Stochastic Fairness and Language-Theoretic Fairness in Planning in Nondeterministic Domains

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Nondeterministic environments capture uncertainty that an agent has at planning time about the effects of its actions. Fairness conditions restrict the possible nondeterminism. 

**Stochastic fairness:** the goal should be achieved with probability 1.

**Language-theoretic fairness:** the goal should be achieved on fair traces. E.g., **state-action fairness:** repeating an action in a state infinitely often results in all possible effects.
Purpose of the paper

Study the relationship between Stochastic Fairness and State-action Fairness

- For reachability goals, the two notions coincide (see discussion in D’Ippolito et al JAIR 2018)
- For temporally extended goals (LTL/LTLf), the two notions differ ...
- Neglecting to observe this difference has resulted in incorrect algorithms, e.g., IJCAI 13,18,19.
Goal: eventually reach left, and two steps afterwards left again.

- There is only one policy (always do action $a$)
- Under stochastic fairness, the environment essentially flips a coin (of fixed, but unknown bias)
  - so the goal is achieved with probability 1.
- Under state-action fairness, the environment infinitely often goes left and infinitely often goes right
  - so the goal is not achieved on the fair trace that alternates in the middle.
Main computational problem

How to solve planning for LTL/LTLf goals under fairness?

- There are algorithms for solving stochastic fairness.
- What about state-action fairness? this paper.
Automata-theoretic Approach

Reduce planning on \((D, \psi)\) to planning on product domain which synchronously simulates the original domain \(D\) and a deterministic automaton \(A_\psi\) for the goal formula, and new goal induced by the acceptance condition of \(A_\psi\).

How to make this work for fair planning problems?

- Works for stochastic fairness (Vardi FOCS 1985).
  - Intuitively, stochastic-fairness is preserved under products
- But state-action fairness is not preserved under products!
  - Intuitively, the reason is that there may be fair traces in \(D\) that do not induce any fair trace in the product.
- Instead, reduce it to a non-fair problem \((D, \varphi_{D,fair} \rightarrow \psi)\).
  - Explicitly express fairness as part of the goal.
  - Take care to get optimal algorithm!
  - Use Rabin acceptance condition.
Theorem

The complexity of solving planning with LTL/LTLf goals assuming state-action fairness is $2^{\text{EXPTIME}}$-complete; moreover,

- Goal complexity is $2^{\text{EXPTIME}}$-complete.
- Domain complexity is in $\text{NEXPTIME}$ (it is known to be $\text{EXPTIME}$-hard).

Lower-bounds

Inspired by Courcoubetis-Yannakakis (JACM 1995).

- Also works for no-fairness, and stochastic-fairness.
Summary

Stochastic fairness and state-action fairness differ.

- Virtually all work in nondeterministic Planning assumes stochastic fairness:
  - practical algorithms for reachability goals, FOND strong-cyclic planners (NDP, FIP, myND, Gamer, PRP, GRENADE, FOND-SAT),
  - simple algorithm for LTLf goals (cf. IJCAI 2018),
  - Principle: nondeterminism is resolved by rolling a dice.

- State-action fairness:
  - No practical algorithms yet for LTL/LTLf goals.
  - Used because it is a language-theoretic alternative to stochastic fairness for reachability goals
  - Is there a principle behind it? Or is it just an ad-hoc fairness condition?