Polynomial
All Outcomes
Determinization

Keller & Eyerich

Probabilistic
Planning

Determinization

FNF-based
Determinization

Evaluation

A Polynomial All Oucomes Determinization for Probabilistic Planning

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Outline

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Probabilistic Planning Task

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Definition: Probabilistic Planning Task

A probabilistic planning task is a 4-tuple $\langle V, s_o, S_\star, O \rangle$, with:

- V, a set of finite-domain state variables v with domain D_v,
- s_0, the initial state,
- $S_\star$, the goal formula, and
- O, a set of probabilistic operators $o = \langle \mathsf{pre}(o), \mathsf{eff}(o), c(o) \rangle$ with precondition $\mathsf{pre}(o)$, effect $\mathsf{eff}(o)$ and cost $c(o) \in \mathbb{N}$.

A state is an assignment of all state variables $v \in V$.

Effects

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Effects may consist of any combination of:

- Empty Effect ($\top$)
- Atomic Effect ($v \leftarrow \text{val}$)
- Conjunctive Effect ($e_1 \wedge e_2$)
- Conditional Effect ($c \triangleright e$)
- Probabilistic Effect ($p_1 e_1 | \ldots | p_n e_n$)

An effect without probabilistic effects is called deterministic.

Example: Canadian Traveler's Problem (CTP)
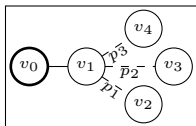
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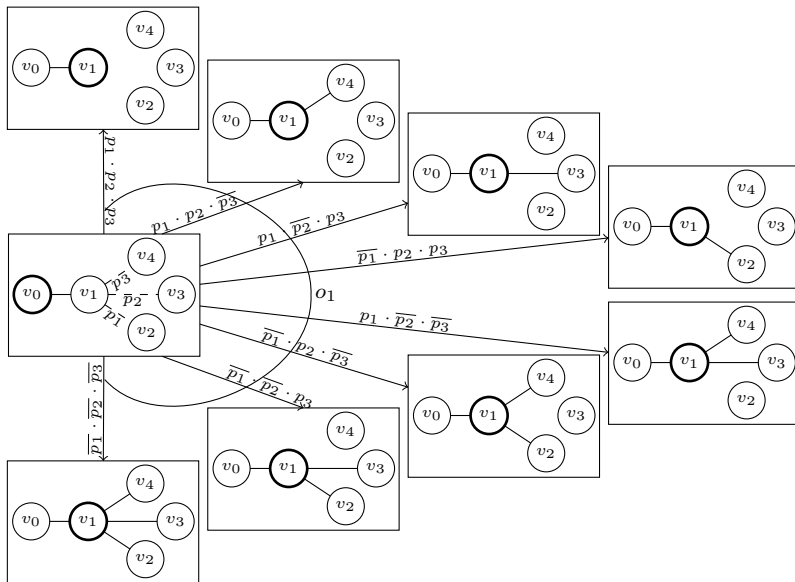
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Example: Part of the State Transition System

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Determinizations are useful in probabilistic planning:

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- To plan on the determinized task, combined with replanning if unexpected outcome occurs (e.g. FF-Replan).

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Determinizations are useful in probabilistic planning:

- To plan on the determinized task, combined with replanning if unexpected outcome occurs (e.g. FF-Replan).
- To plan on the determinized task and use the result as a heuristic for, e.g. LAO*.
- To enable the use of heuristics from classical planning for, e.g. LAO*.

Motivation: Determinization

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- To plan on the determinized task, combined with replanning if unexpected outcome occurs (e.g. FF-Replan).
- To plan on the determinized task and use the result as a heuristic for, e.g. LAO*.
- To enable the use of heuristics from classical planning for, e.g. LAO*.
- To give UCT an initial guidance, as e.g. in PROST.

Determinization Strategies

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- Single Outcome Determinization
  - One deterministic operator per probabilistic operator (e.g. the most likely outcome).
  - Task in determinization potentially unsolvable.
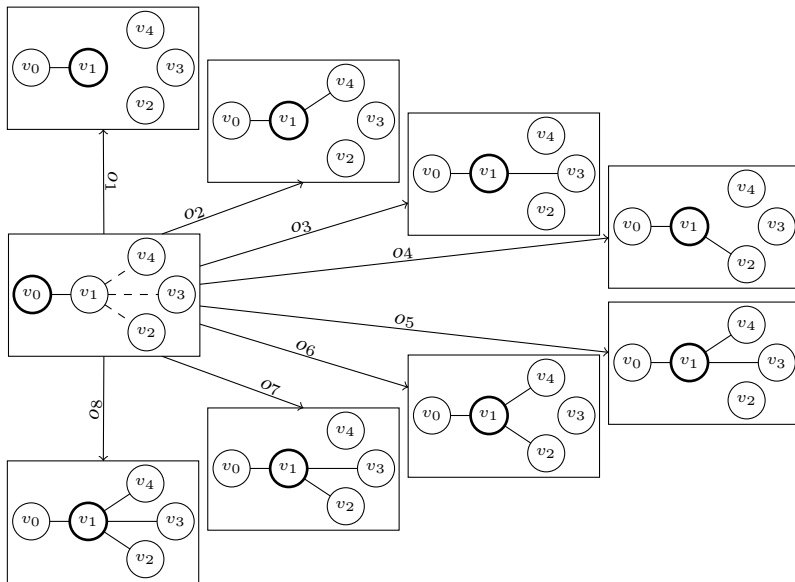
Example: Single Outcome Determinization
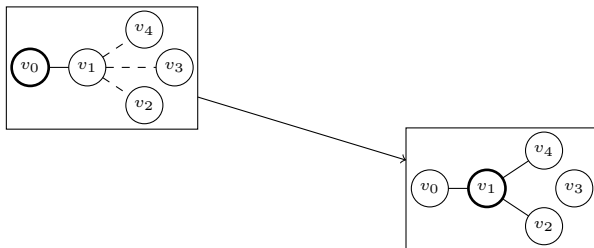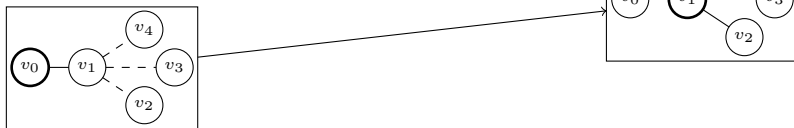
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Example: Single Outcome Determinization

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Evaluation

- Single Outcome Determinization
  - One deterministic operator per probabilistic operator (e.g. the most likely outcome).
  - Task in determinization potentially unsolvable.
- All Outcomes Determinization:
  - All potential outcomes in determinization.
  - Solution preserving.
  - Might lead to exponentially many operators.

Example: 1ND-based All Outcomes Determinization

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Polynomial Determinization

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- Conjunctions of probabilistic effects lead to exponential blowup in all outcomes determinization.
- Split operators such that parallel probabilistic effects are applied sequentially.
- Introduce a helper variable v_{aux} to control applicability of operators.

Forked Normal Form (FNF)

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Forked Normal Form

An operator $o = \langle \mathsf{pre}(o), \mathsf{eff}(o), c(o) \rangle$ is in forked normal form (FNF) if its effect $\mathsf{eff}(o)$ is deterministic or of the form

$$(p_1 e_1 | \ldots | p_i e_i | \ldots | p_n e_n) \wedge \bigwedge_j e_j$$

where all e_i, e_j are conditional effects $c \triangleright e'$ with atomic effects e'.

Theorem

Each probabilistic planning task can be normalized polynomially to an equivalent task where all operators are in FNF.

Example: FNF-based All Outcomes Determinization

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Polynomial
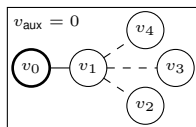All Outcomes
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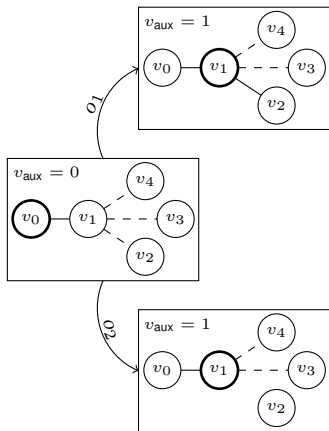
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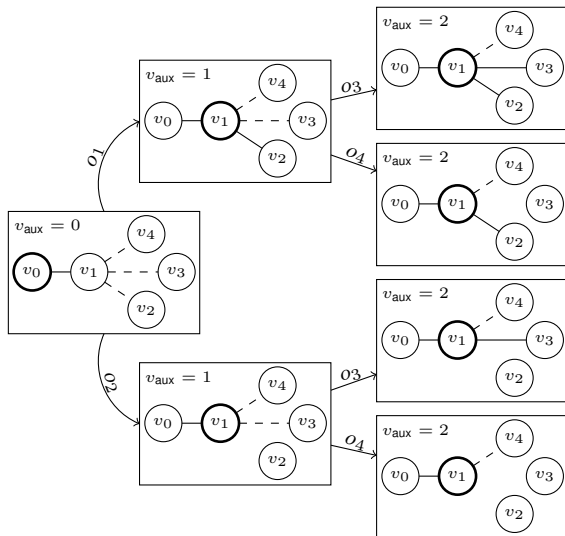Determinization

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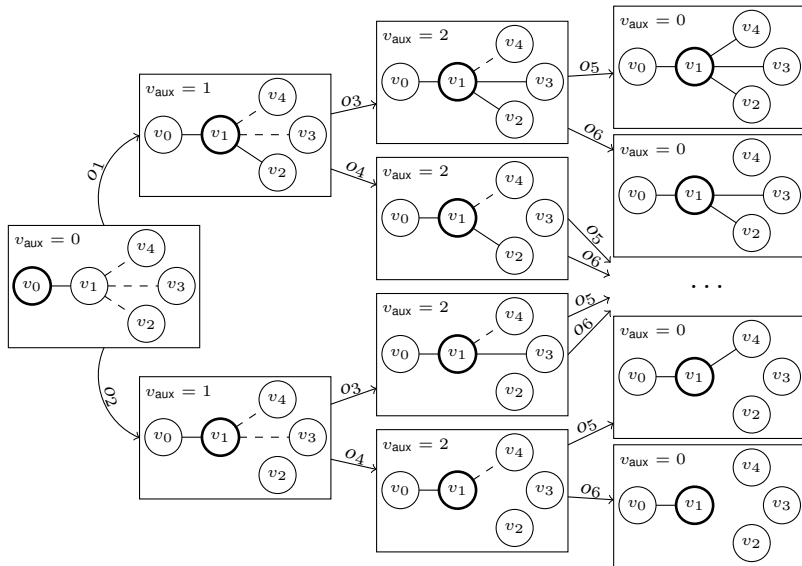Determinization

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Nodes/ Actions	Avg. # Roads	Determi- nization	Deterministic Actions	Avg. # Effects
20/98	4.9 ± 3.7	FNF	1122 ↑11.4	3.7
		1ND	6008 ↑61.3	21.9
50/278	5.56 ± 4.8	FNF	3550 ↑12.8	3.7
		1ND	29744 ↑107.0	25.3
100/568	5.68 ± 3.7	FNF	7348 ↑12.9	3.7
		1ND	55160 ↑97.0	23.7

Conclusion

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- All outcomes determinization where number of operators is polynomially bound.
- Experimental evaluation on the CTP domain shows significant improvement to previous all outcomes determinzation.
- Future Work: Runtime comparison with planners that invoke determinization.