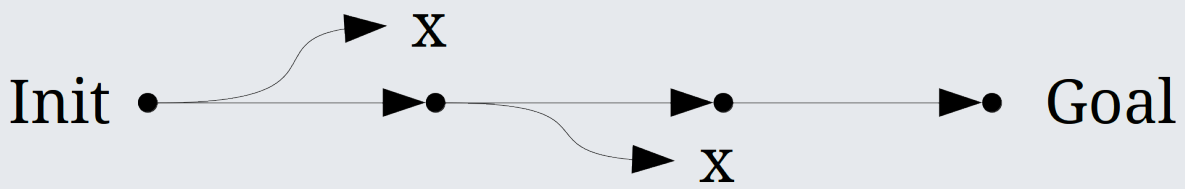
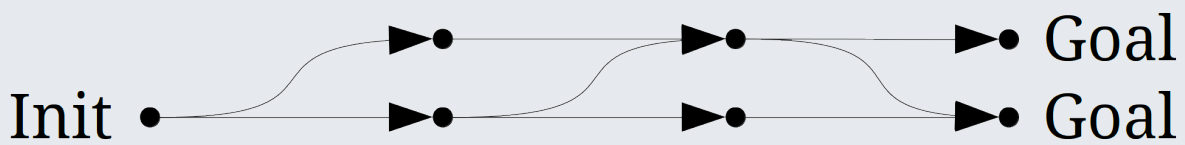


Strong Plan



FOND Solutions and Representation

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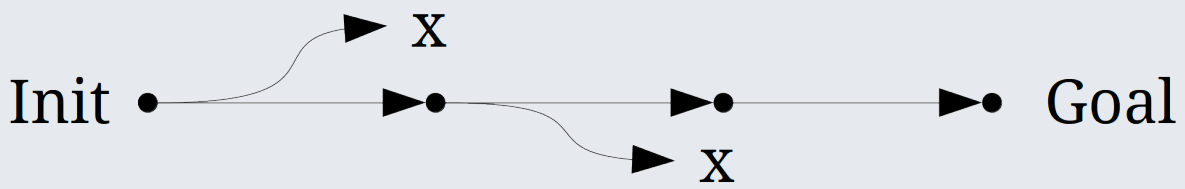

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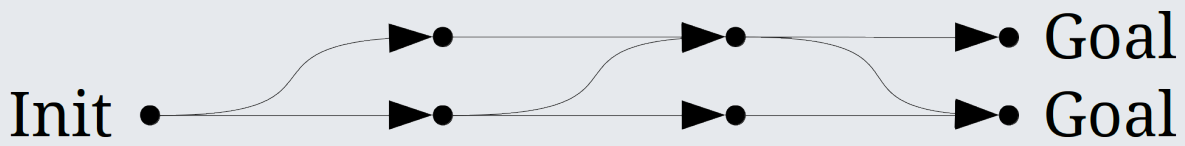
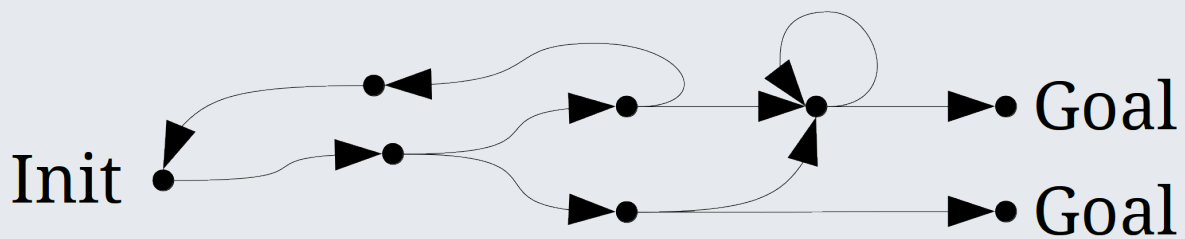


Strong Cyclic Plan

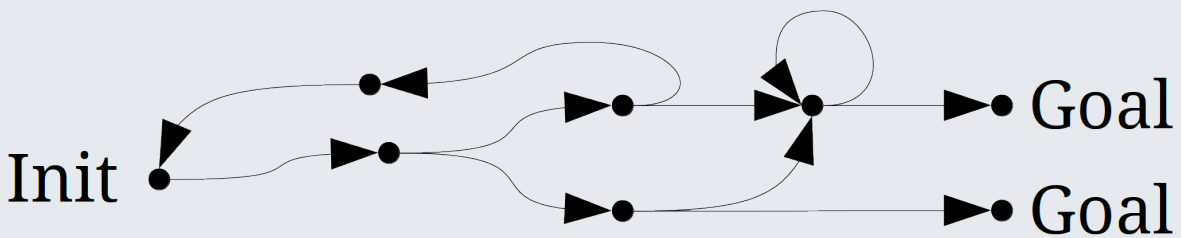


FOND Solutions and Representation

Policy

$P(s)$: Given a set of triples of the form $\langle p, a, c \rangle$ where p is a partial state, a an action, and c a cost, return the action a in state s from the pair with the lowest cost c such that $s \models p$.

Strong Cyclic Plan



First-Person Multi-agent Planning

Key Idea We are just a single agent operating in a multi-agent world. Planning should *not* be omnipotent, but rather conditioned on what others may do.

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First-Person MAP Problem $\langle \overrightarrow{ag}, App, \Pi \rangle$:

- $\overrightarrow{ag}$: Sequence of agents to act in the world
- $i \in \overrightarrow{ag}, App(i)$: Set of actions agent i can execute. $App(s, i) \subseteq App(i)$ are those also applicable in state s

We control agent $me \in \overrightarrow{ag}$, but must react to anything the other agents may do when it is their turn to "play"

Solution: Same as FOND!!

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2. Approach
   - (modified) PRP Algorithm
   - Plausible Outcomes

Computing Strong Cyclic Solutions

Input: FOND planning task $\Pi = \langle \mathcal{F}, \mathcal{G}, \mathcal{I}, \mathcal{A} \rangle$
Output: Partial policy P
Initialize policy P
while P changes **do**

return P;

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while P changes **do**
    $Open = \{\mathcal{I}\}$; $Seen = \{\}$;
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    ProcessDeadends();
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            $Seen$.add(s);
            if $P(s)$ is undefined **then**
                GENPLANPAIRS$(\langle \mathcal{F}, \mathcal{G}, s, \mathcal{A} \rangle, P)$;
    PROCESSDEADENDS();
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            if $P(s)$ is defined **then**
                for $s' \in$ **GenerateSuccessors**$(s, P(s))$ **do**
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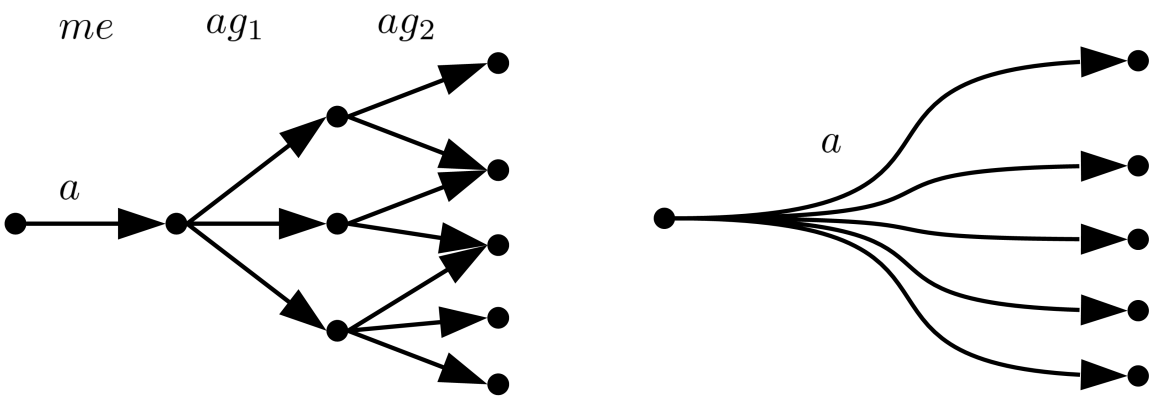
Reinterpreting Multi-agent Actions



GenerateSuccessors

Input: State s, action a
Output: Set of successor states S

$S = \{Prog(s, a, e) \mid e \in \mathrm{Eff}_a\}$;
for $i = 1 \ldots |\overrightarrow{ag}|$ **do**
    $S' = \emptyset$;
    for $s' \in S$ **do**
        for $a' \in App(s', \overrightarrow{ag}[i])$ **do**
            $S' = S' \cup \{Prog(s', a', e) \mid e \in \mathrm{Eff}_{a'}\}$;
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Key Idea If we know the goal of some agents, then we should only consider their *plausible* actions.

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Plausibility Function

Top k actions from $App(s, ag)$ according to $Score$:

$$Score(s, a, ag, \mathcal{G}) = \min_{e \in \mathrm{Eff}_a} h_{FF}(Prog(s, a, e), \mathcal{G}(ag))$$

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Generalized Plausibility We can substitute any heuristic in place of h_{FF}. Further, we can consider *any* reasonable notion of plausibility: UCT sampling, nested ToM, etc.

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for $i = 1 \ldots |\overrightarrow{ag}|$ **do**
    $S' = \emptyset$;
    for $s' \in S$ **do**
        for $a' \in \mathbf{Plausible}(s', \overrightarrow{ag}[i])$ **do**
            $S' = S' \cup \{Prog(s', a', e) \mid e \in \mathrm{Eff}_{a'}\}$;
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$$Plausible(s', \overrightarrow{ag}[i]) \subseteq App(s', \overrightarrow{ag}[i])$$

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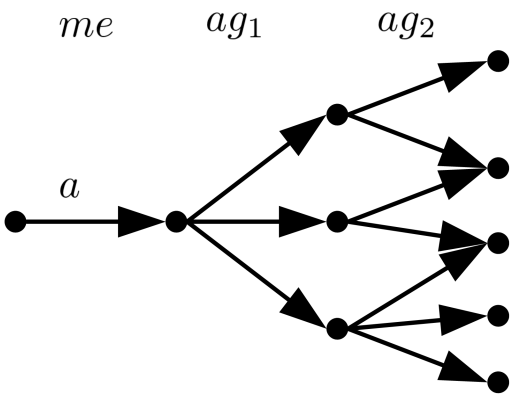

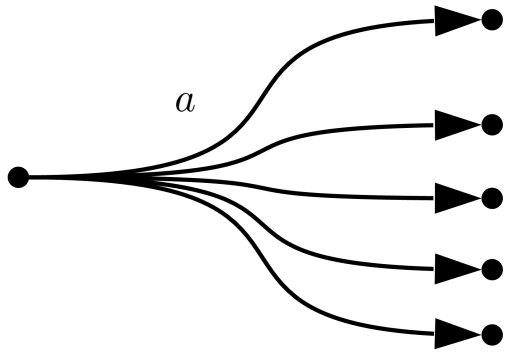

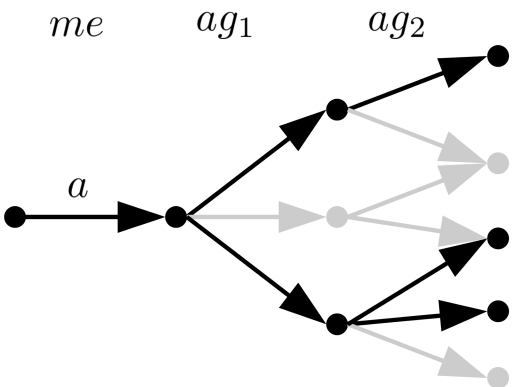

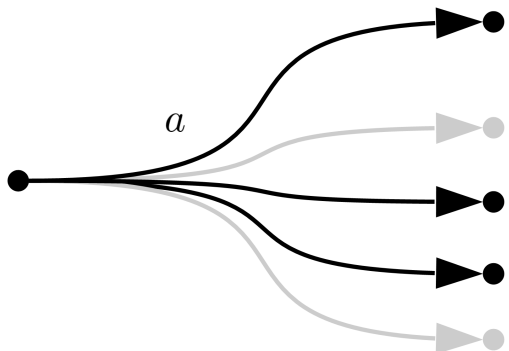

Outline

Setup

Behaviour of "Others"

- Not reasonable for agents to follow the same plausibility function (overfitting) or random moves (uninformative).
- **Compromise**: Other agents use 1000 Monte-Carlo roll-outs per action to see which is most appealing given their own goal.

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Metrics

Policy size:	The number of partial state-action pairs in the best found policy.
Success rate:	The percentage of the 1000 trials that ended in success for the planning agent.
Planning time:	The number of seconds required to compute the policy (after 30m, best policy is used).

Tic-Tac-Toe

p1 Open board, goal to draw.

p2 Same as **p1**, not using noops.

p3 Open board, goal to win.

p4 Bottom corners played, goal to win.

	N	p1	p2	p3	p4
Success rate (%)	1	0	1	45	48
	2	0	2	47	100
	3	0	4	47	100
	4	16	3	47	100
	∞	100	100	79	100
	Rnd	39	81	52	100
Policy size	1	42	47	14	7
	2	88	107	26	15
	3	121	260	19	15
	4	871	250	22	15
	∞	1358	651	69	15
	Rnd	827	606	27	12
Planning time (s)	1	5	1	0.01	0.01
	2	155	11	0.26	0.01
	3	658	40	0.50	0.01
	4	978	39	7.34	0.01
	∞	1765	114	39.32	0.01
	Rnd	30m	130	0.01	0.01

Blocksworld

	N	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10
Success rate (%)	1	38	63	31	20	0	4	0	19	12	11
	2	62	66	61	73	17	22	47	81	18	39
	3	92	97	90	96	49	62	81	90	84	76
	4	100	100	100	100	95	70	89	100	98	86
	∞	100	100	100	100	100	68	85	100	100	100
	Rnd	100	100	100	100	100	68	88	100	100	100
Policy size	1	32	27	31	111	49	25	68	63	43	30
	2	48	77	78	316	141	99	175	217	73	83
	3	125	114	157	576	298	246	445	459	126	164
	4	337	236	593	932	757	973	892	830	593	526
	∞	550	286	631	1113	1149	785	987	699	867	818
	Rnd	586	444	671	1045	1076	662	1006	763	745	818
Planning time (s)	1	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.01
	2	0.02	0.04	0.04	0.14	0.06	0.04	0.08	0.12	0.02	0.04
	3	0.06	0.06	0.06	0.32	0.24	0.16	0.56	0.36	0.04	0.10
	4	0.24	0.14	0.62	1.02	1.10	1.08	0.98	0.90	0.68	0.54
	∞	0.14	0.06	0.26	0.44	0.46	0.30	0.40	0.22	0.32	0.48
	Rnd	0.20	0.12	0.28	0.44	0.44	0.28	0.44	0.26	0.28	0.36

Sokoban

	N	p1	p2	p3	p4	p5
Success rate (%)	1	100	99	97	67	28
	2	100	98	96	98	100
	3	100	98	96	97	100
	4	100	✘	✘	99	100
	∞	100	✘	✘	✘	✘
	Rnd	100	71	48	37	✘
Policy size	1	11	27	27	138	906
	2	11	26	31	5990	7891
	3	11	26	31	10952	10223
	4	11	✘	✘	10312	9270
	∞	11	✘	✘	✘	✘
	Rnd	11	11	11	11	✘
Planning time (s)	1	0.06	0.08	0.08	0.46	195
	2	0.06	0.08	0.10	30m	30m
	3	0.06	0. 10	0.12	30m	30m
	4	0.06	✘	✘	30m	30m
	∞	0.06	✘	✘	✘	✘
	Rnd	0.08	0.06	0.08	0.08	✘

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Considerations of Efficiency

The value of doing nothing

Under what situations does it pay off to model noop actions for the other agents?

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Issues with FOND as a black box

What prevents us from casting the First-Person MAP problem using a traditional FOND encoding / planner?

Considerations of Interpretation

Winning -vs- not losing

Is it better to win most of the time with some chance of losing, or to never lose but draw often?

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(Un)Fair non-determinism

How damaging is the assumption of fairness in MAP? (e.g., unfair adversaries, livelocks, etc)

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Summary

- Addressed a complex and understudied form of multi-agent planning problems
- Employed state-of-the-art FOND planning techniques to compute compact solutions
- Introduced a mechanism for reducing the amount of non-determinism based on a model of the other agents

Future Work

- Gracefully move from very plausible to all outcomes
- Explore richer notions for a plausibility function
- Experiment on General Game Playing domains

Any Questions?

Demo, benchmarks, code, and slides available at:
`http://www.haz.ca/research/map-as-fond/`

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