Planning for AI (B4M36PUI)

Modelling Languages, Knowledge Engineering Tools, Domain Reformulation

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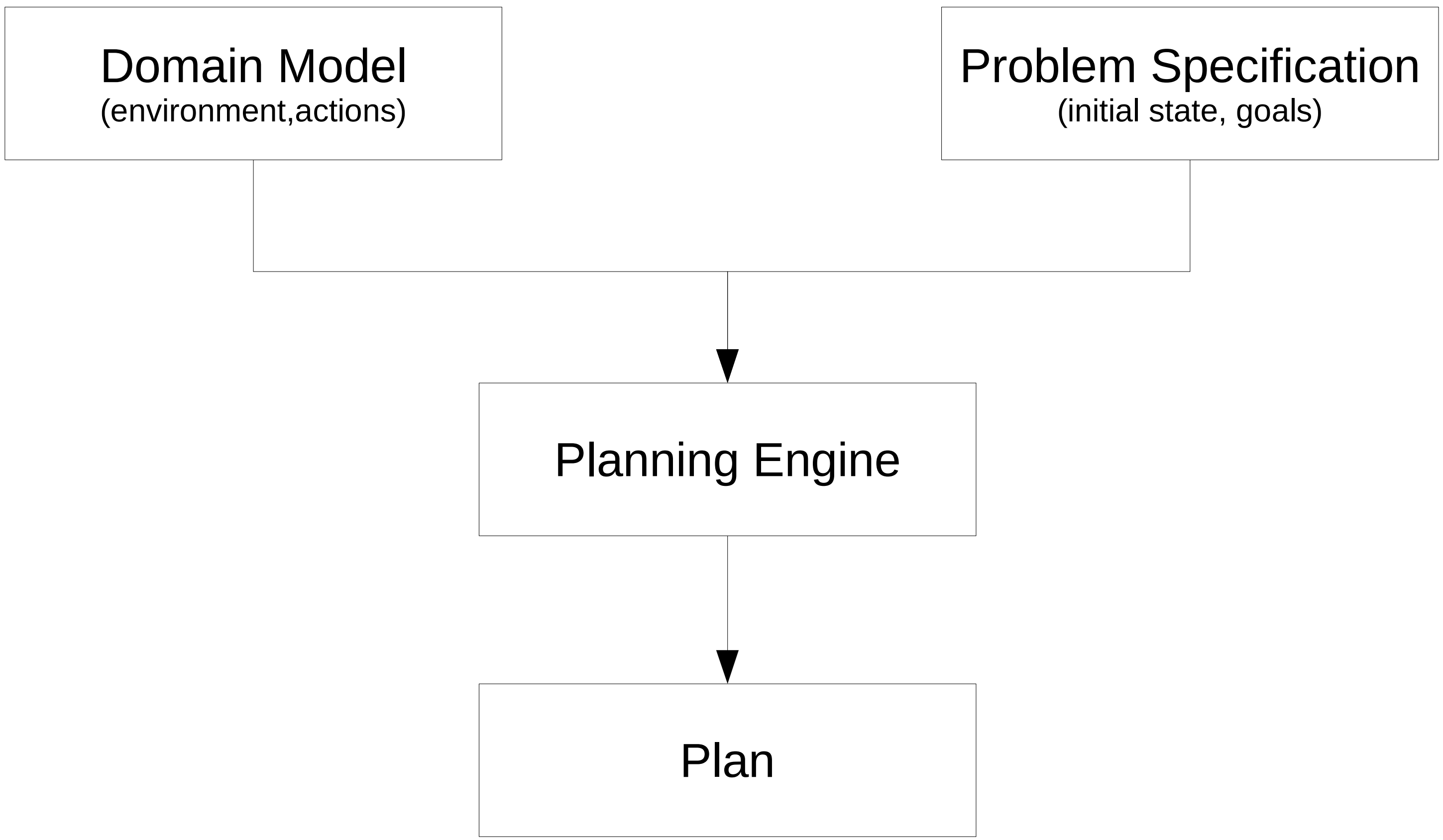
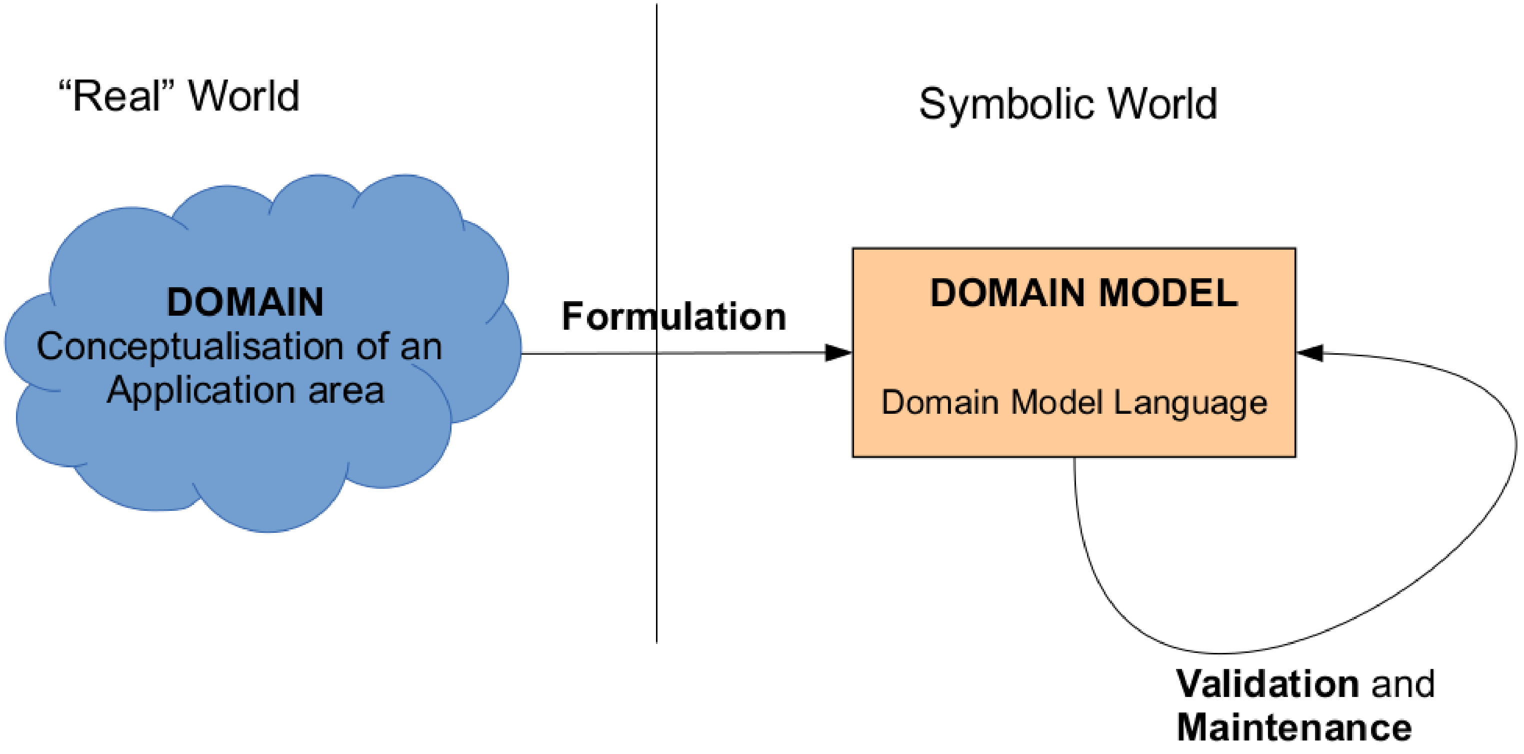
Domain-independent Planning Concept



Domain-independent Planning Concept

- A (description) **language**
  - Describe domain model and problem specification
    (usually one domain model for a class of problems)
- A **planning engine**
  - must support the language
  - should be efficient for the given domain model
- **Plans** interpreting

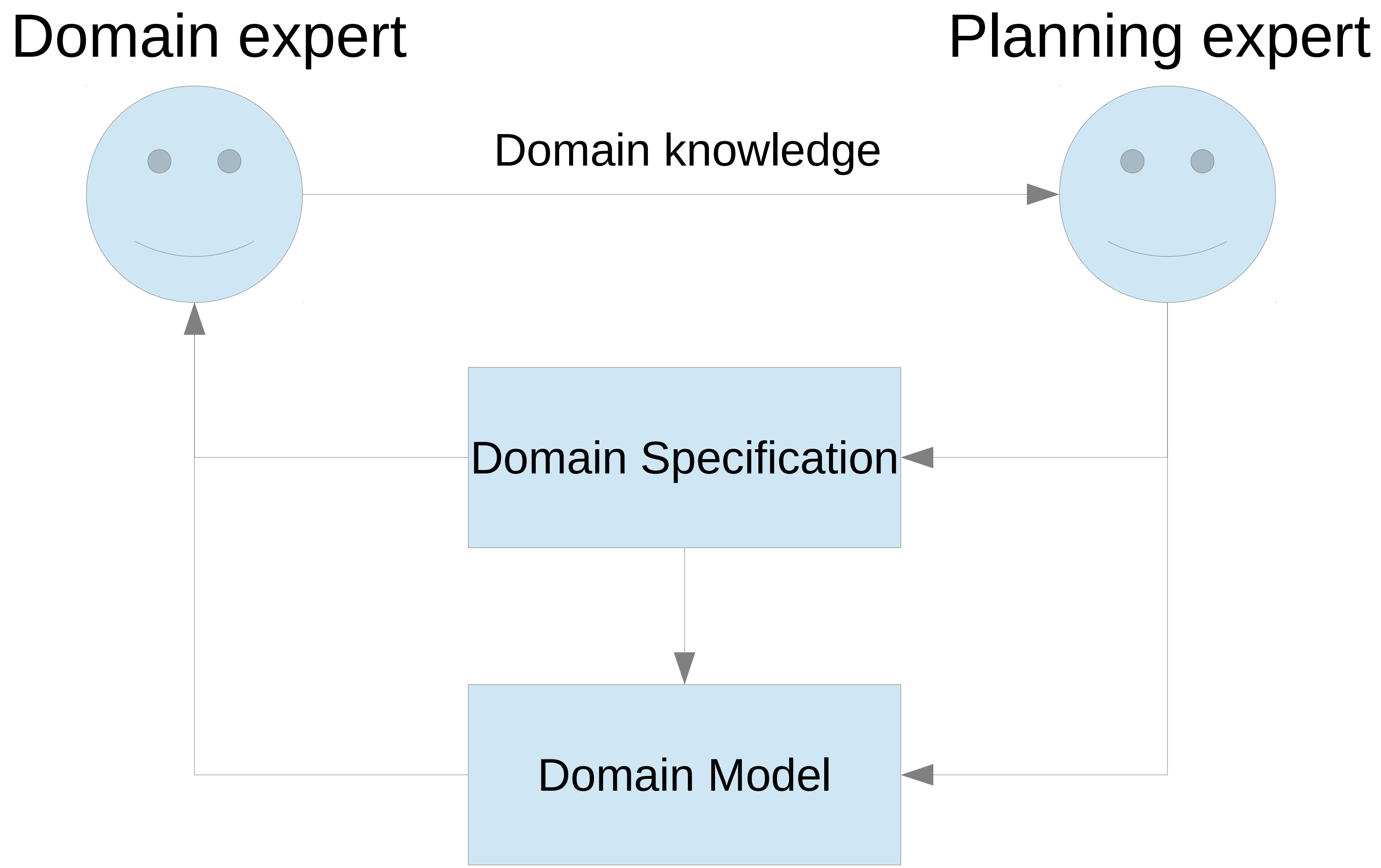
Knowledge Engineering in Planning



Properties of a Domain Model

- **Accuracy –** There is a mapping between domain requirements and a domain model
- **Consistency –** All assertions (invariants) are true
- **Completeness –** Solution plans correspond to real-world solutions
- **Adequacy –** A domain model is expressive enough to capture domain requirements
- **Operationality –** Planning engines can find solution plans in reasonable time/memory constraints

Knowledge Engineering Process



An iterative process – can take a long time !

Modelling Languages

PDDL [McDermott et al, 1998]

- Planning Domain Definition Language (PDDL)
- Inspired by the STRIPS and ADL languages
- Most widespread
- Official language of International Planning Competitions (IPCs)

```
(define (domain blocksworld)
  (: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))
)
…
```

Versions of PDDL

- **PDDL 1.2**
  - Predicate centric (i.e., classical representation)
  - Object types
  - ADL features (e.g., conditional effects, equality)
- **PDDL 2.1**
  - Numeric Fluents
  - Durative Actions
- **PDDL 2.2**
  - Timed-initial literals
  - Derived Predicates
- **PDDL 3.0**
  - State-trajectory constraints (hard constraints for the planning process)
  - Preferences (soft constraints for the planning process)
- **PDDL 3.1**
  - Object Fluents

Extensions of PDDL

- **PDDL+**
  - Continuous processes
  - Exogenous events
- **PPDDL**
  - Probabilistic action effects
  - Reward fluents
- **MA-PDDL**
  - Multi-agent planning

NDDL [Frank & Jonsson, 2002]

- NASA's response to PDDL
- Variable representation
- Timelines/activities
- Constraints between activities

```
class Instrument
{
    Rover rover;
    InstrumentLocation location;
    InstrumentState state;

    Instrument(Rover r)
    {
             rover = r;
             location = new InstrumentLocation();
                  state = new InstrumentState();
    }

     action TakeSample{
                  Location rock;
             eq(10, duration);
     }
     …
}

Instrument::TakeSample
{
      met_by(condition object.state.Placed on);
      eq(on.rock, rock);

    contained_by(condition object.location.Unstowed);

      equals(effect object.state.Sampling sample);
      eq(sample.rock, rock);

      starts(effect object.rover.mainBattery.consume tx);
      eq(tx.quantity, 120); // consume battery power
}
```

https://github.com/nasa/europa/wiki/Example-Rover

ANML [Smith et al., 2008]

- Combines aspects from NDDL and PDDL
  - Actions and states (PDDL)
  - Variable representation (NDDL)
  - Temporal Constraints (NDDL)
- Hierarchical methods

```
action Pickup (crew ev, object item)
{
duration := 5 ;
[start] located(ev) == located(item);
[all] possesses(ev,item) == FALSE:
->TRUE ;
[end] located(item) := POSSESSED ;
}

action Putaway (crew ev, object item,
location stowage)
{
Duration := 10 ;
[start] located(ev) == stowage ;
[all] possesses(ev, item) ==  TRUE:
->FALSE ;
[end] located(item):= stowage ;
}
```

[Boddy & Bonasso, 2010]

RDDL [Sanner, 2011]

- became the official language of the probabilistic track of the IPC since 2011
- models partial observability
- efficient description of (PO)MDPs

```
domain wildfire_mdp {

types {
x_pos : object;
y_pos : object;
};

pvariables {

// Action costs and penalties
COST_CUTOUT        : {non-fluent, real, default =   -5 }; // Cost
to cut-out fuel from a cell
COST_PUTOUT        : {non-fluent, real, default =  -10 }; // Cost
to put-out a fire from a cell
PENALTY_TARGET_BURN : {non-fluent, real, default = -100 }; //
Penalty for each target cell that is burning
PENALTY_NONTARGET_BURN : {non-fluent, real, default =   -5 }; //
Penalty for each non-target cell that is burning
…..
}

cpfs{
burning'(?x, ?y) =  if ( put-out(?x, ?y) ) // Intervention to
put out fire?
                     then false
         // Modification: targets can only start to burn if at
least one neighbor is on fire
            else if (~out-of-fuel(?x, ?y) ^ ~burning(?x, ?y)) //
Ignition of a new fire? Depends on neighbors.
              then [if (TARGET(?x, ?y) ^ ~exists_{?x2: x_pos, ?
y2: y_pos} (NEIGHBOR(?x, ?y, ?x2, ?y2) ^ burning(?x2, ?y2)))
                    then false
                    else Bernoulli( 1.0 / (1.0 + exp[4.5 -
(sum_{?x2: x_pos, ?y2: y_pos} (NEIGHBOR(?x, ?y, ?x2, ?y2) ^
burning(?x2, ?y2))]) ) ]
              else
              burning(?x, ?y); // State persists
…
}
```

https://cs.uwaterloo.ca/~mgrzes/IPPC_2014/

Domain-independent Planners

- Dozens of classical planners
  - support typed STRIPS
  - newer planners support action costs, and some ADL features
  - many of them are optimal
- Several temporal planners
  - support durative actions
  - few support numeric fluents or timed-initial literals
  - few fully support concurrency
  - very few are optimal
- Several probabilistic planners
  - (PO)MDP
  - FOND
- A few continuous planners
- ....

Language Expressiveness vs. Planning Engines

- “*It is almost a law in PDDL planning that for every language feature one adds to a domain definition, the number of planners that can solve (or even parse) it, and the efficiency of those planners, falls exponentially*” [anonymous reviewer]

- Motivate **development of more expressive** planning engines
- **Reduce** the number of **features** in models

KE Tools for Planning Domain Modelling

Purpose of KE tools

- Assist in domain developing process
  - Support development cycle (as in SW engineering)
  - Visualize (parts of) the model
  - Verification and Validation support (e.g. consistency check)
  - …
- Usable by non-experts (but with basic knowledge of planning)

GIPO [Simpson et al., 2007]

- GIPO (Graphical Interface for Planning with Objects) won the ICKEPS 2005 competition
- Based on the **OCL** (Object-Centred Language)
- Define **life histories** of **objects**
- Supports **“classical” PDDL** (limitedly also ”durative” actions)
- Supports **HTN** (HyHTN planner is integrated) [McCluskey et al., 2003]

ItSimple [Vaquero et al., 2007;2012]

- Supports development cycle
- Exploits **UML** for domain modelling
- Exploits **Petri Nets** for dynamic analysis of **state machines** (e.g. reachability analysis)
- Supports **PDDL 3.1**

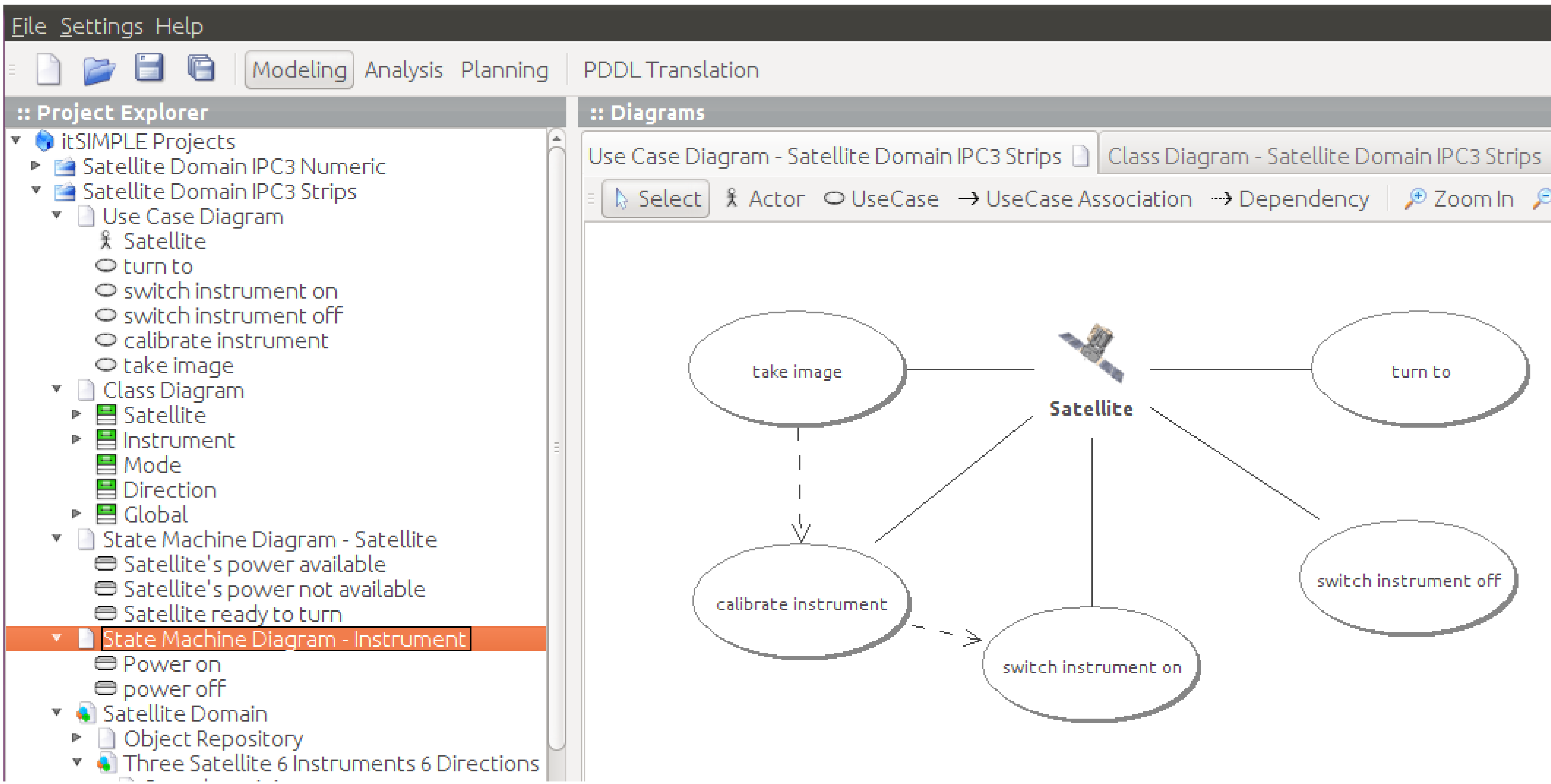
https://code.google.com/archive/p/itsimple/

- Project webpage

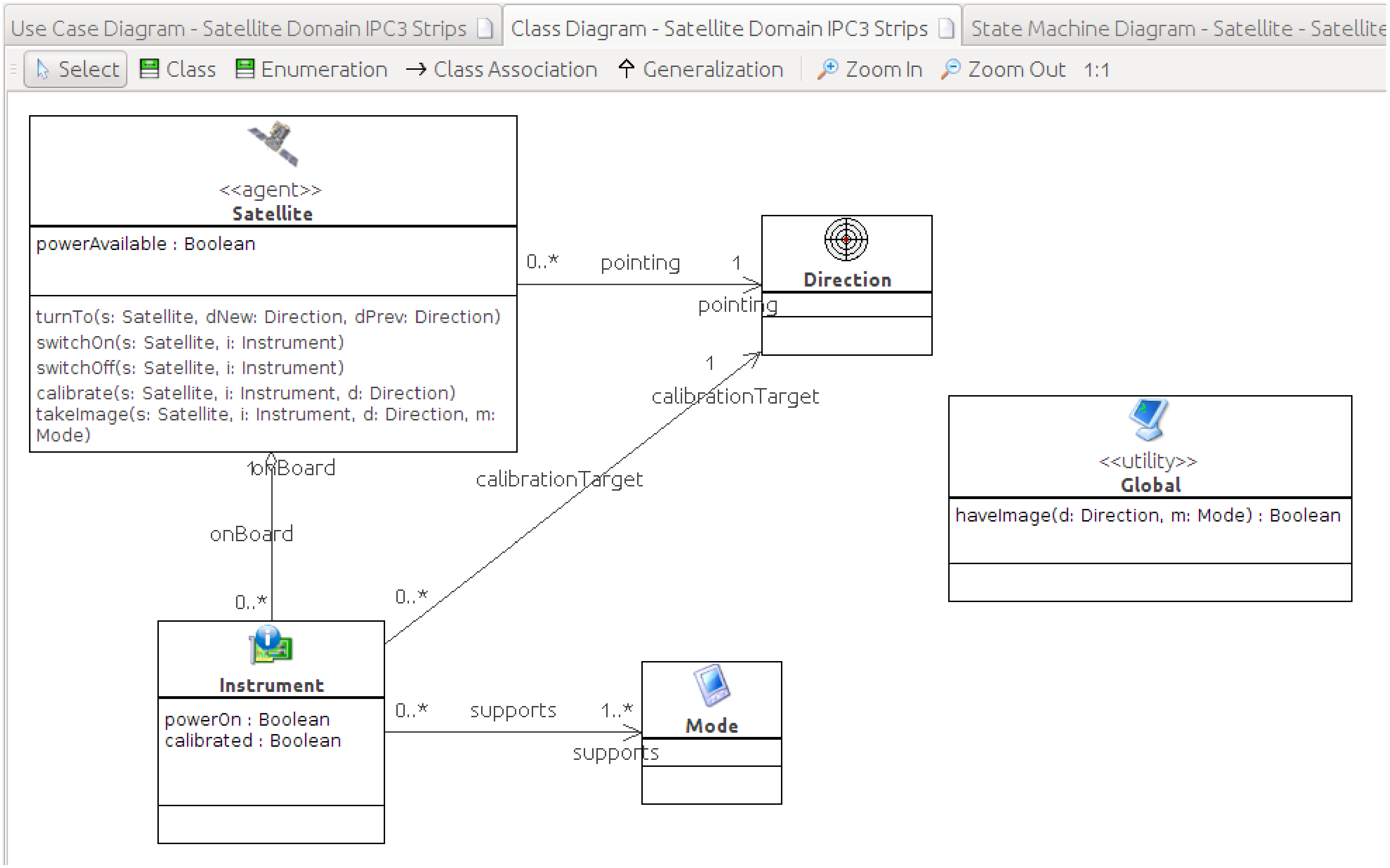
http://www.youtube.com/watch?feature=player_embedded&v=FGBhvBnzyvo

- Tutorial on domain modelling it ItSimple by Chris Muise

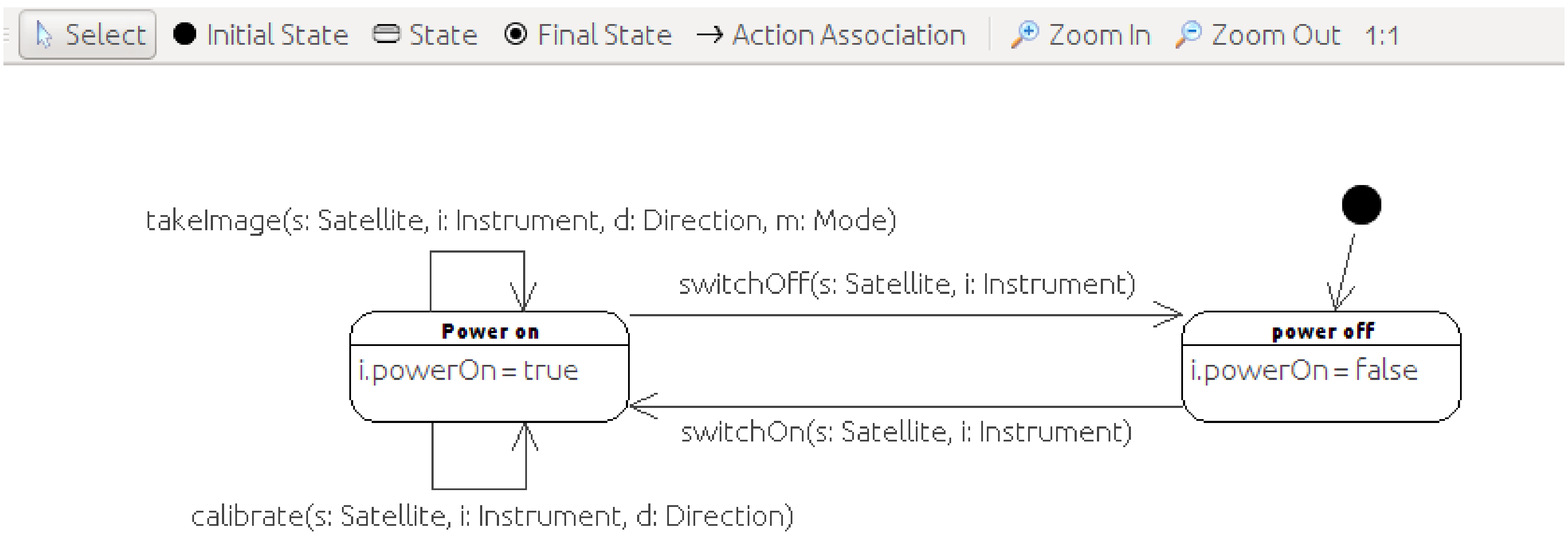
ItSimple – Sample Use Case



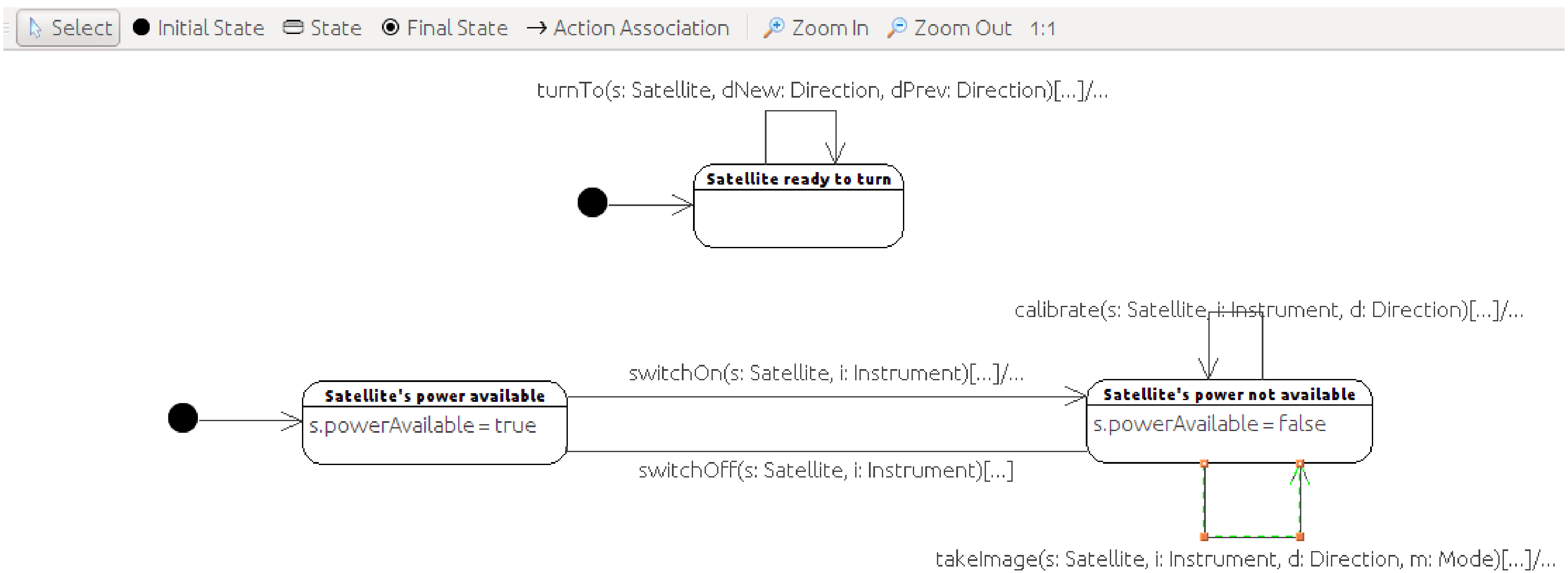
ItSimple – Sample Class Diagram



ItSimple – Sample State Machine (Satellite)



ItSimple – Sample State Machine (Instrument)



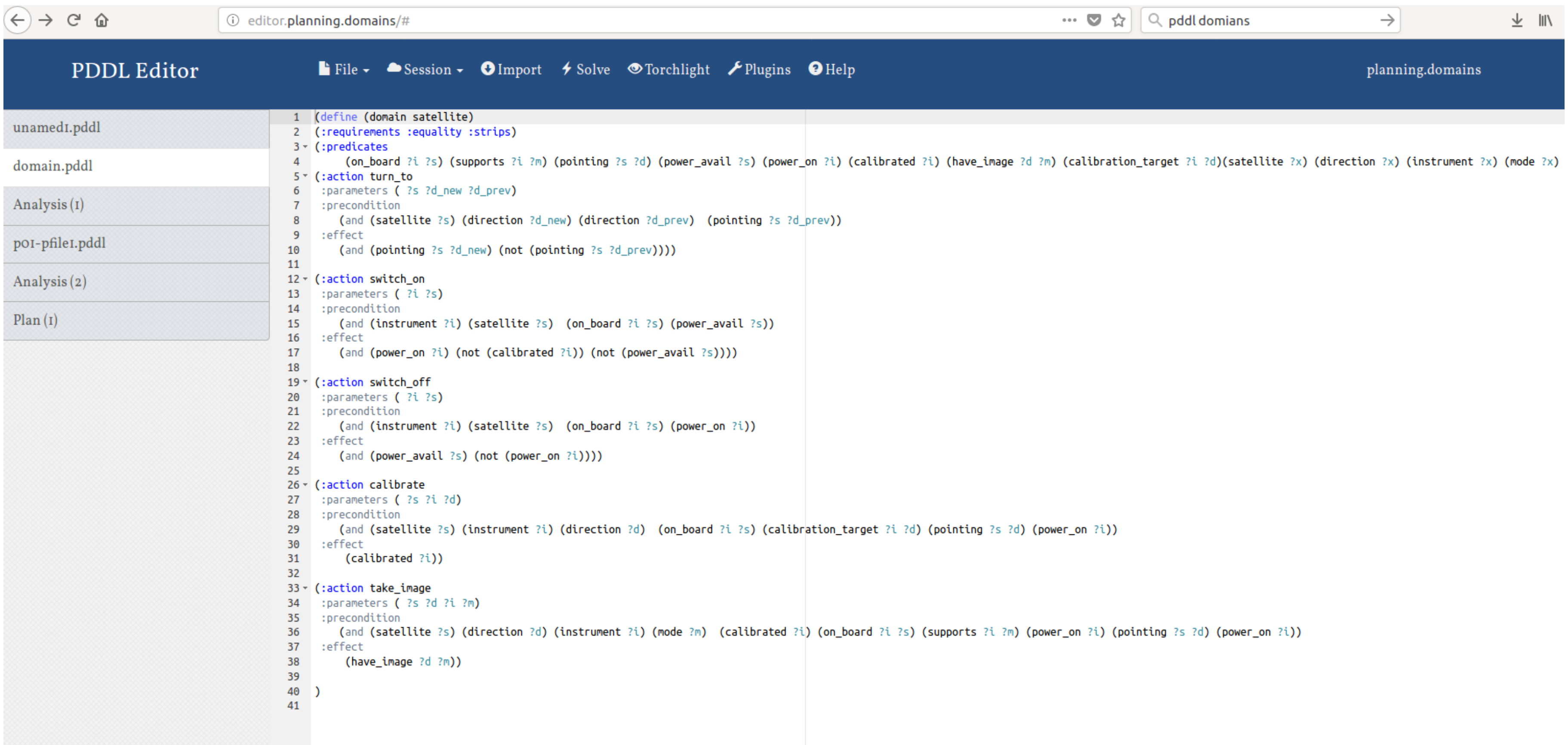
Some other KE Frameworks

- EUROPA [Barreiro et al., 2012]
  - Framework supporting NDDL and ANML
- JABBAH [Gonzalez-Ferrer et al., 2009]
  - Supports HTN
- KEWI [Wickler et al., 2014]
  - Object Centred (including inheritance)
  - Web Application (supports collaboration)
- VIZ [Vodrazka & Chrpa, 2010]
  - A “light-weight” KE tool

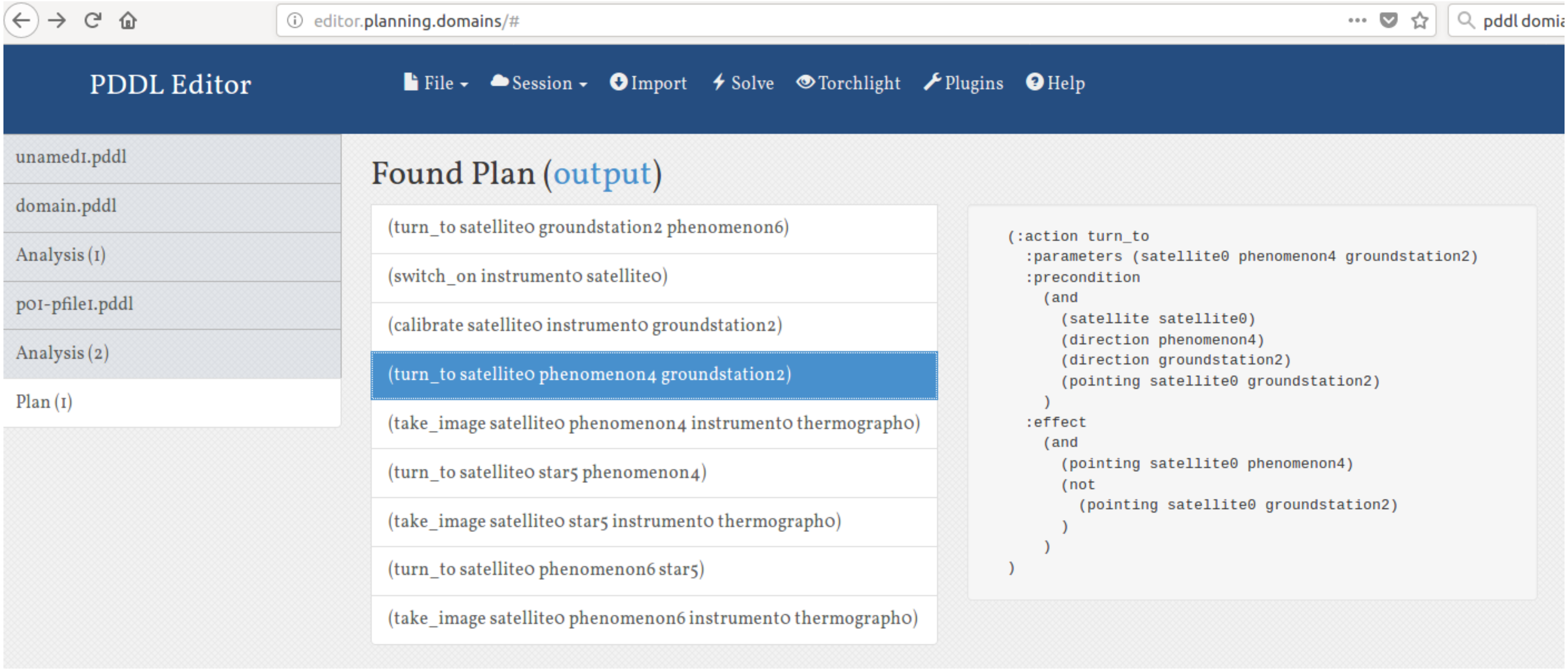
Planning.Domains

- “A Collection of Tools for Working with Planning Domains” [Muise]
- Web application
- Rich editor (syntax highlighting, autocomplete, etc.)
- Plug-in support
- Repository of all domains and problems from the IPCs

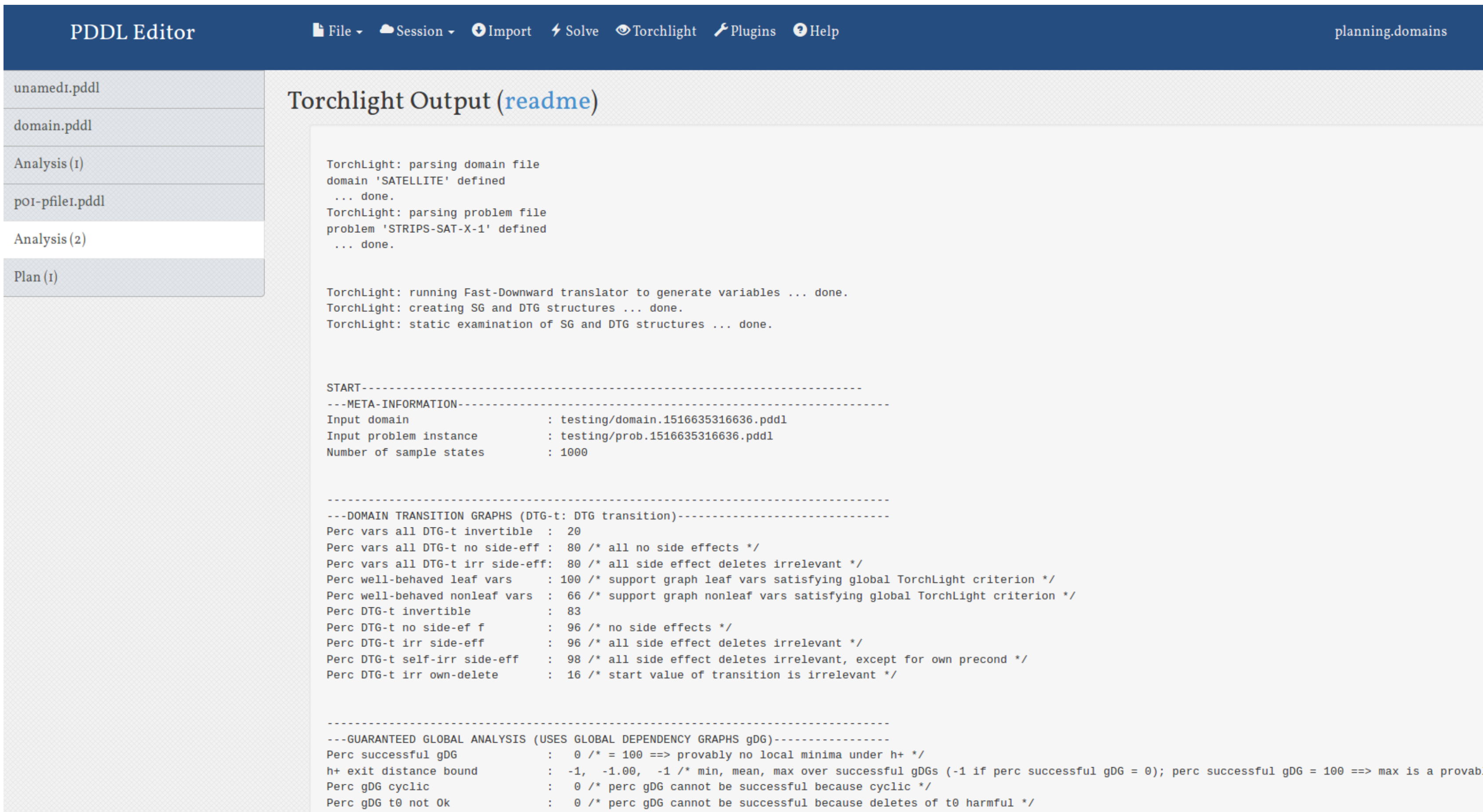
Planning.Domains – Sample Domain (Satellite)



Planning.Domains – Sample Plan (Satellite domain)



Planning.Domains – Analysis (by TorchLight)

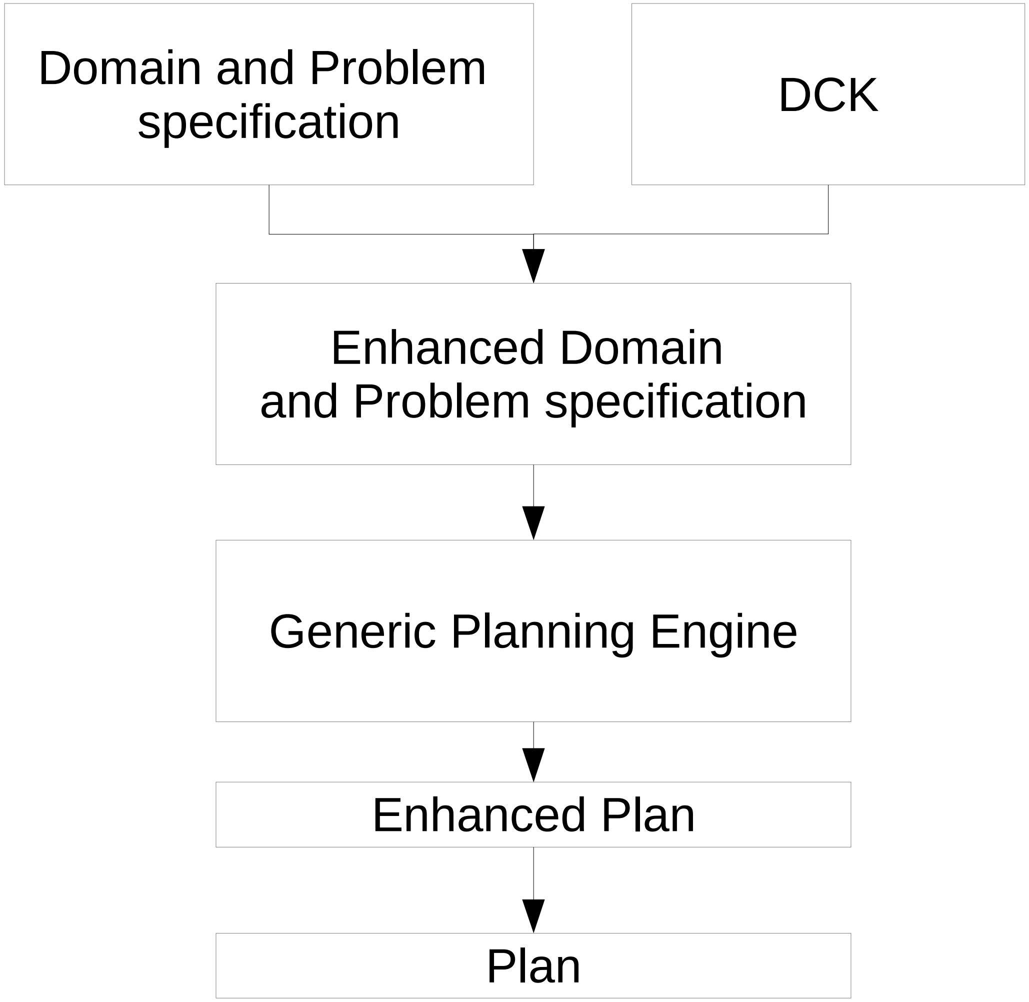


Domain Control Knowledge and Model Reformulation

Domain Control Knowledge (DCK)

- Captures useful domain-specific information
- Provides “guidance” for planning engines
- Complement “raw” domain model specification
- Two main categories of DCK
  - Planner-specific (e.g. TALPlanner, Roller)
  - Planner-independent (this talk !)

Planner-independent DCK



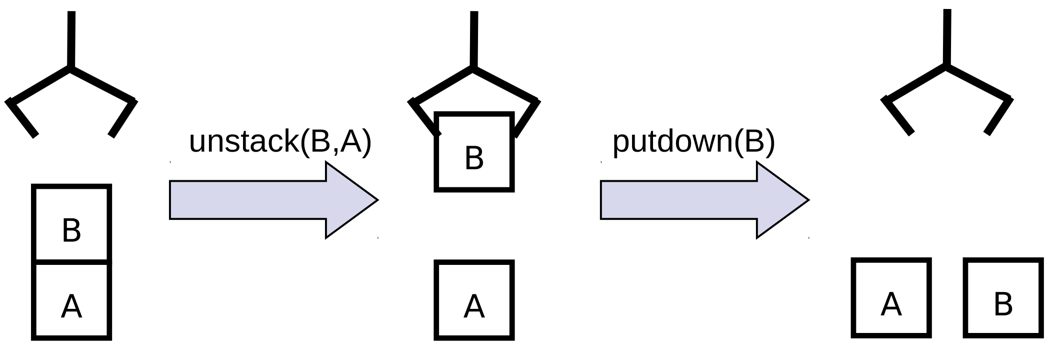
Obtaining DCK

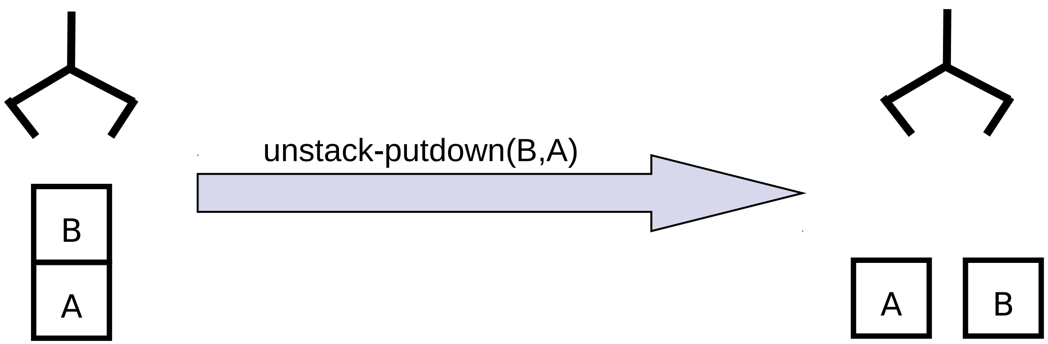
- Automatically
  - training based
  - online
- Manually

Macro-operators (Macros)

- Primitive operators can be assembled into one single operator – macro-operator (macro)
- Assemblage of operators o_i and o_j into $o_{i,j}$:
  - $pre(o_{i,j}) = pre(o_i) \cup (pre(o_j) - add(o_i))$
  - $del(o_{i,j}) = (del(o_i) - add(o_j)) \cup del(o_j)$
  - $add(o_{i,j}) = (add(o_i) - del(o_j)) \cup add(o_j)$
- Widely studied (e.g. Macro-FF, Wizard, MUM, BLOMA)

Macros - example





unstack(X,Y) =
{ {on(X,Y),clear(X),handempty} //prec
  {on(X,Y),clear(X),handempty} //neg eff
  {holding(X),clear(Y)} } //pos eff

pudown(X) =
{ {**holding(X)**} //prec
  {holding(X)} //neg eff
  {ontable(X),on(X),clear(X),handempty} } //pos eff

unstack-putdown(X,Y) =
{ {on(X,Y),clear(X),handempty} //prec
  {on(X,Y),holding(X),} //neg eff
  {clear(X),clear(Y),ontable(X),handempty} } //pos eff

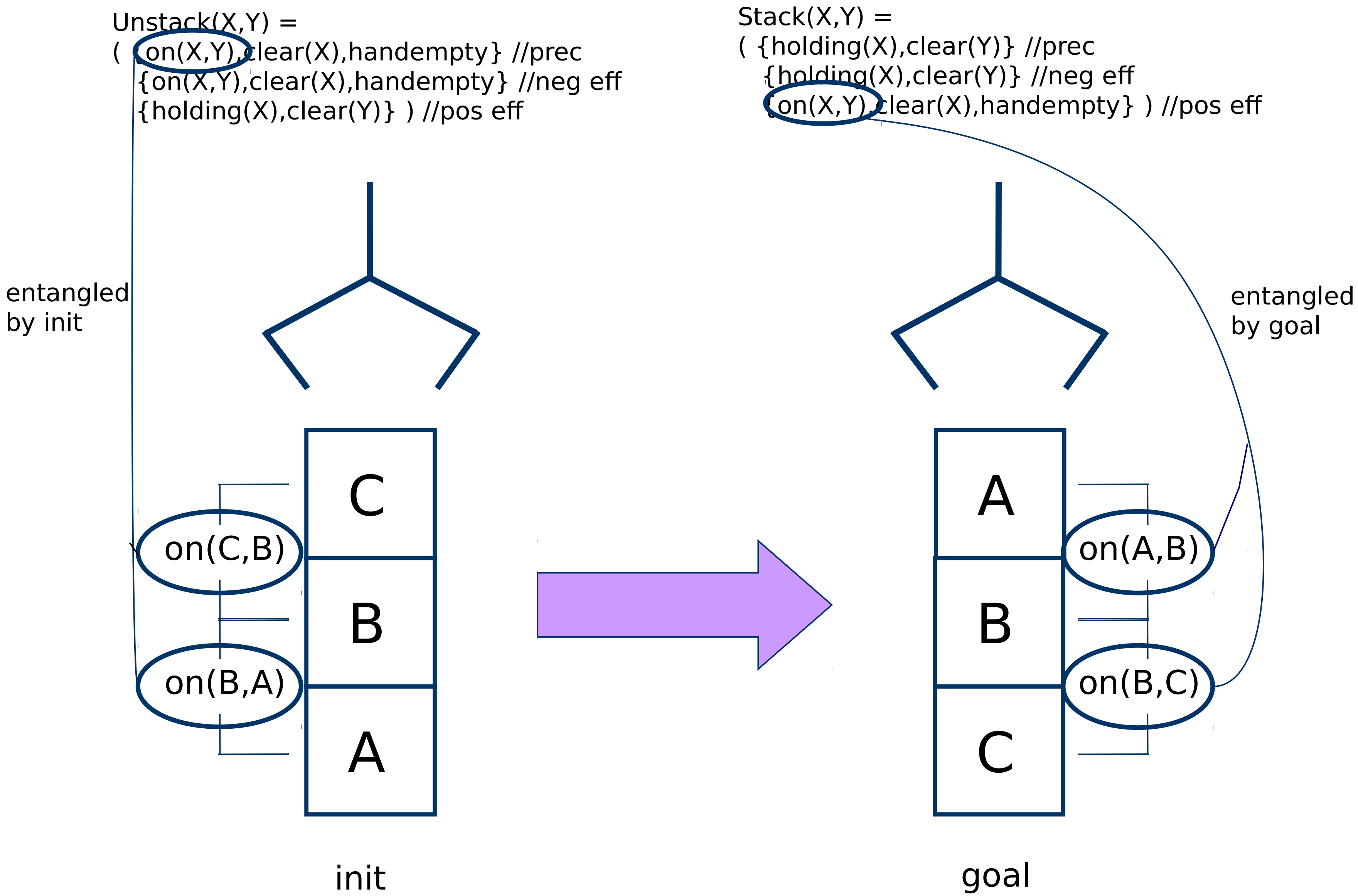
Macros – Benefits and Shortcomings

- Macros can be understood as **'short-cuts'** in the search space
- Solution plans can be **much shorter**
- Introducing macros can **increase branching factor** considerably !
- There might be **high memory requirements** for planners

"A short-cut is the longest way between two points"

Outer Entanglements [Chrpa & McCluskey 2012]

- Outer entanglements are relations between planning operators and initial or goal predicates
- **Entanglement by init –** allows only such instances of an operator requiring an initial predicate
- **Entanglement by goal –** allows only such instances of an operator achieving goal predicates



allowed: Unstack(C,B), Unstack(B,A)

allowed: Stack(A,B), Stack(B,C)

Outer Entanglements – benefits and shortcomings

- Outer Entanglements **restrict** the number of instantiated operators
- Outer Entanglements (significantly) **reduces** memory requirements
- The method for extracting outer entanglements **does not ensure completeness**

Combining Macros and Outer Entanglements

- MUM [Chrpa et al., 2014]
  - Outer entanglements can **reduce branching factor** the macros introduce
  - Applying outer entanglements only on macros **does not compromise completeness**
  - Outer entanglements **provide heuristics** in the macro learning process
- OMA [Chrpa et al., 2015] – an online version of MUM

Transition-based DCK [Chrpa & Bartak, 2016]

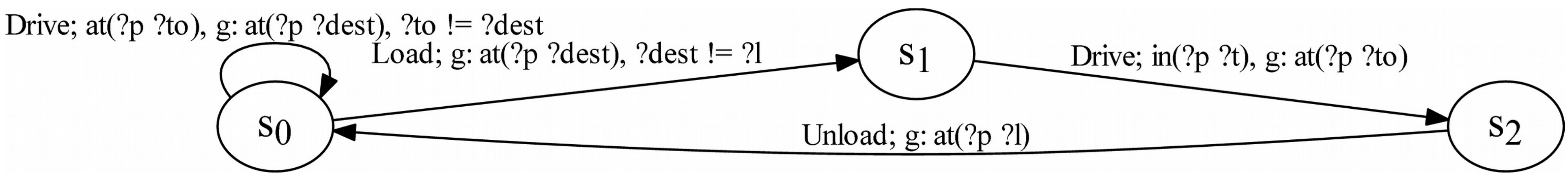
- Inspired by Finite State Automata
- Define “grammar” of solution plans
- “Schematical” representation is easier to understand by non-experts in planning
- Can be incorporated in planning domain models

Transition-based DCK – formal specification

- A quadruple (S,O,T,s_0) where
  - S is a set of **DCK states**
  - $s_0 \in S$ is the **initial DCK state**
  - O is a set of **planning operators**
  - T is a set of **transitions**
- Each transition is in the form (s,o,C,s') where
  - $s,s' \in S$, $o \in O$
  - C is a set of **constraints** where each is in the form
    - $p, \neg p$ – p **must or must not be** in the current planning state
    - g: p – p must be **an open goal** in the current planning state

Specifying Transition-based DCK – an example

- An empty truck (can carry at most one package) should move only to locations where some package is waiting to be delivered
- After a package that has to be delivered is loaded into the truck, the truck moves to package's goal location where the package is then unloaded



Impact of DCK

- Macros and Entanglements **have considerable impact on performance** in some cases
- Transition-based DCK in some cases **“determinize”** the planning process

- Changes in the domain model might require **considerable changes** in DCK

Impact of DCK on the KE process

- In practice, separating the “raw” domain model and DCK is easier to maintain
- Extend existing KE tools (e.g. itSimple, Planning.Domains) by supporting automatic/manual DCK acquisition
- Understanding in which cases planners fail and how DCK can alleviate such an issue
  - Even changing the order of operators and predicates in their preconditions/effects have a significant impact on planners' performance !

Conclusions

- KE process in planning is still “black art”
  - No guidelines/methodologies
  - Little support of KE tools
  - Effective DCK acquisition support
- A little to nothing has been done in non-classical planning
- **Addressing these issues will significantly strengthen the position of domain-independent planning in other AI areas**