
IDP-Z3

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This document describes the IDP-Z3 ecosystem for FO(.). Other learning resources include:

- [IDP-Z3 by example.](#)
- [the FO\[.\] standard](#)

Feel free to contact us on [our Matrix channel](#) if you have any question on this documentation.

INTRODUCTION

IDP-Z3 is a software collection implementing the Knowledge Base paradigm using the FO[] language. FO[] (aka FO-dot) is First Order logic, extended with definitions, types, arithmetic, aggregates and intensional objects. In the Knowledge Base paradigm, the knowledge about a particular problem domain is encoded using a declarative language, and later used to solve particular problems by applying the appropriate type of reasoning, or “inference”. The inferences include:

- model checking: does a particular solution satisfy the laws in the knowledge base ?
- model search: extend a partial solution into a full solution
- model propagation: find the facts that are common to all solutions that extend a partial one

The *IDP-Z3 engine* enables the creation of these solutions:

- the *Interactive Consultant*, which allow a knowledge expert to enter knowledge about a particular problem domain, and an end user to interactively find solutions for particular problem instances;
- *a program* with a command line interface to compute inferences on a knowledge base;
- a *web-based Interactive Development Environment (IDE)* to create Knowledge bases.

Warning: You may want to verify that you are seeing the documentation relevant for the version of IDP-Z3 you are using. On *readthedocs*, you can see the version under the title (top left corner), and you can change it using the listbox at the bottom left corner.

1.1 Installation using poetry

Poetry is a package manager for python.

- Install `python3` on your machine
- Install `poetry`
 - after that, logout and login if requested, to update `$PATH`
- Use git to clone <https://gitlab.com/krr/IDP-Z3> to a directory on your machine
- Open a terminal in that directory
- If you have several versions of `python3`, and want to run on a particular one, e.g., 3.9:
 - run `poetry env use 3.9`
 - replace `python3` by `python3.9` in the commands below
- **Run `poetry install`**

- Run `poetry install --no-dev` if you do not plan to contribute to IDP-Z3 development

To launch the Interactive Consultant web server:

- open a terminal in that directory and run `poetry run python3 main.py`

After that, you can open

- the Interactive Consultant at <http://127.0.0.1:5000>
- the webIDE at <http://127.0.0.1:5000/IDE>

1.2 Installation using pip

IDP-Z3 can be installed using the python package ecosystem.

- install python 3, with pip3, making sure that python3 is in the PATH.
- use git to clone <https://gitlab.com/krr/IDP-Z3> to a directory on your machine
- (For Linux and MacOS) open a terminal in that directory and run the following commands.

```
python3 -m venv .
source bin/activate
python3 -m pip install -r requirements.txt
```

- (For Windows) open a terminal in that directory and run the following commands.

```
python3 -m venv .
.\Scripts\activate
python3 -m pip install -r requirements.txt
```

To launch the web server on Linux/MacOS, run

```
source bin/activate
python3 main.py
```

On Windows, the commands are:

```
.\Scripts\activate
python3 main.py
```

After that, you can open

- the Interactive Consultant at <http://127.0.0.1:5000>
- the webIDE at <http://127.0.0.1:5000/IDE>

1.3 Installation of idp_engine module

The `idp_engine` module is available for installation through the official Python package repository. This comes with a command line program, `idp_engine` that functions as described in *Command Line Interface*.

To install the module via poetry, the following commands can be used to add the module, and then install it.

```
poetry add idp_engine
poetry install
```

Installing the module via pip can be done as such:

```
pip3 install idp_engine
```


THE FO[] LANGUAGE

2.1 Overview

The FO[] (aka FO-dot) language is used to create knowledge bases. It is described in the [FO-dot standard](#). This document presents the implementation in IDP-Z3.

An FO-dot knowledge base is a text file containing the following blocks of code:

vocabulary specify the types, predicates, functions and constants used to describe the problem domain.

theory specify the definitions and axioms satisfied by any solutions.

structure (optional) specify the interpretation of some predicates, functions and constants.

The basic skeleton of an FO-dot knowledge base is as follows:

```
vocabulary {
    // here comes the specification of the vocabulary
}

theory {
    // here comes the definitions and axioms
}

structure {
    // here comes the interpretation of some symbols
}
```

Everything between `//` and the end of the line is a comment. Multi-line comments are also supported using `/*` to start and `*/` to close them.

2.2 Shebang

New in version 0.5.5

The first line of an IDP-Z3 program may be a [shebang](#) line, specifying the version of IDP-Z3 to be used. When a version is specified, the Interactive Consultant and webIDE will be redirected to a server on the web running that version. The list of versions is available [here](#). (The IDP-Z3 executable ignores the shebang.)

Example: `#! IDP-Z3 0.5.4`

2.3 Vocabulary

```
vocabulary V {
  // here comes the vocabulary named V
}
```

The *vocabulary* block specifies the types, predicates, functions and variables used to describe the problem domain. If the name is omitted, the vocabulary is named V.

Each declaration goes on a new line (or are space separated). Symbols begins with a word character excluding digits, followed by word characters. Word characters include alphabetic characters, digits, `_`, and unicode characters that can occur in words. Symbols can also be string literals delimited by `'`, e.g., `'blue planet'`.

2.3.1 Types

IDP-Z3 supports built-in and custom types and subtypes.

The built-in types are: `_, Date`, and `Concept [signature]` (where *signature* is any type signature, e.g. `()->Bool`). The equivalent ASCII symbols are `Bool`, `Int`, and `Real`.

The type `Concept [signature]` has one constructor for each symbol (i.e., function, predicate or constant) declared in the vocabulary with that type signature. The constructors are the names of the symbol, prefixed with ```.

Custom types are declared using one of these templates:

```
type T
type T {<an enumeration>}
type T T1
type T {<an enumeration>} T1
```

where `T1` is a previously declared type. The third and fourth declarations say that `T` is a subtype of `T1`, i.e., that its interpretation is a subset of the interpretation of `T1`. The name of types should be singular and capitalized, by convention. The ASCII equivalent of ``` is `<`.

The extension of a type must be defined in a *structure*, or directly in the vocabulary, by specifying:

- a list of (ranges of) numeric literals, e.g., `type someNumbers {0,1,2}` or `type byte {0..255}` (the ASCII equivalent of `is :=`)
- a list of (ranges of) dates, e.g., `type dates {#2021-01-01, #2022-01-01}` or `type dates {#2021-01-01 .. #2022-01-01}`
- a list of nullary constructors, e.g., `type Color {Red, Blue, Green}`
- a list of n-ary constructors; in that case, the enumeration must be preceded by `constructed from`, e.g., `type Color2 constructed from {Red, Blue, Green, RGB(R: Byte, G: Byte, B: Byte)}`

In the above example, the constructors of ``Color` are `: Red, Blue, Green`.

The constructors of ``Color2` are `: Red, Blue, Green` and `RGB`. Each constructor have an associated function (e.g., `is_Red`, or `is_RGB`) to test if a `Color2` term was created with that constructor. The `RGB` constructor takes 3 arguments of type `Byte`. `R`, `G` and `B` are accessor functions: when given a `Color2` term constructed with `RGB`, they return the associated `Byte`. (When given a `Color2` not constructed with `RGB`, they may raise an error)

Constructors can be used to construct *recursive datatypes*, e.g., `type List := constructed from {nil, cons(car:Color, cdr: List)}`.

(However, unsatisfiable theories with recursive definitions do not terminate; propagation and explanation inferences are not supported).

2.3.2 Predicates

A predicate is declared using one of these templates:

```
p : T1..Tn →
```

where T_1, \dots, T_n are previously declared types.

The declaration says that p takes arguments of type $T_1 \dots T_n$.

The predicate names should start with a lowercase letter, by convention. The ASCII equivalent of \rightarrow is \rightarrow and of \leftarrow is \leftarrow .

A unary predicate is always interpreted as a subset of a type. A nullary predicate is a subset of the singleton set containing the empty tuple.

2.3.3 Functions

A function is declared using one of these templates:

```
f : total T1..Tn → T
f : T1..Tn → T (domain: p1..pn, codomain: q)
f : T1..Tn → T (domain: p, codomain: q)
f : partial T1..Tn → T
```

where T_1, \dots, T_n, T are previously declared types and p, p_1, \dots, p_n, q are previously-declared types or predicates.

All 4 declarations say that f takes arguments of type $T_1 \dots T_n$. The first declaration says that f is a total function. The `total` keyword is optional but recommended. The second declaration says that f is defined over exactly the cross-products of the sets $p_1 \dots p_n$, and that its image is a subset of q ($T \rightarrow \text{Bool}$). The third declaration says that f is defined over exactly p (with type signature $T_1 \dots T_n \rightarrow \text{Bool}$), and that its image is a subset of q ($T \rightarrow \text{Bool}$). The fourth declaration says that f is defined over exactly dom_f , where dom_f is an implicitly declared predicate with type signature $T_1 \dots T_n \rightarrow \text{Bool}$.

The `domain` (resp. `codomain`) specifies the domain of definition (resp. the codomain) of the function. It can be omitted when it is $T_1 \dots T_n$ (resp. T), but must be given otherwise.

The function names should start with a lowercase letter, by convention. The ASCII equivalent of \rightarrow is \rightarrow , and of \rightarrow is \rightarrow .

2.3.4 Variable Declarations

A variable may be declared with its type:

```
var x T
```

This is convenient for quantifications: the type of the variable may be omitted in quantifications: its declared type will be assumed.

A quantification cannot use a declared variable to quantify over another type than the declared one.

The variables x_1, x_2, \dots are implicitly declared with the same type as x . (the variable in the declaration may not have a digital suffix)

2.3.5 Built-in functions

The following functions are built-in:

- `abs: Int → Int` (or `abs: Float → Float`) yields the absolute value of an integer (or float) expression;

2.3.6 Propositions and Constants

A proposition is a predicate of arity 0; a constant is a function of arity 0.

```
MyProposition : () →
MyConstant: () → Int
```

2.3.7 Include another vocabulary

A vocabulary `W` may include a previously defined vocabulary `V`:

```
vocabulary W {
  import V
  // here comes the vocabulary named W
}
```

2.3.8 Symbol annotations

To improve the display of functions and predicates in the *Interactive Consultant*, their declaration in the vocabulary can be annotated with their intended meaning, a short comment, or a long comment. These annotations are enclosed in `[and]`, and come before the symbol declaration.

Intended meaning `[this is a text]` specifies the intended meaning of the symbol. This text is shown in the header of the symbol's box.

Short info `[short:this is a short comment]` specifies the short comment of the symbol. This comment is shown when the mouse is over the info icon in the header of the symbol's box.

Long info `[long:this is a long comment]` specifies the long comment of the symbol. This comment is shown when the user clicks the info icon in the header of the symbol's box.

English expression `[EN:{1} is a prime]` specifies the English expression for `prime: Int -> Bool`. This information is used to generate the informal reading of a Theory. The number between brackets represents a placeholder for the English reading of the `nth` argument.

Slider `[slider: (a, b) in (0, 100)]` displays as slider for a numeric value. The slider has a maximum range of `[0, 100]` that is reduced to `[a(), b()]` when the values of `a()` and `b()` are known (`a` and `b` are symbols in the vocabulary).

2.3.9 URIs

New in version 0.11.1

IDP-Z3 has support for URIs in virtually every place where you can write a string: block names, symbol names, names of type elements and constructor names. The only exception are variable names, which cannot be written using a URI.

There are a number of reasons for introducing URIs in your FO(·) specification, but the main benefit is providing a simple way to refer to “external concepts”. Additionally, it offers improved interoperability with knowledge graph technologies.

The syntax of URIs in FO(·) aims to stay as close as possible to that of the commonly used [RDF standard](#). An example of a vocabulary declaration with absolute URIs is as follows:

```
vocabulary V {
  type <http://www.example.org/whatever#Type>
  type Whatever
  <http://www.example.org/whatever#foo>: <http://www.example.org/whatever#Type> -> Bool
  bar: Whatever -> <http://www.example.org/whatever#Type>
  <http://www.example.org/whatever#Somethingelse>: -> Int
}
```

To prevent lengthy names, you may also shorten your URIs by introducing a [prefix](#). The syntax to declare the prefix is as follows: `@prefix: *name* <https://www.your.uri/something#>..` It must either be declared at the top of the file, in which case it is valid to use everywhere in the FO(·) specification, or at the top of a vocabulary block, in which case you may only use it inside that vocabulary and all blocks that inherit it. The syntax to use the prefix is `we::foo`, which is equivalent to `<http://www.example.org/whatever#foo>`. As an example:

```
@prefix we: <http://www.example.org/whatever#>.
vocabulary V {
  type we::Type
  we::bar: () -> we::Type
}
```

Note: Internally, IDP-Z3 will not expand prefixed URIs to absolute URIs, meaning that IDP-Z3 will regard the same concept expressed using an absolute and prefixed URI differently: e.g., `we::foo` \neq `<http://www.example.org/whatever#foo>`

2.4 Theory

```
theory T:V {
  // here comes the theory named T, on vocabulary named V
}
```

A *theory* is a set of axioms and definitions to be satisfied, and of symbol interpretations. If the names are omitted, the theory is named T, for vocabulary V.

Symbol interpretations are described in the Section on [Structure](#). Before explaining the syntax of axioms and definitions, we need to introduce the concept of term.

2.4.1 Mathematical expressions and Terms

A *term* is inductively defined as follows:

Boolean, Numeric and Date literals

`true` and `false` are boolean terms.

Numeric literals that follow the [Python conventions](#) are numerical terms of type `Int` or `Real`.

Date literals are terms. They follow ISO 8601 conventions, prefixed with `#` (i.e., `#yyyy-mm-dd`). `#TODAY` is also a Date literal representing today's date. `#TODAY(y, m, d)` is a Date literal representing today shifted by `y` years, `m` months and `d` days, where `y`, `m` and `d` are integer literals (e.g., `#TODAY(-18, 0, 0)` is today 18 years ago).

Constructor Each constructor of a *type* is a term having that type.

Variable A variable is a term. Its *type* is derived from the *quantifier expression* that declares it (see below).

Function application $F(t_1, t_2, \dots, t_n)$ is a term, when F is a *function* symbol of arity n , and t_1, t_2, \dots, t_n are terms. Each term must be of the appropriate *type*, and in the domain of the function, as defined in the function declaration in the vocabulary. The resulting type and range of the function application is also defined in the function declaration. If the arity of F is 0, i.e., if F is a *constant*, then $F()$ is a term.

Warning: The knowledge engineer must use appropriate if-then-else guards to ensure that the value of a function outside of its domain has no influence on the truth value of a statement.

For example: `if y = 0 then 0 else x/y`.

$\$(s)(t_1, t_2, \dots, t_n)$ is a term, when s is an expression of type `Concept` that denotes a function of arity n , and t_1, t_2, \dots, t_n are terms.

Please note that there are built-in *functions* (see [Built-in functions](#)).

Negation $\neg t$ is a numerical term, when t is a numerical term.

Arithmetic $t_1 \ t_2$ is a numerical term, when t_1, t_2 are two numerical terms, and op is one of the following math operators `+`, `-`, `*` (or `⋅`), `/`, `^`, `%`. Mathematical operators can be chained as customary (e.g. `x+y+z`). The usual order of binding is used.

Parenthesis (t) is a term, when t is a term

Cardinality aggregate $\#\{v_1 \text{ in } \text{typeOf}V_1, \dots, v_n \text{ in } \text{typeOf}V_n : p\}$ is a numerical term when v_1, v_2, \dots, v_n are variables, and p is a *sentence* containing these variables. If p is omitted, p is presumed to be true.

The term denotes the number of tuples of distinct values for v_1, v_2, \dots, v_n which make p true.

Aggregate over sets $\text{agg}\{t \mid v_1 \text{ in } \text{typeOf}V_1, \dots, v_n \text{ in } \text{typeOf}V_n : p\}$ is a numerical term where agg can be `min` or `max`, v_1, v_2, \dots, v_n are variables, t is a term and p is a boolean expression. The variables declared by the aggregate can occur in t and p . If p is omitted, p is presumed to be true.

This aggregate denotes the minimum (resp. maximum) of term t for each value of the variables that satisfies p . Note that the set must be non-empty.

Aggregate over multisets The term $\text{agg}\{\{t \mid v_1 \text{ in } \text{typeOf}V_1, \dots, v_n \text{ in } \text{typeOf}V_n : p\}\}$ where agg can be `sum`, `min` or `max`, denotes the aggregate of the term t for each value of the variables that satisfies boolean expression p . The variables declared by the aggregate can occur in t and p . If p is omitted, p is presumed to be true. Note that the set must be non-empty, or the aggregate must be "sum".

(if .. then .. else ..) (if t_1 then t_2 else t_3) is a term when t_1 is a formula, t_2 and t_3 are terms of the same type.

2.4.2 Sentences and axioms

An *axiom* is a sentence followed by `..`. A *sentence* is a well-formed formula without free variables (i.e., in which every variable appear in the scope of a quantifier that declares it). A *formula* is inductively defined as follows:

true and false true and false are formulae.

Predicate application $P(t_1, t_2, \dots, t_n)$ is a formula, when P is a *predicate* symbol of arity n , and t_1, t_2, \dots, t_n are terms. Each term must be of the appropriate *type*, as defined in the predicate declaration. If the arity of P is 0, i.e., if P is a proposition, then $P()$ is a formula.

$\$(s)(t_1, t_2, \dots, t_n)$ is a formula, when s is an expression of type `Concept` that denotes a predicate of arity n , and t_1, t_2, \dots, t_n are terms.

Comparison $t_1 \text{ } t_2$ is a formula, when t_1, t_2 are two numerical terms and `is` is one of the following comparison operators `<`, `=`, `>`, `<=`, `>=`, `~=` (or, using ascii characters: `<`, `>`, `~=`). Comparison operators can be chained as customary.

Negation `~` is a formula (or, using ascii characters: `~`) when `is` is a formula.

Logic connectives `_1 _2` is a formula when `_1, _2` are two formulae and `is` is one of the following logic connectives `, , ,` (or using ascii characters: `|`, `\&`, `=>`, `<=`, `<=>` respectively). Logic connectives can be chained as customary.

Connectives can be written in English, e.g. `and`. See full list of English connectives in *Syntax summary*.

Parenthesis `()` is a formula when `is` is a formula.

Enumeration An enumeration (e.g. `p := {1, 2, 3}`) is a formula. An enumeration must be top-level (i.e., an assertion in a theory) Enumerations follow the syntax described in *structure*.

Quantified formulas *Quantified formulas* are formulae. They have one of the following forms, where v_1, \dots, v_n are variables, p, p_1, \dots, p_n are types or predicates, and `is` is a formula involving those variables:

```

v_1, v_n p: (v_1, v_n).

(v_1, v_n) p: (v_1, v_n).

v_1 p_1, v_n p_n: (v_1, v_n).

```

Alternatively, the existential quantifier, `∃`, can be used. Ascii characters can also be used: `?`, `!`, respectively. For example, `! x, y in Int: f(x,y)=f(y,x)`.

A variable may only occur in the formula of a quantifier declaring that variable. In the first form above, the variables must have been declared (without any numeric suffix) in the vocabulary.

Generalised existential quantification A generalised existential quantified formula is a short-hand formula that represents a cardinality constraint. It is of the form `n`, where `is` is one of the following comparison operators `<`, `=`, `>`, and n is an integer:

```

=1 v p: (v)

>1 v p: (v)

1 v p: (v)

```

Its semantics corresponds to the following formula: $\#\{v \ p: \ (v)\} \ n$

“**is enumerated**” $f(a, b)$ **is enumerated** is a formula, where f is a function defined by a (partial) enumeration and applied to arguments a and b . Its truth value reflects whether (a, b) is enumerated in f 's (partial) enumeration. If the enumeration has a default value, every tuple of arguments is enumerated.

“**in {1,2,3,4}**” $f(\text{args})$ **in enum** is a formula, where f is a function applied to arguments args and enum is an enumeration. This can also be written using Unicode: $f() \ \{1,2,3\}$.

if .. then .. else .. $\text{if } t_1 \text{ then } t_2 \text{ else } t_3$ is a formula when t_1, t_2 and t_3 are formulae.

2.4.3 Definitions

A *definition* defines concepts, i.e. *predicates* or *functions*, in terms of other concepts. A definition consists of a set of rules, enclosed by $\{$ and $\}$.

If a predicate is inductively defined in terms of itself, the definition employs the *well-founded* mode of interpretation by default. The other possible modes of interpretation are *completion*, *Kripke-Kleene*, *co-induction*, *stable''* and *recursive* (for *recursive datatypes*). They can be selected by placing the keyword in parenthesis at the beginning of the definition, e.g., $\{ \text{(completion)} \dots \}$.

Rules have one of the following forms:

$$v_1 \ T_1, \ v_n \ T_n: P(t_1, \dots, t_n) \leftarrow |\text{phi}|.$$

$$v_1 \ T_1, \ v_n \ T_n: F(t_1, \dots, t_n) = t \leftarrow |\text{phi}|.$$

where P is a *predicate* symbol, F is a *function* symbol, t, t_1, t_2, \dots, t_n are terms that may contain the variables $v_1 \ v_2 \dots v_n$ and phi is a formula that may contain these variables. $P(t_1, t_2, \dots, t_n)$ is called the *head* of the rule and the *body*. \leftarrow can be used instead of \leftarrow , and $=$ instead of $=$. If the body is **true**, the left arrow and body of the rule can be omitted.

2.4.4 Annotations

Some expressions can be annotated with their informal meaning, between brackets. For example, $[\text{age is a positive number}] \ 0 \ =< \ \text{age}()$. Such annotations are used in the [Interactive Consultant](#).

The following expressions can be annotated:

- Definitions
- Rules
- Constraints
- Quantified formula
- Comparisons
- Membership in an enumeration
- Brackets

When necessary, use parenthesis to avoid ambiguity, e.g. $[\text{Positive or } p] \ ([\text{Positive}] \ x()<0 \) \ | \ p()..$

2.5 Structure

```
structure S:V {
  // here comes the structure named S, for vocabulary named V
}
```

A *structure* specifies the interpretation of some *type*, *predicates* and *functions*. If the names are omitted, the structure is named S, for vocabulary V.

A structure is a set of symbol interpretations of the form :

- <symbol> <total interpretation>., e.g., P {1..9},
- <symbol> <partial interpretation>., e.g., P {A->1}.

(The ASCII equivalent of is :=, and of is :>)

A total interpretation fully specifies the interpretation of the symbol; a partial interpretation does not.

An error occurs when the domain of the symbol is already known by enumeration, and its total interpretation does not cover the domain. If the domain of the symbol is not known, it is inferred from the total interpretation.

A total interpretation takes one of these forms:

for nullary predicates (propositions) true or false

for non-numeric types and unary predicates: a set of rigid terms (numbers, dates, identifiers, or constructors applied to rigid terms), e.g., {red, blue, green}.

for numeric types and unary predicates: a set of numeric literals and ranges, e.g., {0, 1, 2}, {0..255} or {0..9, 90..99}

for date types and unary predicates: a set of date literals and ranges, e.g., {#2021-01-01, #2022-01-01} or {#2021-01-01 .. #2022-01-01}

for types: a set of n-ary constructors, preceded by constructed from, e.g., constructed from {Red, Blue, Green, RGB(R: Byte, G: Byte, B: Byte)} (see more details in *types*)

for n-ary predicates: a set of tuples of rigid terms, e.g., {(a,b), (a,c)}.

for nullary functions: a rigid term, e.g. 5 or #2021-01-01, or red or rgb(0,0,0)

for n-ary functions: a set of tuples and their associated values, e.g., { (1,2)->3, (4, 5)->6 }. The interpretation may be followed by else <default>, where <default> is a default value (a rigid term), i.e., a value for the non-enumerated tuples, if any.

A partial interpretation takes one of these forms:

for n-ary functions: a set of tuples and their associated values, e.g., { (1,2)->3, (4, 5)->6 }

Additional notes:

- the set of tuples in the interpretation of a predicate is exactly the set of tuples that make the predicate true; any other tuple makes it false.
- parenthesis around a tuple can be omitted when the arity is 1, e.g., {1-2, 3->4}
- the interpretation of a predicate may be specified using the CSV format, with one tuple per line, e.g., :

```
P := {
1 2
3 4
```

(continues on next page)

```
5 6
}
```

- The interpretation of `goal_string` is used to compute relevance relative to goals (see the `determine_relevance` method in the *Theory class*).
- The tuples of an interpretation can be given in any order.

2.6 Differences with IDP3

Here are the main differences with IDP3 (the previous version of IDP-Z3), listed for migration purposes:

Infinite domains IDP-Z3 supports infinite domains: `Int`, `Real`. However, quantifications over infinite domains is discouraged.

Type IDP-Z3 supports type hierarchies differently from IDP3: subtypes are now represented by unary predicates; unary predicates can be used wherever types can be used, i.e., in type signatures and in quantifiers.

LTC IDP-Z3 does not support LTC vocabularies.

Namespaces IDP-Z3 does not support namespaces.

Partial functions The handling of division by 0 may differ. See [IEP 07](#)

Syntax changes The syntax of quantifications and aggregates has slightly change. IDP-Z3 does not support qualified quantifications, e.g. `!2 x[color]: p(x) ..` (p. 11 of the IDP3 manual). Such statements can be implemented in IDP-Z3 using cardinality constraints instead.

if .. then .. else .. IDP-Z3 supports *if.. then .. else ..* terms and sentences.

Structure IDP-Z3 supports partial interpretations of functions using the `>` sign. (It currently does not support partial interpretations of predicates)

Procedure blocks IDP-Z3 only recognizes the `main()` block, written in Python (instead of in Lua).

To improve performance, do not quantify over the value of a function. Use `p(f(x))` instead of `?y: f(x)=y & p(y)`.

IDP-Z3 is used to perform reasoning on FO[] knowledge bases. It can be invoked in 3 ways:

- via a web interface, called webIDE.
- in a shell, using the Command Line Interface of IDP-Z3.
- in a Python program: by using classes and functions imported from the `idp_engine` package available on [Pypi](#).

These methods are further described below.

Warning: An *FO-dot* program is a text file containing only *vocabulary*, *theory* and, *structure* blocks, as described in *FO-dot*. An *IDP* program may additionally contain a *main()* procedure block, with instructions to process the *FO-dot* program. This procedure block is described later in this chapter.

3.1 webIDE

The webIDE of IDP-Z3 is accessible [online](#), and can be *run locally*.

The webIDE allows you to enter an IDP-Z3 program, with *FO-dot vocabulary*, *theory*, *structure* blocks and a *main block*, and to run it.

3.1.1 Main block

The *main block* consists of python-like statements to be executed by the *IDP-Z3 executable* or the *webIDE*, in the context of the knowledge base. Below is an example of a main block.

```
procedure main() {
  pretty_print(Theory(T, S).propagate())
  duration("End")
}
```

Within that block, the following variables, classes and functions are available:

- variables containing the vocabularies, theories and structures specified in the same IDP-Z3 program. The variables have the name of the block;
- the functions exposed by the `idp_engine`, described [here](#);
- the `Theory` class, described [here](#).

3.1.2 idp_engine functions

The following Python functions can be used to perform computations using FO-dot knowledge bases:

model_check(*theories)

Returns a string stating whether the combination of theories is satisfiable.

For example, `print(model_check(T, S))` will print `sat` if theory named `T` has a model expanding structure named `S`.

Parameters `theories` (`Union[TheoryBlock, Structure, Theory]`) – 1 or more (data) theories.

Returns `sat`, `unsat` or `unknown`

Return type `str`

model_expand(*theories, max=10, timeout_seconds=10, complete=False, extended=False, sort=False)

Returns a (possibly empty) list of models of the combination of theories, followed by a string message.

For example, `print(model_expand(T, S))` will return (up to) 10 string representations of models of theory named `T` expanding structure named `S`.

The string message can be one of the following:

- No models.
- More models may be available. Change the `max` argument to see them.
- More models may be available. Change the `timeout_seconds` argument to see them.
- More models may be available. Change the `max` and `timeout_seconds` arguments to see them.

Parameters

- **theories** (`Union[TheoryBlock, Structure, Theory]`) – 1 or more (data) theories.
- **max** (`int`, *optional*) – max number of models. Defaults to 10.
- **timeout_seconds** (`int`, *optional*) – timeout_seconds seconds. Defaults to 10.
- **complete** (`bool`, *optional*) – True to obtain complete structures. Defaults to False.
- **extended** (`bool`, *optional*) – use `True` when the truth value of inequalities and quantified formula is of interest (e.g. for the Interactive Consultant). Defaults to False.
- **sort** (`bool`, *optional*) – True if the models should be in alphabetical order. Defaults to False.

Yields `str`

Return type `Iterator[str]`

model_propagate(*theories, sort=False, complete=False)

Returns a list of assignments that are true in any model of the combination of theories.

Terms and symbols starting with ‘_’ are ignored.

For example, `print(model_propagate(T, S))` will return the assignments that are true in any expansion of the structure named `S` consistent with the theory named `T`.

Parameters

- **theories** (`Union[TheoryBlock, Structure, Theory]`) – 1 or more (data) theories.

- **sort** (*bool*, *optional*) – True if the assignments should be in alphabetical order. Defaults to False.
- **complete** (*bool*, *optional*) – True when requiring a propagation including negated function value assignments. Defaults to False.

Yields *str*

Return type *Iterator[str]*

maximize (**theories*, *term*)

Returns a model that maximizes *term*.

Parameters

- **theories** (*Union[TheoryBlock, Structure, Theory]*) – 1 or more (data) theories.
- **term** (*str*) – a string representing a term

Yields *str*

Return type *idp_engine.Theory.Theory*

minimize (**theories*, *term*)

Returns a model that minimizes *term*.

Parameters

- **theories** (*Union[TheoryBlock, Structure, Theory]*) – 1 or more (data) theories.
- **term** (*str*) – a string representing a term

Yields *str*

Return type *idp_engine.Theory.Theory*

decision_table (**theories*, *goal_string="*, *timeout_seconds=20*, *max_rows=50*, *first_hit=True*, *verify=False*)

Experimental. Returns a decision table for *goal_string*, given the combination of theories.

Parameters

- **theories** (*Union[TheoryBlock, Structure, Theory]*) – 1 or more (data) theories.
- **goal_string** (*str*, *optional*) – the last column of the table. Must be a predicate application defined in the theory, e.g. `eligible()`.
- **timeout_seconds** (*int*, *optional*) – maximum duration in seconds. Defaults to 20.
- **max_rows** (*int*, *optional*) – maximum number of rows. Defaults to 50.
- **first_hit** (*bool*, *optional*) – requested hit-policy. Defaults to True.
- **verify** (*bool*, *optional*) – request verification of table completeness. Defaults to False

Yields a textual representation of each rule

Return type *Iterator[str]*

determine_relevance (**theories*)

Generates a list of questions that are relevant, or that can appear in a justification of a `goal_symbol`.

The questions are preceded with `` ? `` when their answer is unknown.

When an *irrelevant* value is changed in a model *M* of the theories, the resulting *M'* structure is still a model. Relevant questions are those that are not irrelevant.

If `goal_symbol` has an enumeration in the theory (e.g., `goal_symbol := {`tax_amount`}`), relevance is computed relative to those goals.

Definitions in the theory are ignored, unless they influence axioms in the theory or goals in `goal_symbol`.

Yields relevant questions

Parameters `theories` (`Union[idp_engine.Parse.TheoryBlock, idp_engine.Parse.Structure, idp_engine.Theory.Theory]`) –

Return type `Iterator[str]`

pretty_print(`x=""`)

Prints its argument on stdout, in a readable form.

Parameters `x` (`Any, optional`) – the result of an API call. Defaults to `""`.

Return type `None`

duration(`msg=""`)

Returns the processing time since the last call to `duration()`, or since the begining of execution

Parameters `msg` (`str`) –

Return type `str`

3.1.3 Theory class

Instances of the Theory class represent a collection of theory and structure blocks.

Many operations on Theory instances can be chained, e.g., `Theory(T, S).propagate().simplify().formula()`.

The class has the following methods:

class `Theory`(*`theories`, `extended=False`)

A collection of theory and structure blocks.

assignments (`Assignments`): **the set of assignments.** The assignments are updated by the different steps of the problem resolution. Assignments include inequalities and quantified formula when the problem is extended

Parameters

- **theories** (`Union[TheoryBlock, Structure, Theory]`) –
- **extended** (`bool`) –

Return type `None`

determine_relevance()

Determines the questions that are relevant in a consistent state of `Theo.Theory self`.

Some definitions: * a consistent state `s` of theory `T` is a partial interpretation of vocabulary `V` of `T` that can be expanded in a model of `T`; * a solution `S` of theory `T` is a state such that every expansion of solution `S` is a model of theory `T`; * a minimal solution for theory `T` in state `s` is a solution that expands state `s` and is not more precise than another solution of theory `T`; * a symbol is relevant for theory `T` in state `s` iff it is interpreted in a minimal solution for theory `T` in state `s`.

This method must be called after a call to `propagate`, on a `Theo.Theory` created with `extended=True`. The method 1) computes a simplified theory equivalent to `self`, 2) collects the relevant questions in that theory. A question is considered relevant if: * it appears in a constraint; * or it is a goal symbol; * or it appears in a `co_constraint` for a relevant question.

The result is found in the `relevant` attribute of the assignments in `self.assignments`.

Returns the `Theo.Theory` with relevant information in `self.assignments`.

Return type `Theo.Theory`

Parameters `self` (`idp_engine.Theory.Theory`) –

EN()

returns a string containing the Theory in controlled English

Parameters `self` (`Theory`) –

Return type `str`

__init__ (`*theories, extended=False`)

Creates an instance of Theory for the list of theories, e.g., Theory(T,S).

Parameters

- **theories** (`Union[TheoryBlock, Structure, Theory]`) – 1 or more (data) theories.
- **extended** (`bool, optional`) – use `True` when the truth value of inequalities and quantified formula is of interest (e.g. for the Interactive Consultant). Defaults to `False`.

Return type `None`

property solver: `z3.z3.Solver`

Beware that the setting of `timeout_seconds` (e.g. in `expand()`) is not thread safe

copy()

Returns an independent copy of a theory.

Return type `idp_engine.Theory.Theory`

add (`*theories`)

Adds a list of theories to the theory.

Parameters **theories** (`Union[TheoryBlock, Structure, Theory]`) – 1 or more (data) theories.

Return type `idp_engine.Theory.Theory`

to_smt_lib()

Returns an SMT-LIB version of the theory

Return type `str`

assert_ (`code, value, status=Status.GIVEN`)

asserts that an expression has a value (or not), e.g. `theory.assert_("p()", True)`

Parameters

- **code** (`str`) – the code of the expression, e.g., "p()"
- **value** (`Any`) – a Python value, e.g., `True`
- **status** (`Status, Optional`) – how the value was obtained. Default: `S.GIVEN`

enable_law (`code`)

Enables a law, represented as a code string taken from the output of `explain(...)`.

The law should not result from a structure (e.g., from `p:=true.`) or from a types (e.g., from `T:={1..10}` and `c: () -> T`).

Parameters **code** (`str`) – the code of the law to be enabled

Raises **AssertionError** – if code is unknown

disable_law (`code`)

Disables a law, represented as a code string taken from the output of `explain(...)`.

The law should not result from a structure (e.g., from `p:=true.`) or from a types (e.g., from `T:={1..10}` and `c: () -> T`).

Parameters `code (str)` – the code of the law to be disabled

Raises `AssertionError` – if code is unknown

constraintz()

list of constraints, `co_constraints` and definitions in Z3 form

Return type `List[z3.z3.BoolRef]`

formula()

Returns a Z3 object representing the logic formula equivalent to the theory.

This object can be converted to a string using `str()`.

Return type `z3.z3.BoolRef`

expand(max=10, timeout_seconds=10, complete=False)

Generates a list of models of the theory that are expansion of the known assignments.

The result is limited to `max` models (10 by default), or unlimited if `max` is 0. The search for new models is stopped when processing exceeds `timeout_seconds` (in seconds) (unless it is 0). The models can be asked to be complete or partial (i.e., in which “don’t care” terms are not specified).

The string message can be one of the following:

- No models.
- No model found in `xx` seconds. Models may be available. Change the `timeout_seconds` argument to see them.
- More models may be available. Change the `max` argument to see them.
- More models may be available. Change the `timeout_seconds` argument to see them.
- More models may be available. Change the `max` and `timeout_seconds` arguments to see them.

Parameters

- `max (int, optional)` – maximum number of models. Defaults to 10.
- `timeout_seconds (int, optional)` – timeout_seconds seconds. Defaults to 10.
- `complete (bool, optional)` – True for complete models. Defaults to False.

Yields the models, followed by a string message

Return type `Iterator[Union[idp_engine.Assignments.Assignments, str]]`

optimize(term, minimize=True)

Updates the value of `term` in the `assignments` property of `self` to the optimal value that is compatible with the theory.

Chain it with a call to `expand` to obtain a model, or to `propagate` to propagate the optimal value.

Parameters

- `term (str)` – e.g., "Length(1)"
- `minimize (bool)` – True to minimize `term`, False to maximize it

Return type `idp_engine.Theory.Theory`

symbolic_propagate(*tag=Status.UNIVERSAL*)

Returns the theory with its assignments property updated with direct consequences of the constraints of the theory.

This propagation is less complete than `propagate()`.

Parameters **tag** (*S*) – the status of propagated assignments

Return type *idp_engine.Theory.Theory*

propagate(*tag=Status.CONSEQUENCE, method=Propagation.DEFAULT, complete=False*)

Returns the theory with its assignments property updated with values for all terms and atoms that have the same value in every model of the theory.

`self.satisfied` is also updated to reflect satisfiability.

Terms and propositions starting with `_` are ignored.

Args:

tag (*S*, **optional**): **the status of propagated assignments.** Defaults to `CONSEQUENCE`.

method (**Propagation**, **optional**): **the particular propagation to use.** Defaults to standard propagation.

complete (**bool**, **optional**): **True when requiring a propagation** including negated function value assignments. Defaults to `False`.

Parameters

- **tag** (*idp_engine.Assignments.Status*) –
- **method** (*idp_engine.Theory.Propagation*) –
- **complete** (*bool*) –

Return type *idp_engine.Theory.Theory*

get_range(*term, complete=False*)

Returns a list of the possible values of the term.

Parameters

- **term** (*str*) – terms whose possible values are requested, e.g. `subtype()`. Must be a key in `self.assignments`
- **complete** (*bool*) –

Returns e.g., `['right triangle', 'regular triangle']`

Return type `List[str]`

explain(*consequence=None, timeout_seconds=0*)

Returns the facts and laws that make the Theory unsatisfiable, or that explains a consequence. Raises an `IDPZ3Error` if the Theory is satisfiable

Parameters

- **self** (*Theory*) – the problem state
- **consequence** (*string, optional*) – the code of the consequence to be explained. Must be a key in `self.assignments`
- **timeout_seconds** (*int*) –

Returns list of facts and laws that explain the consequence

Return type (List[Assignment], List[Expression])

simplify (*for_relevance=False*)

Returns a simpler copy of the theory, with a simplified formula obtained by substituting terms and atoms by their known values.

Parameters **for_relevance** – If true, numeric comparisons with known values are ignored.

Return type *idp_engine.Theory.Theory*

decision_table (*goal_string=""*, *timeout_seconds=20*, *max_rows=50*, *first_hit=True*, *verify=False*)

Experimental. Returns the rows for a decision table that defines `goal_string`.

`goal_string` must be a predicate application defined in the theory. The theory must be created with `extended=True`.

Parameters

- **goal_string** (*str*, *optional*) – the last column of the table.
- **timeout_seconds** (*int*, *optional*) – maximum duration in seconds. Defaults to 20.
- **max_rows** (*int*, *optional*) – maximum number of rows. Defaults to 50.
- **first_hit** (*bool*, *optional*) – requested hit-policy. Defaults to True.
- **verify** (*bool*, *optional*) – request verification of table completeness. Defaults to False

Returns the non-empty cells of the decision table for `goal_string`, given `self`. `bool`: whether or not the timeout limit was reached.

Return type list(list(Assignment))

3.2 Command Line Interface

IDP-Z3 can be run through a Command Line Interface.

If you have downloaded IDP-Z3 from the GitLab repo, you may run the CLI using poetry (see [Installation](#)):

```
poetry run python3 idp-engine.py path/to/file.idp
```

where `path/to/file.idp` is the path to the file containing the IDP-Z3 program to be run. This file must contain an *FO-dot* knowledge base (vocabulary, theory and structure blocks), and a *main block*.

Alternatively, if you installed it via pip, you can run it with the following command:

```
idp-engine path/to/file.idp
```

The usage of the CLI is as follows:

```
usage: idp-engine.py [-h] [--version] [-o OUTPUT] [--full-formula] [--no-timing] FILE
```

IDP-Z3

positional arguments:

FILE path to the .idp file

options:

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```

-h, --help          show this help message and exit
--version, -v       show program's version number and exit
-o OUTPUT, --output OUTPUT
                    name of the output file
--full-formula      show the full formula
--no-timing         don't display timing information

```

3.3 Python API

The core of the IDP-Z3 software is a Python component [available on Pypi](#). The following code illustrates how to invoke it.

```

from idp_engine import IDP, Theory, duration
kb = IDP.from_file("path/to/file.idp")
T, S = kb.get_blocks("T, S")
theory = Theory(T, S)
for model in theory.expand():
    print(model)
duration("End")

```

The file `path/to/file.idp` must contain an *FO-dot* knowledge base (with vocabulary, theory and, optionally, structure blocks).

`idp_engine` exposes *useful functions*, as well as the `Theory` (described [here](#)) and `IDP` classes.

3.3.1 IDP class

The `IDP` class exposes the following methods:

class `IDP(**kwargs)`

The class of AST nodes representing an IDP-Z3 program.

__init__(**kwargs)

classmethod `from_file(file)`

parse an IDP program from file

Parameters `file` (*str*) – path to the source file

Returns the result of parsing the IDP program

Return type *IDP*

classmethod `from_str(code)`

parse an IDP program

Parameters `code` (*str*) – source code to be parsed

Returns the result of parsing the IDP program

Return type *IDP*

classmethod `parse(file_or_string)`

DEPRECATED: parse an IDP program

Parameters `file_or_string` (*str*) – path to the source file, or the source code itself

Returns the result of parsing the IDP program

Return type *IDP*

get_blocks(*blocks*)

returns the AST nodes for the blocks whose names are given

Parameters **blocks** (*List[str]*) – list of names of the blocks to retrieve

Returns list of AST nodes

Return type List[Union[Vocabulary, TheoryBlock, Structure, Procedure, Display]]

execute(*capture_print=False*)

Execute the main() procedure block in the IDP program

Parameters

- **self** (*idp_engine.Parse.IDP*) –
- **capture_print** (*bool*) –

Return type Optional[str]

INTERACTIVE CONSULTANT

The Interactive Consultant tool enables experts to digitize their knowledge of a specific problem domain. With the resulting knowledge base, an online interface is automatically created that serves as a web tool supporting end users to find solutions for specific problems within that knowledge domain.

The tool uses source code in the IDP-Z3 language as input. It recognizes the *annotations in vocabulary* and *in expressions*. However, there are some specific changes and additions when using IDP-Z3 in the Interactive Consultant, which are explained further in this chapter.

4.1 Display block

The *display block* configures the user interface of the *Interactive Consultant*. It consists of a set of *display facts*, i.e., *predicate* and *function applications* terminated by ..

The following predicates and functions are available:

expand `expand := {`s1, .., `sn}`. specifies that *symbols* `s1, .., sn` are shown expanded, i.e., that all sub-sentences of the theory where they occur are shown on the screen.

For example, `expand := {`length}`. will force the Interactive Consultant to show all sub-sentences containing *length*.

hide `hide(`s1, .., `sn)` specifies that symbols `s1, .., sn` are not shown on the screen.

For example, `hide(`length)`. will force the Interactive Consultant to not display the box containing *length* information.

view() `view() = normal`. (default) specifies that symbols are displayed in normal mode.

`view() = expanded`. specifies that symbols are displayed expanded.

goal_symbol `goal_symbol := {`s1, .., `sn}`. specifies that symbols `s1, .., sn` are always relevant, i.e. that they should never be greyed out. `goal_symbol` can only be used in an enumeration.

Irrelevant symbols and questions, i.e. expressions whose interpretation do not constrain the interpretation of the relevant symbols, are greyed out by the Interactive Consultant.

moveSymbols When the *display block* contains `moveSymbols()`, the Interactive Consultant is allowed to change the layout of symbols on the screen, so that relevant symbols come first.

By default, the symbols do not move.

optionalPropagation When the *display block* contains `optionalPropagation()`, a toggle button is shown next to the menu to allow toggling immediate propagation on and off.

By default, this button is not present.

manualPropagation When `manualPropagation()` is present in the *display block*, automatic propagation is disabled in the interface. Instead, a button is added to the menu that computes propagation when clicked.

optionalRelevance When the *display block* contains `optionalRelevance()`, a toggle button is shown next to the menu to allow toggling immediate computation of relevance on and off.

By default, this button is not present.

manualRelevance When `manualRelevance()` is present in the *display block*, automatic computation of relevant questions is disabled in the interface. Instead, a menu option is available in the “Reasoning” menu that computes relevance when selected.

unit `unit('unitstr', `s1, ..., `sn)` specifies the unit of one or more symbols. This unit will then show up in the symbol’s header in the Interactive Consultant. `unitstr` may not be a symbol declared in the vocabulary.

For example: `unit('m', `length, `perimeter)`.

heading Experimental: this feature is likely to change in the future.

`heading('label', `p1, ..., `pn)` will force the display of the `p1, ..., pn` symbols under a heading called `label`. `label` may not be a symbol declared in the vocabulary.

counter `counter := {`p1, ..., `pn}` Enables a counter displaying the number of possible values next to drop-downs in the IC.

introduction `introduction('html text')` allows you to show an introductory message when the interface is opened, which can for instance be used to communicate the purpose of a KB to a user. This message may be formatted in html.

noOptimization `noOptimization(`s1, .., `sn)` specifies that no optimization buttons appear in the Interactive Consultant for symbols `s1, .., sn`.

For example, `noOptimization(`angle)`. will hide the arrow up and arrow down buttons next to the input fields for *angle*.

4.2 Environment & Decision

Often, some elements of a problem instance are under the control of the user (possibly indirectly), while others are not.

To capture this difference, the FO[] language allows the creation of 2 vocabularies and 2 theories. The first one is called ‘environment’, the second ‘decision’. Hence, a more advanced skeleton of an IDP-Z3 program is:

```
vocabulary environment {
  // here comes the specification of the vocabulary to describe the environment
}

vocabulary decision {
  import environment
  // here comes the specification of the vocabulary to describe the decisions and
  ↪ their consequences
}

theory environment:environment {
  // here comes the definitions and axioms satisfied by any environment possibly faced
  ↪ by the user
}

theory decision:decision {
```

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```
// here comes the definitions and axioms to be satisfied by any solution
}

structure environment:environment {
  // here comes the interpretation of some environmental symbols
}

structure decision:decision {
  // here comes the interpretation of some decision symbols
}

display {
  // here comes the configuration of the user interface
}
```

4.3 Default Structure

The *default structure* functions similarly to a normal *Structure*, in the sense that it can be used to set values of symbols. However, these values are set as if they were given by the user: they are shown in the interface as selected values. The symbols can still be assigned different values, or they can be unset.

In this way, this type of structure is used to form a *default* set of values for symbols. Such a structure is given the name 'default', to denote that it specifies default values. The syntax of the block remains the same.

```
structure default {
  // here comes the structure
}
```

4.4 Alternative Notations

Besides the FO(-) editor, IDP-Z3's online interface also supports some other notations to offer an alternative modeling language for specific types of problems. These alternative languages can help lower modeling difficulty for those problems, but are not well-suited for other problem domains.

4.4.1 cDMN

cDMN is short for *constraint Decision Model and Notation*, a user-friendly and table-based alternative for a fragment of FO(-). If you would like to learn more about it, you can find more information on [the cDMN documentation](#).

4.4.2 Feature Modeling

Feature modeling is an industry standard for modeling product configurations in a visual way, by building a tree-like structure which represents all the possible configurations of a product. For more information on feature modeling, check out its tutorial page in the IDP-Z3 web environment.

EXPLANATIONS

This section clarifies particular topics.

5.1 Type checking

IDP-Z3 performs a static type check of the statements in each theory and structure block. It determines the type of each sub-expression, and checks that this type is expected where the sub-expression occurs.

Declaring a subset of integers can not be done as follows.

```
vocabulary V {  
  type Row  
  c: -> Row  
}  
theory { c() < 3. }  
structure S1:V { Row := {1..5}. }  
structure S2:V { Row := {A, B, C}. }
```

IDP-Z3 does not accept the theory because it cannot infer that $c()$ is a number in $c() < 3$. Indeed, it depends on whether $S1$ or $S2$ is used.

If Row is intended to be a set of integers that can be used in arithmetic expressions, it should be declared in the vocabulary as a subtype of Int :

```
type Row <: Int
```

At some point, we may decide that the elements of $type\ Row := \{1..5\}$ are identifiers that may not participate in arithmetic expressions.

5.2 Type inference in quantifications

It is often convenient to omit the type of variables in quantifications and aggregates, e.g.,

```
! p: 0 =< age(p).
```

It is also customary to use evocative names for variables, e.g., to use p for a variable ranging over persons, or col for a variable ranging over a set of columns. By extension, one would also consider $p1$, $p2$ as variables ranging over persons.

Therefore, we allow knowledge engineers to declare variables in the vocabulary, e.g.,

```
var p in Person
var col in Column
```

This allows IDP-Z3 to properly infer the type of `p` in our example above. IDP-Z3 also uses the variable declaration to infer the type of variables `p1, p2, ...`, e.g., in `? p1, p2: married(p1, p2)`. (the variable declaration in the vocabulary cannot end with a number)

Note that the variable declaration is only used when the type is not given in the quantification. In `! p in Column: ...`, `p` ranges over the set of Columns, even if variable `p` is declared differently in the vocabulary.

Note also that `! p, c in Col: ..` raises an error because `p` is ambiguous: is it a Person or a Col ?

5.3 Recursive datatypes

A recursive data type is a datatype whose constructor accepts arguments of the type being declared. An idiomatic example is a list of Int:

```
type List := constructed from {nil, cons(car:Int, cdr: List)}
```

Note that this List only contains Int. A different type declaration must be used for lists of other types (with different constructors).

A list `[1, 2, 3]` can be constructed as follows:

```
cons(1, cons(2, cons(3, nil)))
```

The length of the list can be computed using a recursive definition:

```
len: (List) -> Int // in vocabulary block

// in definition block
{ (recursive)
  len(nil) = 0.
  ! x in List: len(x) = len(cdr(x))+1 <- is_cons(x).
}
```

The `(recursive)` keyword is required to avoid non-terminating model search on satisfiable theories. Model search for an unsatisfiable theory with recursive definitions usually do not terminate, as the reasoning engine considers ever longer lists. This prevents the use of recursive datatypes for propagation and explanation problems, and thus in the Interactive Consultant.

Recursive datatypes and recursive definitions are natively supported by the Z3 solver that powers the IDP-Z3 reasoning engine.

Here is a definition of membership:

```
member: Int * List -> Bool // in vocabulary block

{ (recursive)
  ! x in Int, l in List: member(x,l) <- is_cons(l) & car(l)=x.
  ! x in Int, l in List: member(x,l) <- is_cons(l) & member(x, cdr(l)).
}
```

A definition can be used to express that the numbers in a list are positive.

```

positive: List -> Bool
l: () -> List

{ (recursive)
  ! x in List: positive(x) <- is_nil(x).
  ! x in List: positive(x) <- is_cons(x) & 0 < car(x) & positive(cdr(x)).
}
positive(l()).

```

(At some point, we might provide a generic List type, with quantification over the list: ! x in l(): 0 < x..)

Here is a complete code example, to find a list of 2 positive Integers that are in increasing order, and containing 1 and 2:

```

vocabulary V {
  type List1 := constructed from {nil1, cons1(car1:Int, cdr1: List1)}
  a: () -> List1
  len1: List1 -> Int
  increasing, positive: List1 -> Bool
  member: Int*List1 -> Bool
}

theory T:V {

  { (recursive)
    len1(nil1) = 0.
    ! x in List1: len1(x) = len1(cdr1(x))+1 <- is_cons1(x). }

  // between 1 and 2
  { (recursive)
    ! x in List1: positive(x) <- is_nil1(x).
    ! x in List1: positive(x) <- is_cons1(x) & 0 < car1(x) < 3 & positive(cdr1(x)).
  }

  { (recursive)
    ! l in List1, x in Int: member(x,l) <- is_cons1(l) & car1(l)=x.
    ! x in Int, l in List1: member(x,l) <- is_cons1(l) & member(x, cdr1(l)).
  }

  { (recursive)
    ! x in List1: increasing(x) <- x = nil1.
    ! x in List1: increasing(x) <- is_cons1(x) & is_nil1(cdr1(x)).
    ! x in List1: increasing(x) <- is_cons1(x) & increasing(cdr1(x))
      & is_cons1(cdr1(x)) & car1(x) < car1(cdr1(x)).}

  len1(a()) = 2. //a() has 2 elements
  positive(a()). // the elements in a() are positive
  increasing(a()). // the elements in a() are increasing
  member(1, a()) | member(2, a()). // 1 and 2 are elements in a()
}

procedure main() {
  print(Theory(T).sexpr())
}

```

(continues on next page)

(continued from previous page)

```
pretty_print(model_expand(T, max=1, sort=True))
}
```

Its output is:

```
Model 1
=====
a := cons1(1, cons1(2, nil)).
```

APPENDIX: IDP-Z3 INTERNAL REFERENCE

Warning: This reference is only intended for the **core IDP-Z3 development team**. If you do not work on the IDP-Z3 engine itself, but just want to use it in your applications, please use our *Python API* instead.

The components of IDP-Z3 are shown below.

- [webIDE](#) client: browser-based application to edit and run IDP-Z3 programs
- [Interactive Consultant](#) client: browser-based user-friendly decision support application
- [Read_the_docs](#) : online documentation
- [Homepage](#)
- IDP-Z3 server: web server for both web applications
- IDP-Z3 command line interface
- IDP-Z3 engine: performs reasoning on IDP-Z3 theories
- [Z3](#): [SMT solver](#) developed by Microsoft

The source code of IDP-Z3 is publicly available under the GNU LGPL v3 license. You may want to check the [Development and deployment guide](#).

6.1 Architecture

This document presents the technical architecture of IDP-Z3.

Essentially, the IDP-Z3 components translate the requested inferences on the knowledge base into satisfiability problems that Z3 can solve.

6.1.1 Web clients

The source code for the web clients is in the [IDP_Z3_web_client](#) folder.

The clients are written in [Typescript](#), using the [Angular](#) framework (version 7.1), and the [primeNG](#) library of widgets. It uses the [Monaco](#) editor. The interactions with the server are controlled by [idp.service.ts](#). The [AppSettings](#) file contains important settings, such as the address of the IDP-Z3 sample theories.

The web clients are sent to the browser by the IDP-Z3 server as static files. The static files are generated by the `/IDP-Z3/deploy.py` script as part of the deployment, and saved in the `/IDP-Z3/idp_web_server/static` folder.

See the Appendix of [Development and deployment guide](#) on the wiki for a discussion on how to set-up your environment to develop web clients.

The `/docs/zettlr/REST.md` file describes the format of the data exchanged between the web client and the server. The exchange of data while using web clients can be visualised in the developer mode of most browsers (Chrome, Mozilla, ...).

The web clients could be packaged into an executable using [nativefier](#).

6.1.2 Read The Docs, Homepage

The [online documentation](#) and [Homepage](#) are written in [ReStructuredText](#), generated using [sphinx](#) and hosted on [readthedocs.org](#) and [GitLab Pages](#) respectively. The contents is in the `/docs` and `/homepage` folders of IDP-Z3.

We use the following sphinx extensions: [Mermaid \(diagrams\)](#), and [Markdown](#).

6.1.3 IDP-Z3 server

The code for the IDP-Z3 server is in the `/idp_web_server` folder.

The IDP-Z3 server is written in python 3.8, using the [Flask framework](#). Pages are served by `/idp_web_server/rest.py`. Static files are served from the `/idp_web_server/static` directory, including the compiled version of the client software.

At start-up, and every time the idp code is changed on the client, the idp code is sent to the `/meta` URL by the client. The server responds with the list of symbols to be displayed. A subsequent call (`/eval`) returns the questions to be displayed. After that, when the user clicks on a GUI element, information is sent to the `/eval` URL, and the server responds as necessary.

The information given by the user is combined with the idp code (in [State.py](#)), and, using adequate inferences, the questions are put in these categories with their associated value (if any):

- given: given by the user
- universal: always true (or false), per idp code
- consequences: consequences of user's input according to theory
- irrelevant: made irrelevant by user's input
- unknown

The IDP-Z3 server implements custom inferences such as the computation of relevance ([Inferences.py](#)), and the handling of environmental vs. decision variables.

API endpoints

The IDP-Z3 server exposes multiple API endpoints, which are used to communicate information between the interface and server.

/run

POST: Runs an IDP program containing a main block. The program is executed by the IDP-Z3 directly, and the output is returned. This endpoint is e.g. used to execute the code in the IDP webIDE.

Arguments:

- **code:** IDP code, containing a main block.

Returns:

- A string, containing the output of the IDP-Z3 engine after executing the program.

/meta

POST: generate the metaJSON for an IDP program. In the IC, this metaJSON is among others used to correctly layout the different symbol tiles and to generate extra expanded symbols.

Arguments:

- **code:** IDP code, with or without main block.

Returns:

- **symbols:** contains information on each symbol used in the FO(\cdot) specification. This information includes symbol name, type, view, ...
- **optionalPropagation:** a bool representing if a propagation toggle should be shown in the interface.
- **manualPropagation:** a bool representing if propagation should be manual via a button.
- **optionalRelevance:** a bool representing if a relevance toggle should be shown in the interface.
- **manualRelevance:** a bool representing if relevance computation should be manual via a button.
- **valueinfo:** contains information on the values for each symbol used in the FO(\cdot) specification.

/eval

POST: execute one of IDP-Z3's inference methods.

Arguments:

- **method:** string containing the method to execute. Supported methods are: *getEnglish*, *propagate*, *get_range*, *modeexpand*, *explain*, *minimize*, and *abstract*.
- **code:** the IDP code.
- **active:** the active assignments, already input in the interface.
- **previous_active:** the assignments after the last full propagation.
- **ignore:** user-disabled laws to ignore.
- **symbol:** the name of a symbol, only used for *minimize*, *explain*.
- **value:** a value, only used for *explain*.
- **field:** the applied symbol for which a range must be determined, only for *get_range*.
- **minimize:** *true* for minimization, *false* for maximization.

Returns:

- **Global**: the global information of the current state of the IC.
- A field for every symbol that appears in the IDP program, containing all its information.

6.1.4 IDP-Z3 engine

The code for the IDP-Z3 engine and IDP-Z3-CLI is in the `/idp_engine` folder. The IDP-Z3 engine exposes an API implemented by *Run.py* and *Problem.py*.

Translating knowledge inferences into satisfiability problems that Z3 can solve involves these steps:

1. parsing the idp code and the info entered by the user,
2. converting it to the Z3 format,
3. calling the appropriate method,
4. formatting the response.

The IDP-Z3 code is parsed into an **abstract syntax tree (AST)** using the `textx` package, according to [this grammar](#). There is one python class per type of AST nodes (see *Parse.py* and *Expression.py*)

The conversion to the Z3 format is performed by the following passes over the AST generated by the parser:

1. annotate the nodes by resolving names, and computing some derived information (e.g. type) (`annotate()`)
2. expand quantifiers in the theory, as far as possible. (`interpret()`)
3. when a structure is given, use the interpretation (`interpret()`), i.e.:
 - a) expand quantifiers based on the structure (grounding); perform type inference as necessary;
 - b) simplify the theory using the data in the structure and the laws of logic;
 - c) instantiate the definitions for every calls of the defined symbols (recursively)
4. convert to Z3, adding the type constraints not enforced by Z3 (`.translate()`)

`Substitute()` modifies the AST “in place”. Because the results of step 1-2 are cached, steps 4-7 are done after copying the AST (`custom copy()`).

The graph of calls is outlined below:

The code is organised by steps, not by classes: for example, all methods to annotate an expression by another are grouped in *Annotate.py*. These methods are always imported into the classes at the top of the declaration.

Important classes of the IDP-Z3 engine are: `Expression`, `Assignment`, `Theory`.

Below is a simplified class diagram for the classes of the Abstract Syntax tree.

And a simplified class diagram for the `Theory` class:

6.1.5 Z3

See [this tutorial](#) for an introduction to Z3 (or [this guide](#)).

You may also want to refer to the [Z3py reference](#).

6.1.6 Appendix: Dependencies and Licences

The IDP-Z3 tools are published under the [GNU LGPL v3 license](#).

The server software uses the following components (see [requirements.txt](#)):

- Z3: MIT license
- Z3-solver: MIT license
- Flask: BSD License (BSD-3-Clause)
- flask_restful : BSD license
- flask_cors : MIT license
- pycallgraph2 : GNU GPLv2
- gunicorn : MIT license
- textx: MIT license

The client-side software uses the following components:

- Angular: MIT-style license
- PrimeNg: MIT license
- ngx-monaco-editor: MIT license
- packery: GPL-3.0
- primeicons: MIT
- isotope-layout: GNU GPL-3.0
- isotope-packery: MIT
- core-js: MIT
- dev: None
- git-describe: MIT
- rxjs: Apache 2.0
- tslib: Apache 2.0
- zone.js: MIT

6.2 Datamodel

Datamodel for type checking:

6.3 idp_engine module

6.3.1 idp_engine.Parse

Classes to parse an IDP-Z3 theory.

str_to_IDP(*val_string*, *type_*)

recursive function to decode a *val_string* in set *type_*

Parameters

- **type** (*SetName*) – set containing the value
- **val_string** (*str*) – a string containing a value
- **type_** (*idp_engine.Expression.SetName*) –

Raises **IDPZ3Error** – if wrong value

Returns the internal representation of the value

Return type *Expression*

class **ViewType**(*value*)

Bases: *enum.Enum*

An enumeration.

class **IDP**(***kwargs*)

Bases: *idp_engine.Expression.ASTNode*

The class of AST nodes representing an IDP-Z3 program.

__init__(***kwargs*)

classmethod **from_file**(*file*)

parse an IDP program from file

Parameters **file** (*str*) – path to the source file

Returns the result of parsing the IDP program

Return type *IDP*

classmethod **from_str**(*code*)

parse an IDP program

Parameters **code** (*str*) – source code to be parsed

Returns the result of parsing the IDP program

Return type *IDP*

classmethod **parse**(*file_or_string*)

DEPRECATED: parse an IDP program

Parameters **file_or_string** (*str*) – path to the source file, or the source code itself

Returns the result of parsing the IDP program

Return type *IDP*

get_blocks(*blocks*)

returns the AST nodes for the blocks whose names are given

Parameters **blocks** (*List[str]*) – list of names of the blocks to retrieve

Returns list of AST nodes

Return type List[Union[Vocabulary, TheoryBlock, Structure, Procedure, Display]]

execute(*capture_print=False*)

Execute the main() procedure block in the IDP program

Parameters

- **self** (*idp_engine.Parse.IDP*) –
- **capture_print** (*bool*) –

Return type Optional[str]

class Vocabulary(*parent, name, prefixes, declarations*)

Bases: *idp_engine.Expression.ASTNode*

The class of AST nodes representing a vocabulary block.

Parameters

- **parent** (*ASTNode*) –
- **name** (*str*) –
- **declarations** (*List[Union[Declaration, VarDeclaration, Import]]*) –

__init__(*parent, name, prefixes, declarations*)

Parameters

- **parent** (*idp_engine.Expression.ASTNode*) –
- **name** (*str*) –
- **declarations** (*List[Union[idp_engine.Parse.TypeDeclaration, idp_engine.Parse.SymbolDeclaration, idp_engine.Parse.VarDeclaration, idp_engine.Parse.Import]]*) –

add_voc_to_block(*block*)

adds the enumerations in a vocabulary to a theory or structure block

Parameters **block** (*Theory*) – the block to be updated

class Import(***kwargs*)

Bases: *idp_engine.Expression.ASTNode*

__init__(***kwargs*)

class TypeDeclaration(*parent, name, constructors=None, enumeration=None, super_set=None*)

Bases: *idp_engine.Expression.ASTNode*

AST node to represent *type <symbol> := <enumeration>*

Parameters

- **name** (*string*) – name of the type
- **arity** (*int*) – the number of arguments
- **domains** (*List[SetName]*) – a singleton list with a set having the type's name
- **codomain** (*SetName*) – the Boolean type
- **super_sets** (*List[SetName]*) – super-type
- **constructors** (*[Constructor]*) – list of constructors in the enumeration

- **interpretation** (*SymbolInterpretation*) – the symbol interpretation
- **map** (*dict[string, Expression]*) – a mapping from code to Expression in range
- **block** (*Vocabulary*) – the vocabulary block that contains it
- **symbol_expr** (*SymbolExpr*) – the symbol expression for the type
- **prefix** (*Optional[str]*) – the type’s prefix
- **enumeration** (*Optional[Enumeration]*) –
- **super_set** (*Optional[SetName]*) –

__init__ (*parent, name, constructors=None, enumeration=None, super_set=None*)

Parameters

- **name** (*str*) –
- **constructors** (*Optional[List[idp_engine.Expression.Constructor]]*) –
- **enumeration** (*Optional[idp_engine.Parse.Enumeration]*) –
- **super_set** (*Optional[idp_engine.Expression.SetName]*) –

contains_element (*term, extensions*)

returns an Expression that is TRUE when *term* is in the type

Parameters

- **term** (*Expression*) –
- **extensions** (*dict[str, Extension]*) –

Return type Expression

class SymbolDeclaration (*parent, annotations, sorts, sort_, symbols=None, name=None, partiality=None, repeat_name=None, domains=None, codomain=None, super_sets=None*)

Bases: *idp_engine.Expression.ASTNode*

The class of AST nodes representing an entry in the vocabulary, declaring one or more symbols. Multi-symbols declaration are replaced by single-symbol declarations before the `annotate()` stage.

Parameters

- **annotations** (*Optional[Annotations]*) –
- **sorts** (*List[SetName]*) –
- **sort_** (*SetName*) –
- **symbols** (*Optional[List[str]]*) –
- **name** (*Optional[str]*) –
- **partiality** (*Optional[str]*) –
- **repeat_name** (*Optional[str]*) –
- **domains** (*Optional[List[SetName]]*) –
- **codomain** (*Optional[SetName]*) –
- **super_sets** (*Optional[List[SetName]]*) –

annotations

the annotations given by the expert.

annotations['reading'] is the annotation giving the intended meaning of the expression (in English).

symbols

the symbols being defined, before expansion

Type [str]

name

the identifier of the symbol, after expansion of the node

Type string

arity

the number of arguments

Type int

sorts

the types of the arguments

Type List[SetName]

out

the type of the symbol applied to arguments

Type SetName

domains

the domain of the symbol (as a cross-product)

Type List[SetName]

codomain

the codomain of the symbol

Type SetName

super_sets

for predicates: immediate superset of the interpretation.

Type List[SetName]

symbol_expr

symbol expression of the same name

Type SymbolExpr, Optional

instances

a mapping from the code of a symbol applied to a tuple of arguments to its parsed AST

Type dict[string, Expression]

range

the list of possible values

Type List[Expression]

private

True if the symbol name starts with '_' (for use in IC)

Type Bool

block

the vocabulary where it is defined

unit

the unit of the symbol, such as m (meters)

Type str

heading

the heading that the symbol should belong to

Type str

optimizable

whether this symbol should get optimize buttons in the IC

Type bool

counter

whether this symbol should get a number counter in the IC

Type bool

by_z3

True if the symbol is created by z3 (testers and accessors of constructors)

Type Bool

__init__(*parent, annotations, sorts, sort_, symbols=None, name=None, partiality=None, repeat_name=None, domains=None, codomain=None, super_sets=None*)

Parameters

- **annotations** (*Optional[List[idp_engine.Expression.Annotations]*) –
- **sorts** (*List[idp_engine.Expression.SetName]*) –
- **sort_** (*idp_engine.Expression.SetName*) –
- **symbols** (*Optional[List[str]]*) –
- **name** (*Optional[str]*) –
- **partiality** (*Optional[str]*) –
- **repeat_name** (*Optional[str]*) –
- **domains** (*Optional[List[idp_engine.Expression.SetName]]*) –
- **codomain** (*Optional[idp_engine.Expression.SetName]*) –
- **super_sets** (*Optional[List[idp_engine.Expression.SetName]]*) –

has_in_domain(*args, interpretations, extensions*)

Returns an expression that is TRUE when *args* are in the domain of the symbol.

Parameters

- **args** (*List[Expression]*) – the list of arguments to be checked, e.g. [1, 2]
- **interpretations** (*dict[str, 'SymbolInterpretation']*) –
- **extensions** (*dict[str, Extension]*) –

Returns whether (1,2) is in the domain of the symbol

Return type Expression

has_in_range(*value, interpretations, extensions*)

Returns an expression that says whether *value* is in the range of the symbol.

Parameters

- **value** (*Expression*) –
- **interpretations** (*dict[str, 'SymbolInterpretation']*) –
- **extensions** (*dict[str, Extension]*) –

Return type *Expression***contains_element** (*term, extensions*)returns an *Expression* that is TRUE when *term* satisfies the predicate**Parameters**

- **term** (*Expression*) –
- **extensions** (*dict[str, Extension]*) –

Return type *Expression***class VarDeclaration** (***kwargs*)Bases: *idp_engine.Expression.ASTNode*

represents a declaration of variable (IEP 24)

name

name of the variable

Type *str***subtype**

type of the variable

Type *SetName***prefix**

prefix of the variable

Type *str, Optional***__init__** (***kwargs*)**class TheoryBlock** (***kwargs*)Bases: *idp_engine.Expression.ASTNode*

The class of AST nodes representing a theory block.

__init__ (***kwargs*)**class Definition** (*parent, annotations, mode, rules*)Bases: *idp_engine.Expression.Expression*

The class of AST nodes representing an inductive definition.

Parameters **annotations** (*Optional[Annotations]*) –**id**

unique identifier for each definition

Type *num***rules**set of rules for the definition, e.g., $!x: p(x) \leftarrow q(x)$ **Type** [*Rule*]

renamed

rules with normalized body for each defined symbol, e.g., $!x: p(x) \leftarrow q(pI_)$ (quantees and head are unchanged)

Type dict[Declaration, List[Rule]]

canonicals

normalized rule for each defined symbol, e.g., $! pI_: p(pI_) \leftarrow q(pI_)$

Type dict[Declaration, List[Rule]]

clarks

normalized rule for each defined symbol (used to be Clark completion) e.g., $! pI_: p(pI_) \iff q(pI_)$

Type dict[Declaration, Transformed Rule]

def_vars

Fresh variables for arguments and result

Type dict[String, dict[String, Variable]]

inductive

set of SymbolDeclaration with an inductive definition

Type set[SymbolDeclaration]

cache

cache of instantiation of the definition

Type dict[SymbolDeclaration, str, Expression]

inst_def_level

depth of recursion during instantiation

Type int

annotate(*voc*, *q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.Expression*) –

Returns an equivalent AST node, with updated type, .variables

Return type Expression

get_def_constraints(*problem*, *for_explain=False*)

returns the constraints for this definition.

The *instantiables* (of the definition) are expanded in *problem*.

Parameters

- **problem** (*Theory*) – contains the structure for the expansion/interpretation of the constraints
- **for_explain** (*Bool*) – Use implications instead of equivalence, for rule-specific explanations

- **self** (*Parse.Definition*) –

Returns a mapping from (SymbolDeclaration, Definition) to the list of constraints

Return type dict[SymbolDeclaration, Definition, List[Expression]]

interpret(*problem*)

updates problem.def_constraints, by expanding the definitions

Parameters

- **problem** (*Theory*) – contains the enumerations for the expansion; is updated with the expanded definitions
- **self** (*Parse.Definition*) –

Return type None

__init__(*parent, annotations, mode, rules*)

Parameters **annotations** (*Optional[idp_engine.Expression.Annotations]*) –

class Rule(*parent, annotations, quantees, definiendum, out, body*)

Bases: idp_engine.Expression.Expression

Parameters

- **annotations** (*Annotations*) –
- **quantees** (*List[Quantee]*) –
- **definiendum** (*AppliedSymbol*) –
- **out** (*Expression*) –
- **body** (*Expression*) –

annotate(*voc, q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.Expression*) –

Returns an equivalent AST node, with updated type, .variables

Return type Expression

instantiate_definition(*new_args, theory*)

Create an instance of the definition for new_args, and interpret it for theory.

Parameters

- **new_args** (*[Expression]*) – tuple of arguments to be applied to the defined symbol
- **theory** (*Theory*) – the context for the interpretation
- **self** (*Parse.Rule*) –

Returns a boolean expression

Return type Expression

__init__(*parent, annotations, quantees, definiendum, out, body*)

Parameters

- **annotations** (*idp_engine.Expression.Annotations*) –
- **quantees** (*List[idp_engine.Expression.Quantee]*) –
- **definiendum** (*idp_engine.Expression.AppliedSymbol*) –
- **out** (*idp_engine.Expression.Expression*) –
- **body** (*idp_engine.Expression.Expression*) –

class Structure(***kwargs*)

Bases: *idp_engine.Expression.ASTNode*

The class of AST nodes representing an structure block.

annotate_block(*idp*)

Annotates the structure with the enumerations found in it. Every enumeration is converted into an assignment, which is added to *self.assignments*.

Parameters

- **idp** (*idp_engine.Parse.IDP*) – a *Parse.IDP* object.
- **self** (*idp_engine.Expression.ASTNode*) –
- **idp** –

Returns None

Return type Union[Exception, List[Exceptions]]

__init__(***kwargs*)

The textx parser creates the Structure object. All information used in this method directly comes from text.

class SymbolInterpretation(*parent, name, sign, enumeration, default*)

Bases: *idp_engine.Expression.Expression*

AST node representing *<symbol> := { <identifiers*> } else <default>*.

Parameters

- **name** (*UnappliedSymbol*) –
- **sign** (*str*) –
- **enumeration** (*Enumeration*) –
- **default** (*Optional[Expression]*) –

name

name of the symbol being enumerated.

Type string

symbol_decl

symbol being enumerated

Type SymbolDeclaration

enumeration

enumeration.

Type [Enumeration]

default

default value (for function enumeration).

Type Expression

is_type_enumeration

True if the enumeration is for a type symbol.

Type Bool

annotate(*voc, q_vars*)

Annotate the symbol.

Parameters

- **block** – a Structure object
- **self** (*Expr.Expression*) –
- **voc** (*Parse.Vocabulary*) –
- **q_vars** (*dict[str, Expr.Variable]*) –

Returns None

Return type Expr.Expression

interpret(*problem*)

expand quantifiers and replace symbols interpreted in the structure by their interpretation

Parameters

- **self** (*Parse.SymbolInterpretation*) – the expression to be interpreted
- **problem** (*Theory*) – the theory to be applied
- **subs** – a dictionary mapping variable names to their value

Returns the interpreted expression

Return type Expression

__init__(*parent, name, sign, enumeration, default*)

Parameters

- **name** (*idp_engine.Expression.UnappliedSymbol*) –
- **sign** (*str*) –
- **enumeration** (*idp_engine.Parse.Enumeration*) –
- **default** (*Optional[idp_engine.Expression.Expression]*) –

interpret_application(*rank, applied, args, tuples=None*)

returns an expression equivalent to *self.symbol* applied to *args*, simplified by the interpretation of *self.symbol*.

This is a recursive function.

Example: assume $f: \{(1,2) \rightarrow A, (1,3) \rightarrow B, (2,1) \rightarrow C\}$ and $args=[g(1),2]$. The returned expression is: `if g(1) = 1 then A else if g(1)=2 then f(g(1),2) else f(g(1),2)`

Parameters

- **rank** (*Int*) – iteration number (from 0)

- **applied** (*AppliedSymbol*) – template to create new *AppliedSymbol* (ex: $g(I),a()$, before interpretation)
- **args** (*List(Expression)*) – interpreted arguments applied to the symbol (ex: $g(I),2$)
- **tuples** (*OrderedSet[TupleIDP]*, *optional*) – relevant tuples for this iteration. Initialized with $[[1,2,A], [1,3,B], [2,1,C]]$

Returns Grounded interpretation of self.symbol applied to args

Return type Expression

class Enumeration(*parent*, *tuples*)

Bases: *idp_engine.Expression.Expression*

Represents an enumeration of tuples of expressions. Used for predicates, or types without n-ary constructors.

Parameters

- **parent** (*ASTNode*) –
- **tuples** (*List[TupleIDP]*) –

tuples

OrderedSet of TupleIDP of Expression

Type OrderedSet[TupleIDP]

sorted_tuples

a sorted list of tuples

lookup

dictionary from arguments to values

constructors

List of Constructor

Type List[Constructor], optional

annotate(*voc*, *q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.Expression*) –

Returns an equivalent AST node, with updated type, .variables

Return type Expression

interpret(*problem*)

expand quantifiers and replace symbols interpreted in the structure by their interpretation

Parameters

- **self** (*Parse.Enumeration*) – the expression to be interpreted
- **problem** (*Theory*) – the theory to be applied
- **subs** – a dictionary mapping variable names to their value

Returns the interpreted expression

Return type Expression

__init__(*parent, tuples*)

Parameters

- **parent** (*idp_engine.Expression.ASTNode*) –
- **tuples** (*List[idp_engine.Parse.TupleIDP]*) –

contains(*args, arity=None, rank=0, tuples=None, theory=None*)
returns an Expression that says whether Tuple args is in the enumeration

Parameters

- **arity** (*Optional[int]*) –
- **rank** (*int*) –
- **tuples** (*Optional[List[TupleIDP]]*) –
- **theory** (*Optional[Theory]*) –

Return type Expression

extensionE(*extensions=None*)
computes the extension of an enumeration, i.e., a set of tuples and a filter

Parameters

- **interpretations** (*dict[str, "SymbolInterpretation"], optional*) – *_description_*. Defaults to None.
- **extensions** (*dict[str, Extension], optional*) – *_description_*. Defaults to None.

Returns *_description_*

Return type Extension

class FunctionEnum(*parent, tuples*)
Bases: *idp_engine.Parse.Enumeration*

Parameters

- **parent** (*ASTNode*) –
- **tuples** (*List[TupleIDP]*) –

extensionE(*extensions=None*)
computes the extension of an enumeration, i.e., a set of tuples and a filter

Parameters

- **interpretations** (*dict[str, "SymbolInterpretation"], optional*) – *_description_*. Defaults to None.
- **extensions** (*dict[str, Extension], optional*) – *_description_*. Defaults to None.

Returns *_description_*

Return type Extension

class CSVEnumeration(*parent, tuples*)
Bases: *idp_engine.Parse.Enumeration*

Parameters

- **parent** (*ASTNode*) –
- **tuples** (*List[TupleIDP]*) –

class ConstructedFrom(*parent, constructed, constructors*)

Bases: `idp_engine.Parse.Enumeration`

Represents a ‘constructed from’ enumeration of constructors

Parameters

- **parent** (*Optional[ASTNode]*) –
- **constructed** (*str*) –
- **constructors** (*List[Constructor]*) –

tuples

OrderedSet of tuples of Expression

Type OrderedSet[TupleIDP], Optional

constructors

List of Constructor

Type List[Constructor]

accessors

index of the accessor in the constructors

Type dict[str, int]

annotate(*voc, q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.ASTNode*) –

Returns an equivalent AST node, with updated type, .variables

Return type Expression

interpret(*problem*)

expand quantifiers and replace symbols interpreted in the structure by their interpretation

Parameters

- **self** (*Parse.ConstructedFrom*) – the expression to be interpreted
- **problem** (*Theory*) – the theory to be applied
- **subs** – a dictionary mapping variable names to their value

Returns the interpreted expression

Return type Expression

__init__(*parent, constructed, constructors*)

Parameters

- **parent** (*Optional*[*idp_engine.Expression.ASTNode*]) –
- **constructed** (*str*) –
- **constructors** (*List*[*idp_engine.Expression.Constructor*]) –

contains(*args*, *arity=None*, *rank=0*, *tuples=None*, *theory=None*)

returns True if args belong to the type enumeration

Parameters

- **arity** (*Optional*[*int*]) –
- **rank** (*int*) –
- **tuples** (*Optional*[*List*[*TupleIDP*]]) –
- **theory** (*Optional*[*Theory*]) –

Return type *Expression*

extensionE(*extensions=None*)

computes the extension of an enumeration, i.e., a set of tuples and a filter

Parameters

- **interpretations** (*dict*[*str*, *"SymbolInterpretation"*], *optional*) – *_description_*. Defaults to None.
- **extensions** (*dict*[*str*, *Extension*], *optional*) – *_description_*. Defaults to None.

Returns *_description_*

Return type *Extension*

class TupleIDP(***kwargs*)

Bases: *idp_engine.Expression.Expression*

annotate(*voc*, *q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict*[*str*, *Variable*]) – the quantifier variables that may appear in the expression
- **self** (*Expr.Expression*) –

Returns an equivalent AST node, with updated type, *.variables*

Return type *Expression*

translate(*problem*)

Converts the syntax tree to a Z3 expression, with lookup in *problem.z3*

Parameters

- **problem** (*Theory*) – holds the context for the translation (e.g. a cache of translations).
- **vars** (*dict*[*id*, *ExprRef*], *optional*) – mapping from *Variable*'s *id* to Z3 translation. Filled in by *AQuantifier*. Defaults to {}.

Returns Z3 expression

Return type *ExprRef*

```

    __init__(**kwargs)
class FunctionTuple(**kwargs)
    Bases: idp_engine.Parse.TupleIDP
    __init__(**kwargs)
class CSVTuple(**kwargs)
    Bases: idp_engine.Parse.TupleIDP
class Ranges(parent, **kwargs)
    Bases: idp_engine.Parse.Enumeration
    Parameters parent (ASTNode) –
    __init__(parent, **kwargs)

    Parameters parent (idp_engine.Expression.ASTNode) –
contains(args, arity=None, rank=0, tuples=None, theory=None)
    returns an Expression that says whether Tuple args is in the enumeration
    Parameters
        • arity (Optional[int]) –
        • rank (int) –
        • tuples (Optional[List[TupleIDP]]) –
        • theory (Optional[Theory]) –
    Return type Expression
extensionE(extensions=None)
    computes the extension of an enumeration, i.e., a set of tuples and a filter
    Parameters
        • interpretations (dict[str, &quot;SymbolInterpretation&quot;], optional) – _description_. Defaults to None.
        • extensions (dict[str, Extension], optional) – _description_. Defaults to None.
    Returns _description_
    Return type Extension
class RangeElement(**kwargs)
    Bases: idp_engine.Expression.Expression
    __init__(**kwargs)
class IntRange
    Bases: idp_engine.Parse.Ranges
    __init__()
    extensionE(extensions=None)
        computes the extension of an enumeration, i.e., a set of tuples and a filter
        Parameters
            • interpretations (dict[str, &quot;SymbolInterpretation&quot;], optional) – _description_. Defaults to None.
            • extensions (dict[str, Extension], optional) – _description_. Defaults to None.

```

Returns `_description_`

Return type `Extension`

class `RealRange`

Bases: `idp_engine.Parse.Ranges`

`__init__()`

extensionE(*extensions=None*)

computes the extension of an enumeration, i.e., a set of tuples and a filter

Parameters

- **interpretations** (*dict[str, "SymbolInterpretation"], optional*) – `_description_`. Defaults to `None`.
- **extensions** (*dict[str, Extension], optional*) – `_description_`. Defaults to `None`.

Returns `_description_`

Return type `Extension`

class `DateRange`

Bases: `idp_engine.Parse.Ranges`

`__init__()`

extensionE(*extensions=None*)

computes the extension of an enumeration, i.e., a set of tuples and a filter

Parameters

- **interpretations** (*dict[str, "SymbolInterpretation"], optional*) – `_description_`. Defaults to `None`.
- **extensions** (*dict[str, Extension], optional*) – `_description_`. Defaults to `None`.

Returns `_description_`

Return type `Extension`

class `Display`(***kwargs*)

Bases: `idp_engine.Expression.ASTNode`

`__init__`(***kwargs*)

`run`(*idp*)

Apply the display block to the idp theory

class `Procedure`(***kwargs*)

Bases: `idp_engine.Expression.ASTNode`

`__init__`(***kwargs*)

class `Call1`(***kwargs*)

Bases: `idp_engine.Expression.ASTNode`

`__init__`(***kwargs*)

class `String`(***kwargs*)

Bases: `idp_engine.Expression.ASTNode`

`__init__`(***kwargs*)

class `PyList`(***kwargs*)

Bases: `idp_engine.Expression.ASTNode`

```
    __init__(**kwargs)
class PyAssignment(**kwargs)
    Bases: idp_engine.Expression.ASTNode
    __init__(**kwargs)
```

6.3.2 idp_engine.Expression

This module contains the ASTNode classes for expressions. Note that many methods are imported from other modules, as done at the top of each class.

```
class ASTNode
    Bases: object
    superclass of all AST nodes
    check(condition, msg)
        raises an exception if condition is not True
        Parameters
            • condition (Bool) – condition to be satisfied
            • msg (str) – error message
        Raises IDPZ3Error – when condition is not met
    dedup_nodes(kwargs, arg_name)
        pops arg_name from kwargs as a list of named items and returns a mapping from name to items
        Parameters
            • kwargs (dict[str, List[ASTNode]]) – dictionary mapping named arguments to list of ASTNodes
            • arg_name (str) – name of the kwargs argument, e.g. “interpretations”
        Returns mapping from name to AST nodes
        Return type dict[str, ASTNode]
        Raises AssertionError – in case of duplicate name
class Annotations(parent, annotations)
    Bases: idp_engine.Expression.ASTNode
        Parameters annotations (List[str]) –
    __init__(parent, annotations)
        Parameters annotations (List[str]) –
class Accessor(parent, out, accessor=None)
    Bases: idp_engine.Expression.ASTNode
    represents an accessor and a type
        Parameters
            • out (SetName) –
            • accessor (Optional[str]) –
```

accessor

name of accessor function

Type str, Optional

codomain

name of the output type of the accessor

Type SetName

decl

declaration of the accessor function

Type SymbolDeclaration

__init__(*parent, out, accessor=None*)

Parameters

- **out** (*idp_engine.Expression.SetName*) –
- **accessor** (*Optional[str]*) –

class Expression(*parent=None, annotations=None*)

Bases: *idp_engine.Expression.ASTNode*

The abstract class of AST nodes representing (sub-)expressions.

Parameters

- **parent** (*Optional[ASTNode]*) –
- **annotations** (*Optional[Annotations]*) –

code

Textual representation of the expression. Often used as a key.

It is generated from the sub-tree.

Type string

str

Textual representation of the simplified expression.

Type string

sub_exprs

The children of the AST node.

The list may be reduced by simplification.

Type List[Expression]

type

The type of the expression, e.g., bool.

Type SetName, Optional

co_constraint

A constraint attached to the node.

For example, the `co_constraint` of `square(length(top()))` is `square(length(top())) = length(top())*length(top())`., assuming `square` is appropriately defined.

The `co_constraint` of a defined symbol applied to arguments is the instantiation of the definition for those arguments. This is useful for definitions over infinite domains, as well as to compute relevant questions.

Type Expression, optional

annotations

The set of annotations given by the expert in the IDP-Z3 program.

`annotations['reading']` is the annotation giving the intended meaning of the expression (in English).

Type dict[str, str]

original

The original expression, before propagation and simplification.

Type Expression

variables

The set of names of the variables in the expression, before interpretation.

Type Set(string)

is_type_constraint_for

name of the symbol for which the expression is a type constraint

Type string

WDF

a formula that is true only when *self* is well-defined (for partial functions)

Type Expression, optional

annotate(*voc*, *q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.Expression*) –

Returns an equivalent AST node, with updated type, .variables

Return type Expression

fill_attributes_and_check()

annotations that are common to `__init__` and `make()`

Parameters **self** (*idp_engine.Expression.Expression*) –

Return type *idp_engine.Expression.Expression*

add_level_mapping(*level_symbols*, *head*, *pos_justification*, *polarity*, *mode*)

Returns an expression where level mapping atoms (e.g., `lvl_p > lvl_q`) are added to atoms containing recursive symbols.

Parameters

- **level_symbols** (-) – the level mapping symbols as well as their corresponding recursive symbols
- **head** (-) – head of the rule we are adding level mapping symbols to.

- **pos_justification** (-) – whether we are adding symbols to the direct positive justification (e.g., head => body) or direct negative justification (e.g., body => head) part of the rule.
- **polarity** (-) – whether the current expression occurs under negation.
- **self** (*Expr.Expression*) –
- **mode** (*Semantics*) –

Return type *Expr.Expression*

collect_nested_symbols (*symbols, is_nested*)

returns the set of symbol declarations that occur (in)directly under an aggregate or some nested term, where *is_nested* is flipped to True the moment we reach such an expression

returns {*Parse.SymbolDeclaration*}

Parameters

- **self** (*idp_engine.Expression.Expression*) –
- **symbols** (*Set[idp_engine.Parse.SymbolDeclaration]*) –
- **is_nested** (*bool*) –

Return type *Set[idp_engine.Parse.SymbolDeclaration]*

translate (*problem, vars={}*)

Converts the syntax tree to a Z3 expression, with lookup in *problem.z3*

Parameters

- **problem** (*Theory*) – holds the context for the translation (e.g. a cache of translations).
- **vars** (*dict[id, ExprRef], optional*) – mapping from Variable's id to Z3 translation. Filled in by *AQuantifier*. Defaults to {}.

Returns Z3 expression

Return type *ExprRef*

interpret (*problem, subs*)

expand quantifiers and replace symbols interpreted in the structure by their interpretation

Parameters

- **self** (*Expr.Expression*) – the expression to be interpreted
- **problem** (*Optional[Theory]*) – the theory to be applied
- **subs** (*dict[str, Expr.Expression]*) – a dictionary mapping variable names to their value

Returns the interpreted expression

Return type *Expression*

update_exprs (*new_exprs*)

change *sub_exprs* and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.Expression*) –
- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –

Return type *idp_engine.Expression.Expression*

propagate1(*assignments, tag, truth*)

returns the list of symbolic_propagate of self, ignoring value and simpler

simplify_with(*assignments, co_constraints_too=True*)

simplify the expression using the assignments

Parameters

- **self** (*Expr.Expression*) –
- **assignments** (*Assignments*) –

Return type Expr.Expression

substitute(*e0, e1, assignments, tag=None*)

recursively substitute e0 by e1 in self (e0 is not a Variable)

if tag is present, updates assignments with symbolic propagation of co-constraints.

implementation for everything but AppliedSymbol, UnappliedSymbol and Fresh_variable

symbolic_propagate(*assignments, tag, truth=None*)

updates assignments with the consequences of *self=truth*.

The consequences are obtained by symbolic processing (no calls to Z3).

Parameters

- **assignments** (*Assignments*) – The set of assignments to update.
- **truth** (*Expression, optional*) – The truth value of the expression *self*. Defaults to TRUE.
- **tag** (*Status*) –

fill_WDF()

Compute the Well-definedness condition of an Expression

Parameters **self** (*idp_engine.Expression.Expression*) –

Return type idp_engine.Expression.Expression

merge_WDFs()

Combine the WDF of the sub-expressions of self

Parameters **self** (*idp_engine.Expression.Expression*) –

Return type idp_engine.Expression.Expression

__init__(*parent=None, annotations=None*)

Parameters

- **parent** (*Optional[idp_engine.Expression.ASTNode]*) –
- **annotations** (*Optional[idp_engine.Expression.Annotations]*) –

collect(*questions, all_=True, co_constraints=True*)

collects the questions in self.

questions is an OrderedSet of Expression Questions are the terms and the simplest sub-formula that can be evaluated.

all_=False : ignore expanded formulas and AppliedSymbol interpreted in a structure

co_constraints=False : ignore co_constraints

default implementation for UnappliedSymbol, AIfExpr, AUnary, Variable, Number_constant, Brackets

Parameters

- **questions** (*idp_engine.utils.OrderedSet*) –
- **all_** (*bool*) –
- **co_constraints** (*bool*) –

collect_symbols(*symbols=None, co_constraints=True*)

returns the list of symbols occurring in self, ignoring type constraints and symbols created by aggregates

Parameters

- **symbols** (*Optional[dict[str, SymbolDeclaration]]*) –
- **co_constraints** (*bool*) –

Return type dict[str, SymbolDeclaration]

generate_constructors(*constructors*)

fills the list *constructors* with all constructors belonging to open types.

Parameters **constructors** (*dict[str, List[Constructor]]*) –

collect_co_constraints(*co_constraints, recursive=True*)

collects the constraints attached to AST nodes, e.g. instantiated definitions

Parameters

- **recursive** – if True, collect co_constraints of co_constraints too
- **co_constraints** (*idp_engine.utils.OrderedSet*) –

is_value()

True for numerals, date, identifiers, and constructors applied to values.

Synonym: “is ground”, “is rigid”

Returns True if *self* represents a value.

Return type bool

is_reified()

False for values and for symbols applied to values.

Returns True if *self* has to be reified to obtain its value in a Z3 model.

Return type bool

is_assignment()

Returns True if *self* assigns a rigid term to a rigid function application

Return type bool

as_set_condition()

Returns an equivalent expression of the type “x in y”, or None

Returns meaning “expr is (not) in enumeration”

Return type Tuple[Optional[AppliedSymbol], Optional[bool], Optional[Enumeration]]

split_equivalences()

Returns an equivalent expression where equivalences are replaced by implications

Returns Expression

Return type `idp_engine.Expression.Expression`

class `Constructor`(*parent, name, args=None*)

Bases: `idp_engine.Expression.ASTNode`

Constructor declaration

Parameters

- **parent** (*Optional[ASTNode]*) –
- **name** (*str*) –
- **args** (*Optional[List[Accessor]]*) –

name

name of the constructor

Type `string`

args

Type `List[Accessor]`

sorts

types of the arguments of the constructor

Type `List[SetName]`

out

type that contains this constructor

Type `SetName`

arity

number of arguments of the constructor

Type `Int`

tester

function to test if the constructor

Type `SymbolDeclaration, Optional`

has been applied to some arguments

Type `e.g., is_rgb`

concept_decl

declaration with name[1:],

Type `SymbolDeclaration, Optional`

only for Concept constructors.

range

the list of identifiers

prefix

the constructor's prefix

Type `str, Optional`

__init__(*parent, name, args=None*)

Parameters

- **parent** (*Optional* [*idp_engine.Expression.ASTNode*]) –
- **name** (*str*) –
- **args** (*Optional* [*List* [*idp_engine.Expression.Accessor*]]) –

class **SetName**(*parent, name, ins=None, out=None*)

Bases: *idp_engine.Expression.Expression*

ASTNode representing a (sub-)type or a *Concept[aSignature]*, e.g., *Concept[T*T->Bool]*

Inherits from *Expression*

Parameters

- **name** (*str*) – name of the concept
- **concept_domains** (*List* [*SetName*], *Optional*) – domain of the Concept signature, e.g., [*T, T*]
- **codomain** (*SetName*, *Optional*) – range of the Concept signature, e.g., *Bool*
- **decl** (*Declaration*, *Optional*) – declaration of the type
- **root_set** (*List* [*SetName*]) – cross-product of root sets that include this set. Used for type checking.
- **ins** (*Optional* [*List* [*SetName*]]) –
- **out** (*Optional* [*SetName*]) –

annotate(*voc, q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict* [*str*, *Variable*]) – the quantifier variables that may appear in the expression
- **self** (*Expr.Expression*) –

Returns an equivalent AST node, with updated type, .variables

Return type *Expression*

translate(*problem, vars={}*)

Converts the syntax tree to a Z3 expression, with lookup in *problem.z3*

Parameters

- **problem** (*Theory*) – holds the context for the translation (e.g. a cache of translations).
- **vars** (*dict* [*id*, *ExprRef*], *optional*) – mapping from *Variable*'s id to Z3 translation. Filled in by *AQuantifier*. Defaults to {}.

Returns Z3 expression

Return type *ExprRef*

extension(*extensions*)

returns the extension of a *SetName*, given some interpretations.

Normally, the extension is already in *extensions* by *SymbolDeclaration.interpret*. However, for *Concept[T->T]*, an additional filtering is applied.

Parameters

- **interpretations** (*dict[str, SymbolInterpretation]*) –
- **symbols** (*the known interpretations of types and*) –
- **extensions** (*dict[str, Expr.Extension]*) –

Returns a superset of the extension of self, and a function that, given arguments, returns an Expression that says whether the arguments are in the extension of self

Return type Extension

__init__ (*parent, name, ins=None, out=None*)

Parameters

- **name** (*str*) –
- **ins** (*Optional[List[idp_engine.Expression.SetName]]*) –
- **out** (*Optional[idp_engine.Expression.SetName]*) –

is_value()

True for numerals, date, identifiers, and constructors applied to values.

Synonym: “is ground”, “is rigid”

Returns True if *self* represents a value.

Return type bool

has_element (*term, extensions*)

Returns an Expression that says whether *term* is in the type/predicate denoted by *self*.

Parameters

- **term** (*Expression*) – the argument to be checked
- **extensions** (*dict[str, Extension]*) –

Returns whether *term term* is in the type denoted by *self*.

Return type Expression

class AIfExpr (*parent, if_f, then_f, else_f*)

Bases: `idp_engine.Expression.Expression`

Parameters

- **if_f** (*Expression*) –
- **then_f** (*Expression*) –
- **else_f** (*Expression*) –

fill_attributes_and_check()

annotations that are common to `__init__` and `make()`

Parameters **self** (*idp_engine.Expression.AIfExpr*) –

Return type `idp_engine.Expression.Expression`

collect_nested_symbols (*symbols, is_nested*)

returns the set of symbol declarations that occur (in) directly under an aggregate or some nested term, where *is_nested* is flipped to True the moment we reach such an expression

returns {`Parse.SymbolDeclaration`}

Parameters

- **self** (*idp_engine.Expression.AIfExpr*) –
- **symbols** (*Set[idp_engine.Parse.SymbolDeclaration]*) –
- **is_nested** (*bool*) –

Return type *Set[idp_engine.Parse.SymbolDeclaration]*

translate1(*problem, vars={}*)

Converts the syntax tree to a Z3 expression, without lookup in *problem.z3*

A lookup is wasteful when *self* is a subformula of a formula that is not in *problem.z3*.

Parameters

- **problem** (*Theory*) – holds the context for the translation (e.g. a cache of translations).
- **vars** (*dict[id, ExprRef], optional*) – mapping from Variable's id to Z3 translation. Filled in by AQuantifier. Defaults to {}.

Returns Z3 expression

Return type *ExprRef*

update_exprs(*new_exprs*)

change *sub_exprs* and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.AIfExpr*) –
- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –

Return type *idp_engine.Expression.Expression*

merge_WDFs()

Combine the WDF of the sub-expressions of *self*

__init__(*parent, if_f, then_f, else_f*)

Parameters

- **if_f** (*idp_engine.Expression.Expression*) –
- **then_f** (*idp_engine.Expression.Expression*) –
- **else_f** (*idp_engine.Expression.Expression*) –

class **Quantee**(*parent, vars, subtype=None, sort=None*)

Bases: *idp_engine.Expression.Expression*

represents the description of quantification, e.g., *x in T* or *(x,y) in P* The *Concept* type may be qualified, e.g. *Concept[Color->Bool]*

Parameters

- **vars** (*Union[List[Variable], List[List[Variable]]]*) –
- **subtype** (*Optional[SetName]*) –
- **sort** (*Optional[SymbolExpr]*) –

vars

the (tuples of) variables being quantified

Type *List[List[Variable]]*

subtype

a literal SetName to quantify over, e.g., *Color* or *Concept[Color->Bool]*.

Type SetName, Optional

sort

a dereferencing expression, e.g., $\$(i)$.

Type SymbolExpr, Optional

sub_exprs

the (unqualified) type or predicate to quantify over,

Type List[SymbolExpr], Optional

e.g., ``[Color]`, `[Concept]` or `[$`

Type *i*

arity

the length of the tuple of variables

Type int

decl

the (unqualified) Declaration to quantify over, after resolution of $\$(i)$.

Type SymbolDeclaration, Optional

e.g., the declaration of ``Color``

fill_attributes_and_check()

annotations that are common to `__init__` and `make()`

Parameters `self (idp_engine.Expression.AQuantification)` –

Return type `idp_engine.Expression.Expression`

translate(problem, vars={})

Converts the syntax tree to a Z3 expression, with lookup in `problem.z3`

Parameters

- **problem** (`Theory`) – holds the context for the translation (e.g. a cache of translations).
- **vars** (`dict[id, ExprRef]`, *optional*) – mapping from Variable's id to Z3 translation. Filled in by `AQuantifier`. Defaults to `{}`.

Returns Z3 expression

Return type `ExprRef`

`__init__` (*parent, vars, subtype=None, sort=None*)

Parameters

- **vars** (`Union[List[idp_engine.Expression.Variable], List[List[idp_engine.Expression.Variable]]]`) –
- **subtype** (`Optional[idp_engine.Expression.SetName]`) –
- **sort** (`Optional[idp_engine.Expression.SymbolExpr]`) –

split_quantees(self)

replaces an untyped quantee *x,y,z* into 3 quantees, so that each variable can have its own sort

Parameters `self` – either a `AQuantification`, `AAggregate` or `Rule`

class AQuantification(*parent, annotations, q, quantees, f*)

Bases: `idp_engine.Expression.Expression`

ASTNode representing a quantified formula

Parameters

- **annotations** (*dict[str, str]*) – The set of annotations given by the expert in the IDP-Z3 program.
 annotations['reading'] is the annotation giving the intended meaning of the expression (in English).
- **q** (*str*) – either ‘*∃*’ or ‘*∀*’
- **quantees** (*List[Quantee]*) – list of variable declarations
- **f** (*Expression*) – the formula being quantified
- **supersets** – attributes used in *interpret*
- **new_quantees** – attributes used in *interpret*
- **vars1** – attributes used in *interpret*
- **parent** (*Optional[ASTNode]*) –

annotate(*voc, q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.Expression*) –

Returns an equivalent AST node, with updated type, .variables

Return type `Expression`

fill_attributes_and_check()

annotations that are common to `__init__` and `make()`

Parameters **self** (*idp_engine.Expression.AQuantification*) –

Return type `idp_engine.Expression.Expression`

update_exprs(*new_exprs*)

change `sub_exprs` and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.AQuantification*) –
- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –

Return type `Union[idp_engine.Expression.AConjunction, idp_engine.Expression.ADisjunction]`

merge_WDFs()

Combine the WDF of the sub-expressions of `self`

`__init__`(*parent, annotations, q, quantees, f*)

Parameters

- **parent** (*Optional[idp_engine.Expression.ASTNode]*) –
- **annotations** (*Optional[idp_engine.Expression.Annotations]*) –
- **q** (*str*) –
- **quantees** (*List[idp_engine.Expression.Quantee]*) –
- **f** (*idp_engine.Expression.Expression*) –

classmethod make (*q, quantees, f, annotations=None*)
make and annotate a quantified formula

Parameters

- **q** (*str*) –
- **quantees** (*List[idp_engine.Expression.Quantee]*) –
- **f** (*idp_engine.Expression.Expression*) –
- **annotations** (*Optional[Dict[str, Union[str, Dict[str, Any]]]]*) –

Return type AQuantification

collect (*questions, all_=True, co_constraints=True*)
collects the questions in self.

questions is an OrderedSet of Expression Questions are the terms and the simplest sub-formula that can be evaluated.

all_=False : ignore expanded formulas and AppliedSymbol interpreted in a structure

co_constraints=False : ignore co_constraints

default implementation for UnappliedSymbol, AIfExpr, AUnary, Variable, Number_constant, Brackets

collect_symbols (*symbols=None, co_constraints=True*)
returns the list of symbols occurring in self, ignoring type constraints and symbols created by aggregates

class AGenExist (*parent, annotations, q, operator, number, quantees, f*)
Bases: *idp_engine.Expression.Expression*

Represents a generalised existential quantification of the form “ OP INT quantor: f”, with OP a comparison operator and INT an integer literal. It represents a shorthand for a cardinality, “#{OP: f} OP INT”. For example, “=1 c in Country: color_of(c) = Blue” states that there must be exactly one country that is assigned blue.

annotate (*voc, q_vars*)
annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expression*) –

Returns an equivalent AST node, with updated type, .variables

Return type Expression

__init__ (*parent, annotations, q, operator, number, quantees, f*)

```

class Operator(parent, operator, sub_exprs, annotations=None)
    Bases: idp_engine.Expression.Expression

    Parameters annotations (Optional[Annotations]) –

fill_attributes_and_check()
    annotations that are common to __init__ and make()

    Parameters self (idp_engine.Expression.Operator) –

    Return type idp_engine.Expression.Expression

collect_nested_symbols(symbols, is_nested)
    returns the set of symbol declarations that occur (in)directly under an aggregate or some nested term, where
    is_nested is flipped to True the moment we reach such an expression

    returns {Parse.SymbolDeclaration}

    Parameters

    • self (idp_engine.Expression.Operator) –
    • symbols (Set[idp_engine.Parse.SymbolDeclaration]) –
    • is_nested (bool) –

__init__(parent, operator, sub_exprs, annotations=None)

    Parameters annotations (Optional[idp_engine.Expression.Annotations]) –

classmethod make(ops, operands, annotations=None, parent=None)
    creates a BinaryOp beware: cls must be specific for ops !

    Parameters

    • ops (Union[str, List[str]]) –
    • operands (List[idp_engine.Expression.Expression]) –
    • annotations (Optional[Dict[str, Union[str, Dict[str, Any]]]]) –

    Return type idp_engine.Expression.Expression

collect(questions, all_=True, co_constraints=True)
    collects the questions in self.

    questions is an OrderedSet of Expression Questions are the terms and the simplest sub-formula that can be
    evaluated.

    all_=False : ignore expanded formulas and AppliedSymbol interpreted in a structure
    co_constraints=False : ignore co_constraints

    default implementation for UnappliedSymbol, AIfExpr, AUnary, Variable, Number_constant, Brackets

class AImplication(parent, operator, sub_exprs, annotations=None)
    Bases: idp_engine.Expression.Operator

    Parameters annotations (Optional[Annotations]) –

fill_attributes_and_check()
    annotations that are common to __init__ and make()

    Parameters self (idp_engine.Expression.AImplication) –

    Return type idp_engine.Expression.Expression

```

add_level_mapping(*level_symbols, head, pos_justification, polarity, mode*)

Returns an expression where level mapping atoms (e.g., `lvl_p > lvl_q`) are added to atoms containing recursive symbols.

Parameters

- **level_symbols** (-) – the level mapping symbols as well as their corresponding recursive symbols
- **head** (-) – head of the rule we are adding level mapping symbols to.
- **pos_justification** (-) – whether we are adding symbols to the direct positive justification (e.g., `head => body`) or direct negative justification (e.g., `body => head`) part of the rule.
- **polarity** (-) – whether the current expression occurs under negation.
- **self** (*Expr.Expression*) –
- **mode** (*Semantics*) –

Return type *Expr.Expression*

update_exprs(*new_exprs*)

change *sub_exprs* and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.AImplication*) –
- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –

Return type *idp_engine.Expression.Expression*

merge_WDFs()

Combine the WDF of the sub-expressions of *self*

class AEquivalence(*parent, operator, sub_exprs, annotations=None*)

Bases: *idp_engine.Expression.Operator*

Parameters *annotations* (*Optional[Annotations]*) –

fill_attributes_and_check()

annotations that are common to `__init__` and `make()`

Parameters **self** (*idp_engine.Expression.AEquivalence*) –

Return type *idp_engine.Expression.Expression*

update_exprs(*new_exprs*)

change *sub_exprs* and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.AEquivalence*) –
- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –

Return type *idp_engine.Expression.Expression*

split_equivalences()

Returns an equivalent expression where equivalences are replaced by implications

Returns *Expression*

class `ARImplication`(*parent, operator, sub_exprs, annotations=None*)

Bases: `idp_engine.Expression.Operator`

Parameters `annotations` (*Optional[Annotations]*) –

annotate(*voc, q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.ARImplication*) –

Returns an equivalent AST node, with updated type, .variables

Return type `Expression`

add_level_mapping(*level_symbols, head, pos_justification, polarity, mode*)

Returns an expression where level mapping atoms (e.g., `lvl_p > lvl_q`) are added to atoms containing recursive symbols.

Parameters

- **level_symbols** (-) – the level mapping symbols as well as their corresponding recursive symbols
- **head** (-) – head of the rule we are adding level mapping symbols to.
- **pos_justification** (-) – whether we are adding symbols to the direct positive justification (e.g., `head => body`) or direct negative justification (e.g., `body => head`) part of the rule.
- **polarity** (-) – whether the current expression occurs under negation.
- **self** (*Expr.ARImplication*) –
- **mode** (*Semantics*) –

Return type `Expr.Expression`

class `ADisjunction`(*parent, operator, sub_exprs, annotations=None*)

Bases: `idp_engine.Expression.Operator`

Parameters `annotations` (*Optional[Annotations]*) –

fill_attributes_and_check()

annotations that are common to `__init__` and `make()`

Parameters `self` (*idp_engine.Expression.Expression*) –

Return type `idp_engine.Expression.Expression`

update_exprs(*new_exprs, replace=True*)

change `sub_exprs` and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.Expression*) –

- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –
- **replace** (*bool*) –

Return type *idp_engine.Expression.Expression*

merge_WDFs()
Combine the WDF of the sub-expressions of self

class AConjunction(*parent, operator, sub_exprs, annotations=None*)
Bases: *idp_engine.Expression.Operator*

Parameters annotations (*Optional[Annotations]*) –

fill_attributes_and_check()
annotations that are common to `__init__` and `make()`

Parameters self (*idp_engine.Expression.Expression*) –

Return type *idp_engine.Expression.Expression*

update_exprs(*new_exprs, replace=True*)
change sub_exprs and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.Expression*) –
- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –
- **replace** (*bool*) –

Return type *idp_engine.Expression.Expression*

propagate1(*assignments, tag, truth=None*)
returns the list of symbolic_propagate of self, ignoring value and simpler

merge_WDFs()
Combine the WDF of the sub-expressions of self

class AComparison(*parent, operator, sub_exprs, annotations=None*)
Bases: *idp_engine.Expression.Operator*

Parameters annotations (*Optional[Annotations]*) –

annotate(*voc, q_vars*)
annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.AComparison*) –

Returns an equivalent AST node, with updated type, .variables

Return type *Expression*

fill_attributes_and_check()
annotations that are common to `__init__` and `make()`

Parameters self (*idp_engine.Expression.AppliedSymbol*) –

Return type `idp_engine.Expression.Expression`

translate_acomparison_optimum(*problem, lhs, op, rhs, vars={}*)

Optimized translation method for `_very_` specific circumstances in which one child is a count and the other child is a literal int (or a symbol interpreted as one). This allows us to use Z3's `AtLeast` and `AtMost` (<https://z3prover.github.io/api/html/namespacesz3py.html#a0369f15ecdb913e47fc7bb645fcfcf08>) instead of converting the aggregate to a sum of it's.

Parameters

- **problem** (`Theory`) –
- **lhs** (`Expr.Expression`) –
- **op** (`Expr.Expression`) –
- **rhs** (`Expr.Expression`) –

Return type `ExprRef`

as_set_condition()

Returns an equivalent expression of the type “x in y”, or None

Returns meaning “expr is (not) in enumeration”

Return type `Tuple[Optional[AppliedSymbol], Optional[bool], Optional[Enumeration]]`

Parameters **self** (`idp_engine.Expression.AComparison`) –

update_exprs(*new_exprs*)

change `sub_exprs` and simplify, while keeping relevant info.

Parameters

- **self** (`idp_engine.Expression.AComparison`) –
- **new_exprs** (`Generator[idp_engine.Expression.Expression, None, None]`) –

Return type `idp_engine.Expression.Expression`

propagate1(*assignments, tag, truth=None*)

returns the list of symbolic_propagate of self, ignoring value and simpler

is_assignment()

Returns True if *self* assigns a rigid term to a rigid function application

Return type `bool`

class ASumMinus(*parent, operator, sub_exprs, annotations=None*)

Bases: `idp_engine.Expression.Operator`

Parameters **annotations** (`Optional[Annotations]`) –

fill_attributes_and_check()

annotations that are common to `__init__` and `make()`

Parameters **self** (`idp_engine.Expression.ASumMinus`) –

Return type `idp_engine.Expression.Expression`

update_exprs(*new_exprs*)

change `sub_exprs` and simplify, while keeping relevant info.

Parameters

- **self** (`idp_engine.Expression.ASumMinus`) –

- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –

Return type *idp_engine.Expression.Expression*

class AMultDiv(*parent, operator, sub_exprs, annotations=None*)
 Bases: *idp_engine.Expression.Operator*

Parameters annotations (*Optional[Annotations]*) –

fill_attributes_and_check()
 annotations that are common to `__init__` and `make()`

Parameters self (*idp_engine.Expression.AMultDiv*) –

Return type *idp_engine.Expression.Expression*

update_exprs(*new_exprs*)
 change `sub_exprs` and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.AMultDiv*) –
- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –

Return type *idp_engine.Expression.Expression*

merge_WDFs()
 Combine the WDF of the sub-expressions of `self`

class APower(*parent, operator, sub_exprs, annotations=None*)
 Bases: *idp_engine.Expression.Operator*

Parameters annotations (*Optional[Annotations]*) –

fill_attributes_and_check()
 annotations that are common to `__init__` and `make()`

Parameters self (*idp_engine.Expression.APower*) –

Return type *idp_engine.Expression.Expression*

update_exprs(*new_exprs*)
 change `sub_exprs` and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.APower*) –
- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –

Return type *idp_engine.Expression.Expression*

class AUnary(*parent, operators, f*)
 Bases: *idp_engine.Expression.Expression*

Parameters

- **operators** (*List[str]*) –
- **f** (*Expression*) –

fill_attributes_and_check()
 annotations that are common to `__init__` and `make()`

Parameters self (*idp_engine.Expression.AUnary*) –

Return type *idp_engine.Expression.Expression*

add_level_mapping(*level_symbols*, *head*, *pos_justification*, *polarity*, *mode*)

Returns an expression where level mapping atoms (e.g., `lvl_p > lvl_q`) are added to atoms containing recursive symbols.

Parameters

- **level_symbols** (-) – the level mapping symbols as well as their corresponding recursive symbols
- **head** (-) – head of the rule we are adding level mapping symbols to.
- **pos_justification** (-) – whether we are adding symbols to the direct positive justification (e.g., `head => body`) or direct negative justification (e.g., `body => head`) part of the rule.
- **polarity** (-) – whether the current expression occurs under negation.
- **self** (*Expr.AUnary*) –
- **mode** (*Semantics*) –

Return type *Expr.Expression*

as_set_condition()

Returns an equivalent expression of the type “x in y”, or None

Returns meaning “expr is (not) in enumeration”

Return type *Tuple[Optional[AppliedSymbol], Optional[bool], Optional[Enumeration]]*

Parameters **self** (*idp_engine.Expression.AUnary*) –

update_exprs(*new_exprs*)

change sub_exprs and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.AUnary*) –
- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –

Return type *idp_engine.Expression.Expression*

propagate1(*assignments*, *tag*, *truth=None*)

returns the list of symbolic_propagate of self, ignoring value and simpler

__init__(*parent*, *operators*, *f*)

Parameters

- **operators** (*List[str]*) –
- **f** (*idp_engine.Expression.Expression*) –

class AAggregate(*parent*, *agctype*, *quantees*, *term=None*, *condition=None*)

Bases: *idp_engine.Expression.Expression*

Parameters

- **parent** (*Optional[Expression]*) –
- **agctype** (*str*) –
- **quantees** (*List[Quantee]*) –

- **term** (*Optional*[*Expression*]) –
- **condition** (*Optional*[*Expression*]) –

annotate(*voc, q_vars*)

Annotation is dependent on the aggtype.

- Sum/card: the sub_exprs are replaced by equivalent ite expressions
- **Min/max: the aggregate is replaced by an applied symbol representing the min/max,** together with a set of co-constraints to define this.

Parameters

- **self** (*Expr.AAggregate*) –
- **voc** (*Parse.Vocabulary*) –
- **q_vars** (*dict*[*str, Expr.Variable*]) –

Return type *Expr.AAggregate* | *Expr.AppliedSymbol*

fill_attributes_and_check()

annotations that are common to `__init__` and `make()`

Parameters **self** (*idp_engine.Expression.AQuantification*) –

Return type *idp_engine.Expression.Expression*

collect_nested_symbols(*symbols, is_nested*)

returns the set of symbol declarations that occur (in)directly under an aggregate or some nested term, where *is_nested* is flipped to True the moment we reach such an expression

returns {*Parse.SymbolDeclaration*}

Parameters

- **self** (*idp_engine.Expression.AAggregate*) –
- **symbols** (*Set*[*idp_engine.Parse.SymbolDeclaration*]) –
- **is_nested** (*bool*) –

Return type *Set*[*idp_engine.Parse.SymbolDeclaration*]

update_exprs(*new_exprs*)

change sub_exprs and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.AAggregate*) –
- **new_exprs** (*Generator*[*idp_engine.Expression.Expression, None, None*]) –

Return type *idp_engine.Expression.Expression*

merge_WDFs()

Combine the WDF of the sub-expressions of self

__init__(*parent, aggtype, quantees, term=None, condition=None*)

Parameters

- **parent** (*Optional*[*idp_engine.Expression.Expression*]) –
- **aggtype** (*str*) –

- **quantees** (*List[idp_engine.Expression.Quantee]*) –
- **term** (*Optional[idp_engine.Expression.Expression]*) –
- **condition** (*Optional[idp_engine.Expression.Expression]*) –

collect(*questions, all_=True, co_constraints=True*)

collects the questions in self.

questions is an OrderedSet of Expression Questions are the terms and the simplest sub-formula that can be evaluated.

all_=False : ignore expanded formulas and AppliedSymbol interpreted in a structure

co_constraints=False : ignore co_constraints

default implementation for UnappliedSymbol, AIfExpr, AUnary, Variable, Number_constant, Brackets

collect_symbols(*symbols=None, co_constraints=True*)

returns the list of symbols occurring in self, ignoring type constraints and symbols created by aggregates

class AppliedSymbol(*parent, symbol, sub_exprs, annotations=None, is_enumerated="", is_enumeration="", in_enumeration=""*)

Bases: *idp_engine.Expression.Expression*

Represents a symbol applied to arguments

Parameters

- **symbol** (*SymbolExpr*) – the symbol to be applied to arguments
- **is_enumerated** (*string*) – ‘’ or ‘is enumerated’
- **is_enumeration** (*string*) – ‘’ or ‘in’
- **in_enumeration** (*Enumeration*) – the enumeration following ‘in’
- **as_disjunction** (*Optional[Expression]*) – the translation of ‘is_enumerated’ and ‘in_enumeration’ as a disjunction
- **decl** (*Declaration*) – the declaration of the symbol, if known
- **in_head** (*Bool*) – True if the AppliedSymbol occurs in the head of a rule
- **prefix** (*Optional[str]*) – the prefix of the symbol
- **annotations** (*Optional[Annotations]*) –

annotate(*voc, q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.AppliedSymbol*) –

Returns an equivalent AST node, with updated type, .variables

Return type Expression

fill_attributes_and_check(*type_check=True*)

annotations that are common to `__init__` and `make()`

Parameters `self (idp_engine.Expression.AppliedSymbol)` –

Return type `idp_engine.Expression.Expression`

add_level_mapping(*level_symbols, head, pos_justification, polarity, mode*)

Returns an expression where level mapping atoms (e.g., `lvl_p > lvl_q`) are added to atoms containing recursive symbols.

Parameters

- **level_symbols** (-) – the level mapping symbols as well as their corresponding recursive symbols
- **head** (-) – head of the rule we are adding level mapping symbols to.
- **pos_justification** (-) – whether we are adding symbols to the direct positive justification (e.g., `head => body`) or direct negative justification (e.g., `body => head`) part of the rule.
- **polarity** (-) – whether the current expression occurs under negation.
- **self** (*Expr.AppliedSymbol*) –
- **mode** (*Semantics*) –

Return type `Expr.Expression`

collect_nested_symbols(*symbols, is_nested*)

returns the set of symbol declarations that occur (in)directly under an aggregate or some nested term, where `is_nested` is flipped to `True` the moment we reach such an expression

returns `{Parse.SymbolDeclaration}`

Parameters

- **self** (*idp_engine.Expression.AppliedSymbol*) –
- **symbols** (*Set[idp_engine.Parse.SymbolDeclaration]*) –
- **is_nested** (*bool*) –

as_set_condition()

Returns an equivalent expression of the type “x in y”, or `None`

Returns meaning “`expr` is (not) in enumeration”

Return type `Tuple[Optional[AppliedSymbol], Optional[bool], Optional[Enumeration]]`

Parameters `self (idp_engine.Expression.AppliedSymbol)` –

update_exprs(*new_exprs*)

change `sub_exprs` and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.AppliedSymbol*) –
- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –

Return type `idp_engine.Expression.Expression`

propagate1(*assignments, tag, truth=None*)

returns the list of symbolic_propagate of `self`, ignoring value and simpler

substitute(*e0, e1, assignments, tag=None*)
 recursively substitute *e0* by *e1* in self

merge_WDFs()
 Combine the WDF of the sub-expressions of self

__init__(*parent, symbol, sub_exprs, annotations=None, is_enumerated="", is_enumeration="", in_enumeration=""*)

Parameters annotations (*Optional[idp_engine.Expression.Annotations]*) –

collect(*questions, all_=True, co_constraints=True*)
 collects the questions in self.

questions is an OrderedSet of Expression Questions are the terms and the simplest sub-formula that can be evaluated.

all_=False : ignore expanded formulas and AppliedSymbol interpreted in a structure

co_constraints=False : ignore *co_constraints*

default implementation for UnappliedSymbol, AIfExpr, AUnary, Variable, Number_constant, Brackets

collect_symbols(*symbols=None, co_constraints=True*)
 returns the list of symbols occurring in self, ignoring type constraints and symbols created by aggregates

is_value()
 True for numerals, date, identifiers, and constructors applied to values.

Synonym: “is ground”, “is rigid”

Returns True if *self* represents a value.

Return type bool

is_reified()
 False for values and for symbols applied to values.

Returns True if *self* has to be reified to obtain its value in a Z3 model.

Return type bool

generate_constructors(*constructors*)
 fills the list *constructors* with all constructors belonging to open types.

Parameters constructors (*dict*) –

class SymbolExpr(*parent, name, eval, s*)
 Bases: `idp_engine.Expression.Expression`

represents either a type name, a symbol name or a $\$(..)$ expression evaluating to a type or symbol name

Parameters

- **name** (*Optional[str]*) –
- **eval** (*Optional[str]*) –
- **s** (*Optional[Expression]*) –

name
 name of the type or symbol, or None

Type Optional[str]

eval

\$ or None

Type Optional[str]**s**

argument of the \$.

Type Optional[Expression]**decl**

the declaration of the symbol

Type Optional[Declaration]

Either *name* and *decl* are not None, or *eval* and *s* are not None. When *eval* is None, *s* is None too.

annotate(*voc*, *q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict*[*str*, *Variable*]) – the quantifier variables that may appear in the expression
- **self** (*Expr.SymbolExpr*) –

Returns an equivalent AST node, with updated type, .variables**Return type** Expression**update_exprs**(*new_exprs*)

change sub_exprs and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.SymbolExpr*) –
- **new_exprs** (*Generator*[*idp_engine.Expression.Expression*, *None*, *None*]) –

Return type *idp_engine.Expression.Expression***__init__**(*parent*, *name*, *eval*, *s*)**Parameters**

- **name** (*Optional*[*str*]) –
- **eval** (*Optional*[*str*]) –
- **s** (*Optional*[*idp_engine.Expression.Expression*]) –

class UnappliedSymbol(*parent*, *name*)Bases: *idp_engine.Expression.Expression*

The result of parsing a symbol not applied to arguments. Can be a constructor or a quantified variable.

Variables are converted to *Variable()* by *annotate()*.**Parameters**

- **parent** (*Optional*[*ASTNode*]) –
- **name** (*str*) –

annotate(*voc, q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.UnappliedSymbol*) –

Returns an equivalent AST node, with updated type, .variables

Return type Expression

__init__(*parent, name*)

Parameters

- **parent** (*Optional[idp_engine.Expression.ASTNode]*) –
- **name** (*str*) –

classmethod construct(*constructor*)

Create an UnappliedSymbol from a constructor

Parameters constructor (*idp_engine.Expression.Constructor*) –

is_value()

True for numerals, date, identifiers, and constructors applied to values.

Synonym: “is ground”, “is rigid”

Returns True if *self* represents a value.

Return type bool

is_reified()

False for values and for symbols applied to values.

Returns True if *self* has to be reified to obtain its value in a Z3 model.

Return type bool

class Variable(*parent, name, type=None*)

Bases: *idp_engine.Expression.Expression*

AST node for a variable in a quantification or aggregate

Parameters

- **name** (*str*) – name of the variable
- **type** (*Optional[Union[SetName]]*) – sort of the variable, if known

annotate(*voc, q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary

- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.Variable*) –

Returns an equivalent AST node, with updated type, .variables

Return type Expression

translate(*problem, vars={}*)

Converts the syntax tree to a Z3 expression, with lookup in problem.z3

Parameters

- **problem** (*Theory*) – holds the context for the translation (e.g. a cache of translations).
- **vars** (*dict[id, ExprRef], optional*) – mapping from Variable’s id to Z3 translation. Filled in by AQuantifier. Defaults to {}.

Returns Z3 expression

Return type ExprRef

substitute(*e0, e1, assignments, tag=None*)

recursively substitute e0 by e1 in self (e0 is not a Variable)

if tag is present, updates assignments with symbolic propagation of co-constraints.

implementation for everything but AppliedSymbol, UnappliedSymbol and Fresh_variable

__init__(*parent, name, type=None*)

Parameters

- **name** (*str*) –
- **type** (*Optional[idp_engine.Expression.SetName]*) –

fill_attributes_and_check()

annotations that are common to **__init__** and **make**()

Parameters **self** (*idp_engine.Expression.Expression*) –

Return type idp_engine.Expression.Expression

class Number(***kwargs*)

Bases: idp_engine.Expression.Expression

annotate(*voc, q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.Number*) –

Returns an equivalent AST node, with updated type, .variables

Return type Expression

translate(*problem*, *vars*={})

Converts the syntax tree to a Z3 expression, with lookup in `problem.z3`

Parameters

- **problem** (`Theory`) – holds the context for the translation (e.g. a cache of translations).
- **vars** (`dict[id, ExprRef]`, *optional*) – mapping from Variable’s id to Z3 translation. Filled in by `AQuantifier`. Defaults to {}.

Returns Z3 expression

Return type `ExprRef`

`__init__`(***kwargs*)

real()

converts the INT number to REAL

is_value()

True for numerals, date, identifiers, and constructors applied to values.

Synonym: “is ground”, “is rigid”

Returns True if *self* represents a value.

Return type `bool`

is_reified()

False for values and for symbols applied to values.

Returns True if *self* has to be reified to obtain its value in a Z3 model.

Return type `bool`

class Date(***kwargs*)

Bases: `idp_engine.Expression.Expression`

translate(*problem*, *vars*={})

Converts the syntax tree to a Z3 expression, with lookup in `problem.z3`

Parameters

- **problem** (`Theory`) – holds the context for the translation (e.g. a cache of translations).
- **vars** (`dict[id, ExprRef]`, *optional*) – mapping from Variable’s id to Z3 translation. Filled in by `AQuantifier`. Defaults to {}.

Returns Z3 expression

Return type `ExprRef`

`__init__`(***kwargs*)

is_value()

True for numerals, date, identifiers, and constructors applied to values.

Synonym: “is ground”, “is rigid”

Returns True if *self* represents a value.

Return type `bool`

is_reified()

False for values and for symbols applied to values.

Returns True if *self* has to be reified to obtain its value in a Z3 model.

Return type bool

class Brackets(*parent, f, annotations=None*)

Bases: `idp_engine.Expression.Expression`

Parameters *annotations* (*Optional [Annotations]*) –

fill_attributes_and_check()

annotations that are common to `__init__` and `make()`

Parameters *self* (*idp_engine.Expression.Brackets*) –

Return type `idp_engine.Expression.Expression`

update_exprs(*new_exprs*)

change `sub_exprs` and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.Brackets*) –
- **new_exprs** (*Generator [idp_engine.Expression.Expression, None, None]*) –

Return type `idp_engine.Expression.Expression`

symbolic_propagate(*assignments, tag, truth=None*)

updates assignments with the consequences of *self=truth*.

The consequences are obtained by symbolic processing (no calls to Z3).

Parameters

- **assignments** (*Assignments*) – The set of assignments to update.
- **truth** (*Expression, optional*) – The truth value of the expression *self*. Defaults to TRUE.

__init__(*parent, f, annotations=None*)

Parameters *annotations* (*Optional [idp_engine.Expression.Annotations]*) –

class RecDef(*parent, name, vars, expr*)

Bases: `idp_engine.Expression.Expression`

represents a recursive definition

__init__(*parent, name, vars, expr*)

6.3.3 idp_engine.Annotate

Methods to annotate the Abstract Syntax Tree (AST) of an IDP-Z3 program.

root_set(*s*)

Recursively finds the root sets of a set in the hierarchy.

For a set of tuples of domain elements, it returns the list of root sets of the elements of the tuple. For example, the root sets of *p: T1 * T2 -> Bool* are [*T1, T2*]

It goes up the hierarchy until a declared type or a `Concept[...]` is found.

Parameters *s* (*idp_engine.Expression.SetName*) –

Return type `List[idp_engine.Expression.SetName]`

collect_warnings(*expr, out*)

recursively finds the deepest Expression that is not well-defined in *expr*, and create a warning

Parameters *expr* (*idp_engine.Expression.Expression*) –

rename_args(*self, subs*)

replace old variables by new variables (ignoring arguments in the head before the it

Parameters

- **self** (*Parse.Rule*) –
- **subs** (*dict[str, Expr.Expression]*) –

Return type None

annotate_block_struct(*self, idp*)

Annotates the structure with the enumerations found in it. Every enumeration is converted into an assignment, which is added to *self.assignments*.

Parameters

- **idp** (*idp_engine.Parse.IDP*) – a *Parse.IDP* object.
- **self** (*idp_engine.Expression.ASTNode*) –
- **idp** –

Returns None

Return type Union[Exception, List[Exceptions]]

annotate_symbolinterpretation(*self, voc, q_vars*)

Annotate the symbol.

Parameters

- **block** – a Structure object
- **self** (*Expr.Expression*) –
- **voc** (*Parse.Vocabulary*) –
- **q_vars** (*dict[str, Expr.Variable]*) –

Returns None

Return type Expr.Expression

annotate_expression(*self, voc, q_vars*)

annotate tree after parsing

Resolve names and determine type as well as variables in the expression

Parameters

- **voc** (*Vocabulary*) – the vocabulary
- **q_vars** (*dict[str, Variable]*) – the quantifier variables that may appear in the expression
- **self** (*Expr.Expression*) –

Returns an equivalent AST node, with updated type, .variables

Return type Expression

fill_attributes_and_check_expression(*self*)

annotations that are common to `__init__` and `make()`

Parameters `self` (*idp_engine.Expression.Expression*) –

Return type *idp_engine.Expression.Expression*

base_type(*exprs*, *bases=None*)

Checks or determines the (sub)types of the expressions in *exprs*.

Raises an error if the (sub)type of an expression is not in *bases*. Raises an error if the expressions have incompatible (sub)types. Returns None if *exprs* is empty.

A mix of Int and Real (or Int and Date) is allowed.

Parameters

- **exprs** (*List[idp_engine.Expression.Expression]*) –

- **bases** (*Optional[List[idp_engine.Expression.SetName]]*) –

Return type *Optional[idp_engine.Expression.SetName]*

agg_create_min_max_appliedsymbol(*agg*, *name*, *voc*, *q_vars*)

Create an applied symbol representing a min/max aggregate. The actual logic for the min/max aggregate is contained in the co-constraints.

Parameters

- **agg** (*Expr.AAggregate*) –

- **name** (*str*) –

- **voc** (*Parse.Vocabulary*) –

- **q_vars** (*dict[str, Expr.Variable]*) –

Return type *Expr.AppliedSymbol*

annotate_aaggregate(*self*, *voc*, *q_vars*)

Annotation is dependent on the aggttype.

- Sum/card: the *sub_exprs* are replaced by equivalent ite expressions
- **Min/max: the aggregate is replaced by an applied symbol representing the min/max**, together with a set of co-constraints to define this.

Parameters

- **self** (*Expr.AAggregate*) –

- **voc** (*Parse.Vocabulary*) –

- **q_vars** (*dict[str, Expr.Variable]*) –

Return type *Expr.AAggregate | Expr.AppliedSymbol*

6.3.4 idp_engine.Interpret

Methods to ground / interpret a theory in a data structure

- expand quantifiers
- replace symbols interpreted in the structure by their interpretation
- instantiate definitions

(see docs/zettlr/Substitute.md)

interpret_definition(*self*, *problem*)

updates *problem.def_constraints*, by expanding the definitions

Parameters

- **problem** (*Theory*) – contains the enumerations for the expansion; is updated with the expanded definitions
- **self** (*Parse.Definition*) –

Return type None

interpret_expression(*self*, *problem*, *subs*)

expand quantifiers and replace symbols interpreted in the structure by their interpretation

Parameters

- **self** (*Expr.Expression*) – the expression to be interpreted
- **problem** (*Optional[Theory]*) – the theory to be applied
- **subs** (*dict[str, Expr.Expression]*) – a dictionary mapping variable names to their value

Returns the interpreted expression

Return type Expression

extension(*self*, *extensions*)

returns the extension of a SetName, given some interpretations.

Normally, the extension is already in *extensions* by *SymbolDeclaration.interpret*. However, for *Concept[T->T]*, an additional filtering is applied.

Parameters

- **interpretations** (*dict[str, SymbolInterpretation]*) –
- **symbols** (*the known interpretations of types and*) –
- **extensions** (*dict[str, Expr.Extension]*) –

Returns a superset of the extension of *self*, and a function that, given arguments, returns an Expression that says whether the arguments are in the extension of *self*

Return type Extension

get_supersets(*self*, *problem*)

determine the extent of the variables, if possible, and add a filter to the quantified expression if needed. This is used to ground quantification over unary predicates.

Example

type $T := \{1,2,3\}$ $p : T \rightarrow \text{Bool}$ // p is a subset of T ! x in p : $q(x)$

The formula is equivalent to $\text{!}x \text{ in } T: p(x) \Rightarrow q(x)$. \rightarrow The superset of p is $\{1,2,3\}$, the filter is $p(x)$. The grounding is $(p(1) \Rightarrow q(1)) \ \& \ (p(2) \Rightarrow q(2)) \ \& \ (p(3) \Rightarrow q(3))$

If p is enumerated ($p := \{1,2\}$) in a structure, however, the superset is now $\{1,2\}$ and there is no need for a filter. The grounding is $q(1) \ \& \ q(2)$

Result: *self.supersets* is updated to contain the supersets *self.sub_exprs* are updated with the appropriate filters

Parameters

- **self** (*Expr.AQuantification* | *Expr.AAggregate*) –
- **problem** (*Optional[Theory]*) –

Return type None

6.3.5 idp_engine.Simplify

Methods to simplify a logic expression.

update_exprs_expression(*self, new_exprs*)
change sub_exprs and simplify, while keeping relevant info.

Parameters

- **self** (*idp_engine.Expression.Expression*) –
- **new_exprs** (*Generator[idp_engine.Expression.Expression, None, None]*) –

Return type *idp_engine.Expression.Expression*

join_set_conditions(*assignments*)

In a list of assignments, merge assignments that are set-conditions on the same term.

An equality and a membership predicate (*in* operator) are both set-conditions.

Parameters **assignments** (*List[Assignment]*) – the list of assignments to make more compact

Returns the compacted list of assignments

Return type *List[Assignment]*

6.3.6 idp_engine.Propagate

Computes the consequences of an expression, i.e., the sub-expressions that are necessarily true (or false) if the expression is true (or false)

It has 2 parts: * symbolic propagation * Z3 propagation

6.3.7 idp_engine.idp_to_Z3

Translates AST tree to Z3

TODO: vocabulary

translate_expression(*self, problem, vars={}*)
Converts the syntax tree to a Z3 expression, with lookup in *problem.z3*

Parameters

- **problem** (*Theory*) – holds the context for the translation (e.g. a cache of translations).
- **vars** (*dict[id, ExprRef], optional*) – mapping from Variable's id to Z3 translation. Filled in by *AQuantifier*. Defaults to {}.

Returns Z3 expression

Return type *ExprRef*

translate1_aifexpr(*self*, *problem*, *vars*={})

Converts the syntax tree to a Z3 expression, without lookup in *problem.z3*

A lookup is wasteful when *self* is a subformula of a formula that is not in *problem.z3*.

Parameters

- **problem** (*Theory*) – holds the context for the translation (e.g. a cache of translations).
- **vars** (*dict[id, ExprRef]*, *optional*) – mapping from Variable’s id to Z3 translation. Filled in by AQuantifier. Defaults to {}.

Returns Z3 expression

Return type ExprRef

translate_acomparison_optimum(*self*, *problem*, *lhs*, *op*, *rhs*, *vars*={})

Optimized translation method for *_very_* specific circumstances in which one child is a count and the other child is a literal int (or a symbol interpreted as one). This allows us to use Z3’s AtLeast and AtMost (<https://z3prover.github.io/api/html/namespacez3py.html#a0369f15ecdb913e47fc7bb645fcfcf08>) instead of converting the aggregate to a sum of it’s.

Parameters

- **problem** (*Theory*) –
- **lhs** (*Expr.Expression*) –
- **op** (*Expr.Expression*) –
- **rhs** (*Expr.Expression*) –

Return type ExprRef

at_most_at_least_possible(*lhs*, *operator*, *rhs*)

Verifies whether an optimized Z3 encoding using “AtMost” or “AtLeast” is possible for two children of an AComparison. This is the case when one child is a cardinality, while the other child is a literal int. See: <https://gitlab.com/krr/IDP-Z3/-/issues/362>

Parameters

- **lhs** (*idp_engine.Expression.Expression*) –
- **operator** (*str*) –
- **rhs** (*idp_engine.Expression.Expression*) –

6.3.8 idp_engine.Theory

Class to represent a collection of theory and structure blocks.

class Propagation(*value*)

Describe propagation method

class Theory(**theories*, *extended*=False)

A collection of theory and structure blocks.

assignments (Assignments): the set of assignments. The assignments are updated by the different steps of the problem resolution. Assignments include inequalities and quantified formula when the problem is extended

Parameters

- **theories** (*Union[TheoryBlock, Structure, Theory]*) –
- **extended** (*bool*) –

Return type None

determine_relevance()

Determines the questions that are relevant in a consistent state of `Theo.Theory self`.

Some definitions: * a consistent state `s` of theory `T` is a partial interpretation of vocabulary `V` of `T` that can be expanded in a model of `T`; * a solution `S` of theory `T` is a state such that every expansion of solution `S` is a model of theory `T`; * a minimal solution for theory `T` in state `s` is a solution that expands state `s` and is not more precise than another solution of theory `T`; * a symbol is relevant for theory `T` in state `s` iff it is interpreted in a minimal solution for theory `T` in state `s`.

This method must be called after a call to `propagate`, on a `Theo.Theory` created with `extended=True`. The method 1) computes a simplified theory equivalent to `self`, 2) collects the relevant questions in that theory. A question is considered relevant if: * it appears in a constraint; * or it is a goal symbol; * or it appears in a `co_constraint` for a relevant question.

The result is found in the `relevant` attribute of the assignments in `self.assignments`.

Returns the `Theo.Theory` with relevant information in `self.assignments`.

Return type `Theo.Theory`

Parameters `self (idp_engine.Theory.Theory)` –

EN()

returns a string containing the Theory in controlled English

Parameters `self (Theory)` –

Return type `str`

__init__(*theories, extended=False)

Creates an instance of `Theory` for the list of theories, e.g., `Theory(T,S)`.

Parameters

- **theories** (`Union[TheoryBlock, Structure, Theory]`) – 1 or more (data) theories.
- **extended** (`bool, optional`) – use `True` when the truth value of inequalities and quantified formula is of interest (e.g. for the Interactive Consultant). Defaults to `False`.

Return type None

property solver: z3.z3.Solver

Beware that the setting of `timeout_seconds` (e.g. in `expand()`) is not thread safe

copy()

Returns an independent copy of a theory.

Return type `idp_engine.Theory.Theory`

add(*theories)

Adds a list of theories to the theory.

Parameters **theories** (`Union[TheoryBlock, Structure, Theory]`) – 1 or more (data) theories.

Return type `idp_engine.Theory.Theory`

to_smt_lib()

Returns an SMT-LIB version of the theory

Return type `str`

assert_(code, value, status=Status.GIVEN)

asserts that an expression has a value (or not), e.g. `theory.assert_("p()", True)`

Parameters

- **code** (*str*) – the code of the expression, e.g., "p()"
- **value** (*Any*) – a Python value, e.g., True
- **status** (*Status, Optional*) – how the value was obtained. Default: S.GIVEN

enable_law(*code*)

Enables a law, represented as a code string taken from the output of `explain(...)`.

The law should not result from a structure (e.g., from `p:=true.`) or from a types (e.g., from `T:={1..10}` and `c: () -> T`).

Parameters **code** (*str*) – the code of the law to be enabled

Raises **AssertionError** – if code is unknown

disable_law(*code*)

Disables a law, represented as a code string taken from the output of `explain(...)`.

The law should not result from a structure (e.g., from `p:=true.`) or from a types (e.g., from `T:={1..10}` and `c: () -> T`).

Parameters **code** (*str*) – the code of the law to be disabled

Raises **AssertionError** – if code is unknown

constraintz()

list of constraints, co_constraints and definitions in Z3 form

Return type List[z3.z3.BoolRef]

formula()

Returns a Z3 object representing the logic formula equivalent to the theory.

This object can be converted to a string using `str()`.

Return type z3.z3.BoolRef

expand(*max=10, timeout_seconds=10, complete=False*)

Generates a list of models of the theory that are expansion of the known assignments.

The result is limited to `max` models (10 by default), or unlimited if `max` is 0. The search for new models is stopped when processing exceeds `timeout_seconds` (in seconds) (unless it is 0). The models can be asked to be complete or partial (i.e., in which “don’t care” terms are not specified).

The string message can be one of the following:

- No models.
- No model found in `xx` seconds. Models may be available. Change the `timeout_seconds` argument to see them.
- More models may be available. Change the `max` argument to see them.
- More models may be available. Change the `timeout_seconds` argument to see them.
- More models may be available. Change the `max` and `timeout_seconds` arguments to see them.

Parameters

- **max** (*int, optional*) – maximum number of models. Defaults to 10.
- **timeout_seconds** (*int, optional*) – timeout_seconds seconds. Defaults to 10.

- **complete** (*bool*, *optional*) – True for complete models. Defaults to False.

Yields the models, followed by a string message

Return type Iterator[Union[idp_engine.Assignments.Assignments, str]]

optimize(*term*, *minimize=True*)

Updates the value of *term* in the `assignments` property of *self* to the optimal value that is compatible with the theory.

Chain it with a call to *expand* to obtain a model, or to *propagate* to propagate the optimal value.

Parameters

- **term** (*str*) – e.g., "Length(1)"
- **minimize** (*bool*) – True to minimize term, False to maximize it

Return type *idp_engine.Theory.Theory*

symbolic_propagate(*tag=Status.UNIVERSAL*)

Returns the theory with its `assignments` property updated with direct consequences of the constraints of the theory.

This propagation is less complete than `propagate()`.

Parameters **tag** (*S*) – the status of propagated assignments

Return type *idp_engine.Theory.Theory*

propagate(*tag=Status.CONSEQUENCE*, *method=Propagation.DEFAULT*, *complete=False*)

Returns the theory with its assignments property updated with values for all terms and atoms that have the same value in every model of the theory.

`self.satisfied` is also updated to reflect satisfiability.

Terms and propositions starting with `_` are ignored.

Args:

tag (*S*, *optional*): **the status of propagated assignments.** Defaults to `CONSEQUENCE`.

method (*Propagation*, *optional*): **the particular propagation to use.** Defaults to standard propagation.

complete (*bool*, *optional*): **True when requiring a propagation** including negated function value assignments. Defaults to False.

Parameters

- **tag** (*idp_engine.Assignments.Status*) –
- **method** (*idp_engine.Theory.Propagation*) –
- **complete** (*bool*) –

Return type *idp_engine.Theory.Theory*

get_range(*term*, *complete=False*)

Returns a list of the possible values of the term.

Parameters

- **term** (*str*) – terms whose possible values are requested, e.g. `subtype()`. Must be a key in `self.assignments`

- **complete** (*bool*) –

Returns e.g., ['right triangle', 'regular triangle']

Return type List[str]

explain(*consequence=None, timeout_seconds=0*)

Returns the facts and laws that make the Theory unsatisfiable, or that explains a consequence. Raises an IDPZ3Error if the Theory is satisfiable

Parameters

- **self** (*Theory*) – the problem state
- **consequence** (*string, optional*) – the code of the consequence to be explained. Must be a key in `self.assignments`
- **timeout_seconds** (*int*) –

Returns list of facts and laws that explain the consequence

Return type (List[Assignment], List[Expression])

simplify(*for_relevance=False*)

Returns a simpler copy of the theory, with a simplified formula obtained by substituting terms and atoms by their known values.

Parameters **for_relevance** – If true, numeric comparisons with known values are ignored.

Return type *idp_engine.Theory.Theory*

decision_table(*goal_string="", timeout_seconds=20, max_rows=50, first_hit=True, verify=False*)

Experimental. Returns the rows for a decision table that defines `goal_string`.

`goal_string` must be a predicate application defined in the theory. The theory must be created with `extended=True`.

Parameters

- **goal_string** (*str, optional*) – the last column of the table.
- **timeout_seconds** (*int, optional*) – maximum duration in seconds. Defaults to 20.
- **max_rows** (*int, optional*) – maximum number of rows. Defaults to 50.
- **first_hit** (*bool, optional*) – requested hit-policy. Defaults to True.
- **verify** (*bool, optional*) – request verification of table completeness. Defaults to False

Returns the non-empty cells of the decision table for `goal_string`, given `self`. `bool`: whether or not the timeout limit was reached.

Return type list(list(Assignment))

6.3.9 idp_engine.Assignments

Classes to store assignments of values to questions

class Status(*value*)

Describes how the value of a question was obtained

class Assignment(*sentence, value, status, relevant=True*)

Represent the assignment of a value to a question. Questions can be:

- predicates and functions applied to arguments,

- comparisons,
- outermost quantified expressions

A value is a rigid term.

An assignment also has a reference to the symbol under which it should be displayed.

Parameters

- **sentence** (*Expression*) –
- **value** (*Optional[Expression]*) –
- **status** (*Optional[Status]*) –
- **relevant** (*Optional[bool]*) –

sentence

the question to be assigned a value

Type Expression

value

a rigid term

Type Expression, optional

status

qualifies how the value was obtained

Type Status, optional

is_certainly_undefined

True for functions applied to arguments certainly outside of its domain

Type bool

relevant

states whether the sentence is relevant

Type bool, optional

symbol_decl

declaration of the symbol under which

Type SymbolDeclaration

it should be displayed in the IC.

__init__ (*sentence, value, status, relevant=True*)

Parameters

- **sentence** (*idp_engine.Expression.Expression*) –
- **value** (*Optional[idp_engine.Expression.Expression]*) –
- **status** (*Optional[idp_engine.Assignments.Status]*) –
- **relevant** (*Optional[bool]*) –

same_as (*other*)

returns True if self has the same sentence and truth value as other.

Parameters **other** (*Assignment*) – an assignment

Returns True if self has the same sentence and truth value as other.

Return type bool

negate()

returns an Assignment for the same sentence, but an opposite truth value.

Raises **AssertionError** – Cannot negate a non-boolean assignment

Returns returns an Assignment for the same sentence, but an opposite truth value.

Return type [type]

as_set_condition()

returns an equivalent set condition, or None

Returns meaning “appSymb is (not) in enumeration”

Return type Tuple[Optional[AppliedSymbol], Optional[bool], Optional[Enumeration]]

unset()

Unsets the value of an assignment.

Returns None

Return type None

class **Assignments**(*arg, **kw)

Contains a set of Assignment

__init__(*arg, **kw)

copy() → a shallow copy of D

Parameters **shallow** (*bool*) –

Return type Assignments

6.3.10 idp_engine.Run

The following Python functions can be used to perform computations using FO-dot knowledge bases:

model_check(*theories)

Returns a string stating whether the combination of theories is satisfiable.

For example, `print(model_check(T, S))` will print `sat` if theory named T has a model expanding structure named S.

Parameters **theories** (*Union[TheoryBlock, Structure, Theory]*) – 1 or more (data) theories.

Returns `sat`, `unsat` or `unknown`

Return type `str`

model_expand(*theories, max=10, timeout_seconds=10, complete=False, extended=False, sort=False)

Returns a (possibly empty) list of models of the combination of theories, followed by a string message.

For example, `print(model_expand(T, S))` will return (up to) 10 string representations of models of theory named T expanding structure named S.

The string message can be one of the following:

- No models.
- More models may be available. Change the max argument to see them.

- More models may be available. Change the `timeout_seconds` argument to see them.
- More models may be available. Change the `max` and `timeout_seconds` arguments to see them.

Parameters

- **theories** (*Union[TheoryBlock, Structure, Theory]*) – 1 or more (data) theories.
- **max** (*int, optional*) – max number of models. Defaults to 10.
- **timeout_seconds** (*int, optional*) – timeout_seconds seconds. Defaults to 10.
- **complete** (*bool, optional*) – True to obtain complete structures. Defaults to False.
- **extended** (*bool, optional*) – use *True* when the truth value of inequalities and quantified formula is of interest (e.g. for the Interactive Consultant). Defaults to False.
- **sort** (*bool, optional*) – True if the models should be in alphabetical order. Defaults to False.

Yields str

Return type Iterator[str]

model_propagate (**theories, sort=False, complete=False*)

Returns a list of assignments that are true in any model of the combination of theories.

Terms and symbols starting with ‘_’ are ignored.

For example, `print(model_propagate(T, S))` will return the assignments that are true in any expansion of the structure named *S* consistent with the theory named *T*.

Parameters

- **theories** (*Union[TheoryBlock, Structure, Theory]*) – 1 or more (data) theories.
- **sort** (*bool, optional*) – True if the assignments should be in alphabetical order. Defaults to False.
- **complete** (*bool, optional*) – True when requiring a propagation including negated function value assignments. Defaults to False.

Yields str

Return type Iterator[str]

maximize (**theories, term*)

Returns a model that maximizes *term*.

Parameters

- **theories** (*Union[TheoryBlock, Structure, Theory]*) – 1 or more (data) theories.
- **term** (*str*) – a string representing a term

Yields str

Return type *idp_engine.Theory.Theory*

minimize (**theories, term*)

Returns a model that minimizes *term*.

Parameters

- **theories** (*Union[TheoryBlock, Structure, Theory]*) – 1 or more (data) theories.
- **term** (*str*) – a string representing a term

Yields str

Return type `idp_engine.Theory.Theory`

decision_table(*theories, goal_string="", timeout_seconds=20, max_rows=50, first_hit=True, verify=False)
Experimental. Returns a decision table for *goal_string*, given the combination of theories.

Parameters

- **theories** (`Union[TheoryBlock, Structure, Theory]`) – 1 or more (data) theories.
- **goal_string** (`str, optional`) – the last column of the table. Must be a predicate application defined in the theory, e.g. `eligible()`.
- **timeout_seconds** (`int, optional`) – maximum duration in seconds. Defaults to 20.
- **max_rows** (`int, optional`) – maximum number of rows. Defaults to 50.
- **first_hit** (`bool, optional`) – requested hit-policy. Defaults to True.
- **verify** (`bool, optional`) – request verification of table completeness. Defaults to False

Yields a textual representation of each rule

Return type `Iterator[str]`

determine_relevance(*theories)

Generates a list of questions that are relevant, or that can appear in a justification of a `goal_symbol`.

The questions are preceded with `` ? `` when their answer is unknown.

When an *irrelevant* value is changed in a model M of the theories, the resulting M' structure is still a model. Relevant questions are those that are not irrelevant.

If `goal_symbol` has an enumeration in the theory (e.g., `goal_symbol := {`tax_amount`}`), relevance is computed relative to those goals.

Definitions in the theory are ignored, unless they influence axioms in the theory or goals in `goal_symbol`.

Yields relevant questions

Parameters **theories** (`Union[idp_engine.Parse.TheoryBlock, idp_engine.Parse.Structure, idp_engine.Theory.Theory]`) –

Return type `Iterator[str]`

pretty_print(x="")

Prints its argument on stdout, in a readable form.

Parameters **x** (`Any, optional`) – the result of an API call. Defaults to "".

Return type `None`

duration(msg="")

Returns the processing time since the last call to `duration()`, or since the begining of execution

Parameters **msg** (`str`) –

Return type `str`

execute(self, capture_print=False)

Execute the `main()` procedure block in the IDP program

Parameters

- **self** (`idp_engine.Parse.IDP`) –
- **capture_print** (`bool`) –

Return type Optional[str]

6.3.11 idp_engine.utils

Various utilities (in particular, OrderedSet)

class Semantics(*value*)
Semantics for inductive definitions

class AggType(*value*)
Aggregate types

PROCESS_TIMINGS = {'ground': 0, 'parse': 0, 'solve': 0}

Module that monkey-patches json module when it's imported so JSONEncoder.default() automatically checks for a special "to_json()" method and uses it to encode the object if found.

exception IDPZ3Error(*msg, node=None, error=True*)
raised whenever an error occurs in the conversion from AST to Z3

Parameters

- **msg** (*str*) –
- **node** (*Optional[ASTNode]*) –
- **error** (*Optional[bool]*) –

__init__(*msg, node=None, error=True*)

Parameters

- **msg** (*str*) –
- **node** (*Optional[ASTNode]*) –
- **error** (*Optional[bool]*) –

class OrderedSet(*els=[]*)
a list of expressions without duplicates (first-in is selected)

__init__(*els=[]*)

6.4 idp_web_server module

6.4.1 idp_web_server.Inferences

This module contains the logic for inferences that are specific for the Interactive Consultant.

6.4.2 idp_web_server.IO

This module contains code to create and analyze messages to/from the web client.

metaJSON(*state*)

Format a response to meta request.

Parameters *idp* – the response

Returns out a meta request

load_json(*assignments, jsonstr, keep_defaults*)

Parse a json string and update assignments in a state accordingly.

Parameters

- **assignments** – an assignments containing the concepts that appear in the json
- **jsonstr** (*str*) – assignments in json
- **keep_defaults** (*bool*) – whether to not delete the default assignments
- **jsonstr** –
- **keep_defaults** –

Post assignments is updated with information in json

6.4.3 idp_web_server.rest

6.4.4 idp_web_server.State

Management of the State of problem solving with the Interactive Consultant.

class State(*idp*)

Contains a state of problem solving

Parameters *idp* (*IDP*) –

classmethod make(*idp, previous_active, active, ignore=None*)

Manage the cache of State

Parameters

- **idp** (*IDP*) – idp source code
- **previous_active** (*str*) – assignments due to previous full propagation
- **active** (*str*) – assignment choices from client
- **ignore** (*str*) – user-disabled laws to ignore

Returns a State

Return type State

__init__(*idp*)

Creates an instance of Theory for the list of theories, e.g., Theory(T,S).

Parameters

- **theories** (*Union[TheoryBlock, Structure, Theory]*) – 1 or more (data) theories.
- **extended** (*bool, optional*) – use *True* when the truth value of inequalities and quantified formula is of interest (e.g. for the Interactive Consultant). Defaults to *False*.

- **idp** (`idp_engine.Parse.IDP`) –

add_given(*jsonstr*, *previous*, *keep_defaults=False*)

Add the assignments that the user gave through the interface. These are in the form of a json string.

Parameters

- **jsonstr** (*str*) – the user’s assignment in json
- **previous** (*str*) – the assignments from the last propagation
- **keep_default** – whether default assignments should not be reset
- **jsonstr** –
- **previous** –
- **keep_defaults** (*bool*) –

Post the state has the jsonstr and previous added

APPENDIX: SYNTAX SUMMARY

The following code illustrates the syntax of the various blocks used in IDP-Z3.

T denotes a type, c a constructor, p a proposition or predicate, f a constant or function. The equivalent ASCII-only encoding is shown on the right.

```
@prefix we: <http://www.example.org/whatever#>.
vocabulary V {
  @prefix se: <http://www.example.org/somethingelse#>.
  type T
  type T {c1, c2, c3}                type T := {c1, c2, c3}
  type T constructed from {c1, c2(T1, f:T2)}
  type T {1,2,3}                    type T := {1,2,3} <: Int
  type T {1..3}                    type T := {1..3} <: Int
  type we::T
  type <http://www.example.org/foo#Type>
  // built-in types: , , , Date, Concept Bool, Int, Real, Date, Concept

  p : () →                          p: () -> Bool
  p1, p2 : T1 T2 →                  p1, p2: T1*T2 -> Bool
  f: total T → T                    f: total T -> T
  f: TT → T (domain: p, codomain: q) f: T*T -> T (domain: p, codomain: q)
  f: partial TT → T                f: partial T*T -> T
  f1, f2: Concept[T1->T2] → T      f1, f2: Concept[T1->T2] -> T

  [this is the intended meaning of p]
  p : () →

  var x T                            var x in T
  import W
}

theory T:V {
  (~p1()p2() p3() p4() p5()) p6(). (~p1()&p2() | p3() => p4() <=> p5()) <= p6().
  p(f1(f2())).
  f1() < f2() f3() = f4() f5() > f6(). f1() < f2() =< f3() = f4() >= f5() > f6().
  f() c.                              f() ~= c.
  x,y T: p(x,y).                       !x,y in T: p(x,y).
  x p, (y,z) q: q(x,x) p(y) p(z). !x in p, (y,z) in q: q(x,x) | p(y) | p(z).
  x Concept[()->B]: $(x)().             ?x in Concept[()->B]: $(x)().
  x: p(x). # if var x declared in voc  ?x: p(x).
  >1 x T: p(x).                         ?>1 x T: p(x).
```

(continues on next page)

```

f() in {1,2,3}.
f() = #{xT: p(x)}.
f() = min{ f(x) | x in T: p(x) }.
f() = sum{{ f(x) | x in T: p(x) }}.
if p1() then p2() else p3().
f1() = if p() then f2() else f3().

p {1,2,3}.
p(#2020-01-01) is enumerated.
p(#TODAY) is not enumerated.

{ p(1). }
{ (co-induction)
  xT: p1(x) <- p2(x).
  f(1)=1.
  x: f(x)=1 <- p(x).
  x: f(x)1 <- p(x).
}

!x in T: p1(x) <- p2(x).
!x: f(x)=1 <- p(x).
!x: f(x):=1 <- p(x).

[this is the intended meaning of the rule]
p().
}

structure S:V {
  p false.
  p {1,2,3}.
  p {0..9, 100}.
  p {#2021-01-01}.
  p {(1,2), (3,4)}.
  p {
    1 2
    3 4
  }.
  f 1.
  f {->1} .
  f {1->1, 2->2}.
  f {(1,2)->3} else 2.
  f {(1,2)->3}.
}

p := false.
p := {1,2,3}.
p := {0..9, 100}.
p := {#2021-01-01}.
p := {(1,2), (3,4)}.
p := {
  1 2
  3 4
}.
f := 1.
f := {-> 1}.
f := {1->1, 2->2}.
f := {(1,2)->3} else 2.
f :=> {(1,2)->3}.

display {
  goal_symbol {\`p1, \`p2}.
  hide(\`p).
  expand {\`p}.
  view() = expanded.
  optionalPropagation().
}

goal_symbol := {\`p1, \`p2}.
expand := {\`p}.

procedure main() {
  pretty_print(model_check (T,S))
}

```

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(continued from previous page)

```

pretty_print(model_expand (T,S))
pretty_print(model_propagate(T,S))
pretty_print(minimize(T,S, term="cost()"))
}

```

See also the *Built-in functions*.

It is possible to use English connectives to create expressions:

for all T x:	x T:
there is a T x:	x T:
p() or q()	p() q()
p() and q()	p() q()
if p(), then q()	p() q()
p() are sufficient conditions for q()	p() q()
p() are necessary conditions for q()	p() q()
p() are necessary and sufficient conditions for q()	p() q()
p() is the same as q()	p() q()
x is y	x = y
x is not y	x y
x is strictly less than y	x < y
x is less than y	x y
x is greater than y	x y
x is strictly greater than y	x > y
the sum of f(x) for each T x such that p(x)	sum{{f(x) xT: p(x) }}
p() if q() .	p() ← q() .

CHAPTER

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