Schematic operators
Schematic operators

- Description of state variables and operators in terms of a given finite set of objects.
- Analogy: propositional logic vs. predicate logic
- Planners take input as schematic operators and translate them into (ground) operators. This is called grounding.
Schematic operators: example

Schematic operator \texttt{drive\_car\_from\_to}(x,y_1,y_2):

\begin{align*}
x & \in \{\text{car1, car2}\}, \\
y_1 & \in \{\text{Freiburg, Strasbourg}\}, \\
y_2 & \in \{\text{Freiburg, Strasbourg}\} \\
\langle in(x, y_1), in(x, y_2) \land \neg in(x, y_1) \rangle
\end{align*}

corresponds to the operators

\begin{align*}
\langle in(\text{car1, Freiburg}), in(\text{car1, Strasbourg}) \land \neg in(\text{car1, Freiburg}) \rangle, \\
\langle in(\text{car1, Strasbourg}), in(\text{car1, Freiburg}) \land \neg in(\text{car1, Strasbourg}) \rangle, \\
\langle in(\text{car2, Freiburg}), in(\text{car2, Strasbourg}) \land \neg in(\text{car2, Freiburg}) \rangle, \\
\langle in(\text{car2, Strasbourg}), in(\text{car2, Freiburg}) \land \neg in(\text{car2, Strasbourg}) \rangle, \\
\end{align*}

plus four operators that are never applicable (inconsistent change set!) and can be ignored, like

\begin{align*}
\langle in(\text{car1, Freiburg}), in(\text{car1, Freiburg}) \land \neg in(\text{car1, Freiburg}) \rangle.
\end{align*}
Schematic operators: quantification

Existential quantification (for formulae only)
Finite disjunctions $\varphi(a_1) \lor \cdots \lor \varphi(a_n)$ represented as
$\exists x \in \{a_1, \ldots, a_n\} : \varphi(x)$.

Universal quantification (for formulae and effects)
Finite conjunctions $\varphi(a_1) \land \cdots \land \varphi(a_n)$ represented as
$\forall x \in \{a_1, \ldots, a_n\} : \varphi(x)$.

Example
$\exists x \in \{A, B, C\} : \text{in}(x, \text{Freiburg})$ is a short-hand for
$\text{in}(A, \text{Freiburg}) \lor \text{in}(B, \text{Freiburg}) \lor \text{in}(C, \text{Freiburg})$. 
PDDL
used by almost all implemented systems for deterministic planning

supports a language comparable to what we have defined above (including schematic operators and quantification)

syntax inspired by the Lisp programming language: e.g. prefix notation for formulae

\[(\text{and} \ (\text{or} \ (\text{on} \ A \ B) \ (\text{on} \ A \ C)) \ (\text{or} \ (\text{on} \ B \ A) \ (\text{on} \ B \ C)) \ (\text{or} \ (\text{on} \ C \ A) \ (\text{on} \ A \ B)))\]
PDDL: domain files

A domain file consists of

- (define (domain DOMAINNAME)
- a :requirements definition (use :strips :typing by default)
- definitions of types (each parameter has a type)
- definitions of predicates
- definitions of operators
Example: blocks world (with hand) in PDDL

Note: Unlike in the previous chapter, here we use a variant of the blocks world domain with an explicitly modeled gripper/hand.

(define (domain BLOCKS)
  (:requirements :strips :typing)
  (:types block)
  (:predicates (on ?x - block ?y - block)
               (ontable ?x - block)
               (clear ?x - block)
               (handempty)
               (holding ?x - block)
  )
PDDL: operator definition

- (:action OPERATORNAME
- list of parameters: (?x - type1 ?y - type2 ?z - type3)
- precondition: a formula

  <schematic-state-var>
  (and <formula> ... <formula>)
  (or <formula> ... <formula>)
  (not <formula>)
  (forall (?x1 - type1 ... ?xn - typen) <formula>)
  (exists (?x1 - type1 ... ?xn - typen) <formula>)
**effect:**

<schematic-state-var>
(not <schematic-state-var>)
(and <effect> ... <effect>)
(when <formula> <effect>)
(forall (?x1 - type1 ... ?xn - typen) <effect>)
(:action stack
  :parameters (?x - block ?y - block)
  :precondition (and (holding ?x) (clear ?y))
  :effect (and (not (holding ?x))
    (not (clear ?y))
    (clear ?x)
    (handempty)
    (on ?x ?y)))
A problem file consists of

- `(define (problem PROBLEMNAME))`  
  declaration of which domain is needed for this problem
- definitions of objects belonging to each type
- definition of the initial state (list of state variables initially true)
- definition of goal states (a formula like operator precondition)
(define (problem example)
  (:domain BLOCKS)
  (:objects a b c d - block)
  (:init (clear a) (clear b) (clear c) (clear d)
          (ontable a) (ontable b) (ontable c)
         (ontable d) (handempty))
  (:goal (and (on d c) (on c b) (on b a)))
)
Fast Downward is the state-of-the-art planner, usable both for research and applications.

Main developers:
- Malte Helmert
- Gabi Röger
- Erez Karpas
- Jendrik Seipp
- Silvan Sievers
- Florian Pommerening
Fast Downward is available at http://www.fast-downward.org/

**Installation:**
Follow instructions at http://www.fast-downward.org/
ObtainingAndRunningFastDownward

**Running:**
Follow instructions at http://www.fast-downward.org/PlannerUsage
Example run of Fast Downward

```bash
# ./fast-downward.py --plan-file plan.txt \
domain.pddl problem.pddl --search "astar(blind())"

[...] INFO Running search.
[...] Solution found!
[...] Plan length: 6 step(s).
[...] Expanded 85 state(s).
[...] Search time: 0s
[...]```
Example plan found by Fast Downward

```plaintext
# cat plan.txt
(pick-up b)
(stack b a)
(pick-up c)
(stack c b)
(pick-up d)
(stack d c)
; cost = 6 (unit cost)
```
In case you are looking for a decent PDDL editor:

- Check out the PDDL editor in the cloud:
  http://editor.planning.domains/

- The website also includes a built-in solver:
  http://solver.planning.domains/

- ...and an API + domain repository:
  http://api.planning.domains/
Example: blocks world in PDDL

(define (domain BLOCKS)
  (:requirements :strips :typing)
  (:types block)
  (:predicates (on ?x - block ?y - block)
    (ontable ?x - block)
    (clear ?x - block)
    (handempty)
    (holding ?x - block)
  )
(:action pick-up
  :parameters (?x - block)
  :precondition (and (clear ?x) (ontable ?x) (handempty))
  :effect (and (not (ontable ?x))
              (not (clear ?x))
              (not (handempty))
              (holding ?x)))
(:action put-down
  :parameters (?x - block)
  :precondition (holding ?x)
  :effect (and (not (holding ?x))
            (clear ?x)
            (handempty)
            (ontable ?x)))
(:action stack
  :parameters (?x - block ?y - block)
  :precondition (and (holding ?x) (clear ?y))
  :effect (and (not (holding ?x))
             (not (clear ?y))
             (clear ?x)
             (handempty)
             (on ?x ?y)))
(:action unstack
  :parameters (?x - block ?y - block)
  :precondition (and (on ?x ?y) (clear ?x)
                  (handempty))
  :effect (and (holding ?x)
              (clear ?y)
              (not (clear ?x))
              (not (handempty))
              (not (on ?x ?y))))
)
(define (problem example)
   (:domain BLOCKS)
   (:objects a b c d - block)
   (:init (clear a) (clear b) (clear c) (clear d)
          (ontable a) (ontable b) (ontable c)
          (ontable d) (handempty))
   (:goal (and (on d c) (on c b) (on b a)))
)