Alternative Representations

Propositions and State-Variables

Literature

- Malik Ghallab, Dana Nau, and Paolo Traverso. *Automated Planning – Theory and Practice*, chapter 2. Elsevier/Morgan Kaufmann, 2004.

Classical Representations

- propositional representation
  - world state is set of propositions
  - action consists of precondition propositions, propositions to be added and removed
- STRIPS representation
  - like propositional representation, but first-order literals instead of propositions
- state-variable representation
  - state is tuple of state variables $\{x_1,\ldots,x_n\}$
  - action is partial function over states

Classical Planning

- task: find solution for planning problem
- planning problem
  - initial state
    - atoms (relations, objects)
  - planning domain
    - operators (name, preconditions, effects)
  - goal
- solution (plan)

Overview

- World States
- Domains and Operators
- Planning Problems
- Plans and Solutions
- Expressiveness

Knowledge Engineering

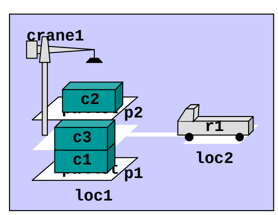
- What types of objects do we need to represent?
  - example: cranes, robots, containers, …
  - note: objects usually only defined in problem
- What relations hold between these objects?
  - example: at(*robot*, *location*), empty(*crane*), …
  - static vs. fluent relations

Representing World States

	STRIPS	propositional	state-variable
state	set of atoms		
atom	first-order atom	proposition	state-variable expression
relations	yes	no	functions
objects/types	yes/maybe	no/no	yes/maybe
static relations	yes	not necessary	no

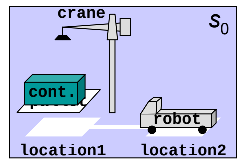
DWR Example: STRIPS States

state = {attached(p1,loc1),
attached(p2,loc1),
in(c1,p1),in(c3,p1),
top(c3,p1), on(c3,c1),
on(c1,pallet), in(c2,p2),
top(c2,p2), on(c2,pallet),
belong(crane1,loc1),
empty(crane1),
adjacent(loc1,loc2),
adjacent(loc2, loc1),
at(r1,loc2), occupied(loc2),
unloaded(r1)}



DWR Example: Propositional States

- L={onpallet,onrobot,holding,at1,at2}
- $S=\{s_0,\ldots,s_5\}$
  - s_0={onpallet,at2}
  - s_1={holding,at2}
  - s_2={onpallet,at1}
  - s_3={holding,at1}
  - s_4={onrobot,at1}
  - s_5={onrobot,at2}



State Variables

- some relations are functions
  - example: at(r1,loc1): relates robot r1 to location loc1 in some state
    - truth value changes from state to state
    - will only be true for exactly one location *l* in each state
- idea: represent such relations using <u>state-variable functions</u> mapping states into objects
  - example: functional representation: rloc:robots×S→locations

DWR Example: State-Variable State Descriptions

- simplified: no cranes, no piles
- state-variable functions:
  - rloc: robots×*S* → locations
  - rolad: robots×*S*→containers ∪ {nil}
  - cpos: containers×*S* → locations ∪ robots
- sample state-variable state descriptions:
  - {rloc(r1)=loc1, rload(r1)=nil, cpos(c1)=loc1, cpos(c2)=loc2, cpos(c3)=loc2}
  - {rloc(r1)=loc1, rload(r1)=c1, cpos(c1)=r1, cpos(c2)=loc2, cpos(c3)=loc2}

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Knowledge Engineering

- What types of actions are there?
  - example: move robots, load containers, …
- For each action type, and each relation, what must (not) hold for the action to be applicable?
  - preconditions
- For each action type, and each relation, what relations will (no longer) hold due to the action?
  - effects (must be consistent)
- For each action type, what objects are involved in performing the action?
  - any object mentioned in the preconditions and effects
  - preconditions should mention all objects

Representing Operators

	STRIPS	propositional	state-variable
name	$n(x_1,\ldots,x_k)$	*name*	$n(x_1,\ldots,x_k)$
preconditions (set of)	first-order literals	propositions	state-variable expressions
applicability	$\text{precond}^+(a) \subseteq s \wedge \text{precond}^-(a) \cap s = \{\}$	$\text{precond}(a) \subseteq s$	$\text{precond}(a) \subseteq s$
effects (set of)	first-order literals	propositional literals	$x_s \leftarrow v$
$\gamma(s,a)$	$(s - \text{effects}^-(a)) \cup \text{effects}^+(a)$	$(s - \text{effects}^-(a)) \cup \text{effects}^+(a)$	$\{x_s = c \mid x \in X\}$ where $x_s \leftarrow c \in \text{effects}(a)$ or $x_s = c \in s$ otherwise

DWR Example: STRIPS Operators

- move(*r*,*l*,*m*)
  - precond: adjacent(*l*,*m*), at(*r*,*l*), ¬occupied(*m*)
  - effects: at(*r*,*m*), occupied(*m*), ¬occupied(*l*), ¬at(*r*,*l*)
- load(*k*,*l*,*c*,*r*)
  - precond: belong(*k*,*l*), holding(*k*,*c*), at(*r*,*l*), unloaded(*r*)
  - effects: empty(*k*), ¬holding(*k*,*c*), loaded(*r*,*c*), ¬unloaded(*r*)
- put(*k*,*l*,*c*,*d*,*p*)
  - precond: belong(*k*,*l*), attached(*p*,*l*), holding(*k*,*c*), top(*d*,*p*)
  - effects: ¬holding(*k*,*c*), empty(*k*), in(*c*,*p*), top(*c*,*p*), on(*c*,*d*), ¬top(*d*,*p*)

DWR Example: Propositional Actions

a	precond(*a*)	effects$^-$(*a*)	effects$^+$(*a*)
take	{onpallet}	{onpallet}	{holding}
put	{holding}	{holding}	{onpallet}
load	{holding,at1}	{holding}	{onrobot}
unload	{onrobot,at1}	{onrobot}	{holding}
move1	{at2}	{at2}	{at1}
move2	{at1}	{at1}	{at2}

DWR Example: State-Variable Operators

- move(r,l,m)
  - precond: rloc(r)=l, adjacent(l,m)
  - effects: rloc(r)$\leftarrow m$
- load(r,c,l)
  - precond: rloc(r)=l, cpos(c)=l, rload(r)=nil
  - effects: cpos(c)$\leftarrow r$, rload(r)$\leftarrow c$
- unload(r,c,l)
  - precond: rloc(r)=l, rload(r)=c
  - effects: rload(r)$\leftarrow$nil, cpos(c)$\leftarrow l$

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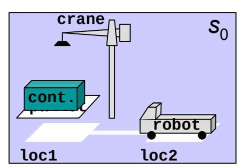
Representing Planning Problems

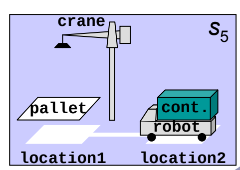
	STRIPS	propositional	state-variable
initial state	world state in respective representation		
domain	domain (set of operators) in respective representation		
goal	same as preconditions in respective representation		

DWR Example: STRIPS Planning Problem

- Σ: STRIPS planning domain for DWR domain
- s_i: any state
  - example: s_0 = {attached(pile,loc1), in(cont,pile), top(cont,pile), on(cont,pallet), belong(crane,loc1), empty(crane), adjacent(loc1,loc2), adjacent(loc2,loc1), at(robot,loc2), occupied(loc2), unloaded(robot)}



- g: any subset of L
  - example: g = {¬unloaded(robot), at(robot,loc2)}, i.e. S_g={s_5}



DWR Example: Propositional Planning Problem

- Σ: propositional planning domain for DWR domain
- s_i: any state
  - example: initial state = $s_0 \in S$
- g: any subset of L
  - example: g={onrobot,at2}, i.e. $S_g=\{s_5\}$

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Classical Plans and Solutions (all Representations)

- A plan is any sequence of actions $\pi=\langle a_1,\ldots,a_k\rangle$, where $k\geq 0$.
  - The extended state transition function for plans is defined as follows:
    - $\gamma(s,\pi)=s$ if $k=0$ (π is empty)
    - $\gamma(s,\pi)=\gamma(\gamma(s,a_1),\langle a_2,\ldots,a_k\rangle)$ if $k>0$ and a_1 applicable in s
    - $\gamma(s,\pi)=$undefined otherwise
- Let $\mathcal{P}=(\Sigma,s_i,g)$ be a planning problem. A plan π is a solution for $\mathcal{P}$ if $\gamma(s_i,\pi)$ satisfies g.

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Grounding a STRIPS Planning Problem

- Let $P=(O,s_i,g)$ be the statement of a STRIPS planning problem and C the set of all the constant symbols that are mentioned in s_i. Let ground(O) be the set of all possible instantiations of operators in O with constant symbols from C consistently replacing variables in preconditions and effects.
- Then P'=(ground(O),s_i,g) is a statement of a STRIPS planning problem and P' has the same solutions as P.

Translation: Propositional Representation to Ground STRIPS

- Let $P=(A,s_i,g)$ be a statement of a propositional planning problem. In the actions A:
  - replace every action (precond(a), effects$^-$(a), effects$^+$(a)) with an operator o with
    - some unique name(o),
    - precond(o) = precond(a), and
    - effects(o) = effects$^+$(a) ∪ $\{\neg p \mid p \in$ effects$^-(a)\}$.

Translation: Ground STRIPS to Propositional Representation

- Let $P=(O,s_i,g)$ be a ground statement of a classical planning problem.
  - In the operators O, in the initial state s_i, and in the goal g replace every atom $P(v_1,\ldots,v_n)$ with a propositional atom $Pv_1,\ldots,v_n$.
  - In every operator o:
    - for all $\neg p$ in precond(o), replace $\neg p$ with p',
    - if p in effects(o), add $\neg p'$ to effects(o),
    - if $\neg p$ in effects(o), add p' to effects(o).
  - In the goal replace $\neg p$ with p'.
  - For every operator o create an action (precond(o), effects$^-$(a), effects$^+$(a)).

Translation: STRIPS to State-Variable Representation

- Let $P=(O,s_i,g)$ be a statement of a classical planning problem. In the operators O, in the initial state s_i, and in the goal g:
  - replace every positive literal $p(t_1,\ldots,t_n)$ with a state-variable expression $p(t_1,\ldots,t_n)=1$ or $p(t_1,\ldots,t_n)\leftarrow 1$ in the operators' effects, and
  - replace every negative literal $\neg p(t_1,\ldots,t_n)$ with a state-variable expression $p(t_1,\ldots,t_n)=0$ or $p(t_1,\ldots,t_n)\leftarrow 0$ in the operators' effects.

Translation: State-Variable to STRIPS Representation

- Let $P=(O,s_i,g)$ be a statement of a state-variable planning problem. In the operators' preconditions, in the initial state s_i, and in the goal g:
  - replace every state-variable expression $p(t_1,\ldots,t_n)=v$ with an atom $p(t_1,\ldots,t_n,v)$, and
- in the operators' effects:
  - replace every state-variable assignment $p(t_1,\ldots,t_n)\leftarrow v$ with a pair of literals $p(t_1,\ldots,t_n,v)$, $\neg p(t_1,\ldots,t_n,w)$, and add $p(t_1,\ldots,t_n,w)$ to the respective operators preconditions.

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