
ZTC: A Type Checker for Z Notation

User's Guide

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1 Introduction

The Z notation [1] is a model-oriented formal specification language developed by the Programming Research Group at Oxford University Computing Laboratory in the early 80's. Since then, Z has been used to specify a wide spectrum of software systems including database systems, transaction systems, distributed computing systems, and operating systems [2]. The most notable success of Z is the specification of CICS Application Programming Interface (API) by IBM United Kingdom Laboratories at Hursley Park [3]. Approximately 37,000 lines of code were produced from Z specifications and designs, and it was reported that the code has approximately 2.5 times fewer problems than the code that was not specified in Z.

This document is not intended to be a tutorial of the Z notation and formal specifications. It assumes that you are familiar with the Z notation. If you are not familiar with Z, there several sources to learn about Z:

- *An Introduction to Z and Formal Specification* [4] by Mike Spivey gives a brief introduction to Z and model-oriented formal specifications.
- *Software Development with Z: A Practical Approach to Formal Methods in Software Engineering* [5] by J.B. Wordsworth and *Z: An Introduction to Formal Methods* [6] by A. Diller are introductory textbooks on formal methods and Z.
- The internet newsgroup `comp.specification.z` and the World-Wide-Web site <http://www.comlab.ox.ac.uk/archive/z.html> provide many pointers to recent development and materials in the field.

Z is a non-executable but strongly-typed specification language. ZTC is a type-checker for Z, which determines if there are syntactical and typing errors in Z specifications. There is no compiler for Z. However, there are tools to animate, or execute, subsets of Z¹.

ZTC accepts two forms of input: \LaTeX with `oz` or `zed` packages, and ZSL. `Oz` [7] and `zed` [8] are \LaTeX packages (style options) developed Paul King and Mike Spivey, respectively, for typesetting Z in \LaTeX . ZSL is an ASCII version of Z designed by the author. ZSL is welcome by students and newcomers of Z who are not familiar with \LaTeX , so they can write and type-check Z specifications without the extra hurdle of learning \LaTeX . Unlike the SGML based Z interchangeable format proposed by the Z Standard Committee, which is primarily intended for tools not human readers, ZSL is designed to be readable and try to retain the visual appearance of Z specifications as much as possible. ZSL is also useful for ASCII based electronic communications, such as e-mail, involving Z specifications. ZTC can perform translations between \LaTeX and ZSL. A brief description and examples of the two input forms are given in Section 2.

If you choose to use the \LaTeX input form but you should first get familiar with with `oz` [7] or `zed` [8]. Then, read Section 3. If you choose to use ZSL, you can safely skip Section 3, read Section 4, Section 5 will discuss many advanced and new features in version 2.0. Most of them applies to both input forms. Use Appendix A as a reference for both input forms.

¹ZANS is an experimental tool developed here at the Software Engineering Laboratory, DePaul University, that animates a subset of Z. ZANS is also freely available and its input format is compatible with that of ZTC. A research project funded by the National Science Foundation to study and develop tools for design refinement and code synthesis based on Z is also underway here.

This user's guide describes ZTC version 2.1. ZTC is now available on the following platforms:

- Microsoft Windows 9x, NT, 2000, and XP, and
- Linux

2 The Input Forms

ZTC accepts two input forms: \LaTeX and ZSL. Semantically, ZSL is as expressive as the \LaTeX form. However, the \LaTeX form is more expressive *visually*. ZTC can translate a Z specification written in ZSL to an equivalent one in \LaTeX , and *vice versa*. Using the \LaTeX form will allow you to fine tune the visual appearance of the specifications, and to take advantage of some features specially designed for \LaTeX (see sections 5.3 and 5.6.)

The following is a segment of a Z specification:

[*NAME*, *INFO*]

<i>DataDictionary</i> <i>dict</i> : <i>NAME</i> \rightarrow <i>INFO</i> <i>defined</i> : \mathbb{P} <i>NAME</i> <hr/> <i>defined</i> = $\text{dom } \textit{dict}$

ZTC accepts most of the \LaTeX source files as is. However, some rules must be observed in order to type-check the input files. These rules are discussed in Section 3. The \LaTeX input file for the above specification is given below:

```

\begin{spec}

\begin{zed}
  [ NAME, INFO ]
\end{zed}

\begin{schema}{DataDictionary}
  dict: NAME \pfun INFO \
  defined: \power NAME
\where
  defined = \dom dict
\end{schema}

\end{spec}

```

ZSL has two style options: the *plain text* style and the *box* style. Using the ZSL plain text style, the Z specification above will be written as follows:

```

specification

[ NAME, INFO ]

schema DataDictionary
  dict      : NAME +-> INFO;
  defined   : P NAME
where
  defined = dom dict
end schema

end specification

```

The box style of ZSL gives a graphical look to schema and generic boxes that resembles the original Z style. The following is the same specification in ZSL box style:

```

specification

[ NAME, INFO ]

--- DataDictionary -----
| dict      : NAME +-> INFO;
| defined   : P NAME
|-----
| defined = dom dict
|-----

end specification

```

The ZSL input form is discussed in detail in section 4.

The complete specification of *DataDictionary*, as well as several other sample specifications in all three input styles are included in the ZTC distribution.

3 The \LaTeX Input — Basics

`zed` and `oz` are two \LaTeX packages for typesetting Z specifications. Z specifications prepared using `oz` or `zed` can be type checked by ZTC, perhaps with some minor modifications. To use the \LaTeX input form, some knowledge of \LaTeX is necessary. If you are not familiar with \LaTeX but want to learn about \LaTeX , consult Leslie Lamport's *\LaTeX : A Document Preparation System* [9]. Otherwise, skip this section, and use ZSL instead. You will have to get familiar with `zed` or `oz` before using ZTC. The `zed` package is described in Mike Spivey's *A Guide to the zed Style Option* [8], and the `oz` package is described in Paul King's *Printing Z and Object-Z \LaTeX Documents*[7].

3.1 Choosing a package

ZTC now accepts specification written with either `zed` and `oz` packages. The two packages are mostly compatible but not completely. The `oz` package has better mnemonic names and includes all the \mathcal{AMS} mathematical symbols, which will be handy when you use user-defined symbols in your specification. Furthermore, `oz` can be used to typeset Object- Z specifications as well as plain Z , although ZTC only accepts plain Z . Another difference of the two packages is due to the fact that \LaTeX is currently undergoing a transition from $\LaTeX 2.09$ to $\LaTeX 2\epsilon$. The `zed` package is not compatible with the current standard $\LaTeX 2\epsilon$, while the `oz` package is distributed as a supported component of $\LaTeX 2\epsilon$.

ZTC supports the following package-selection modes:

- a) `zed` mode.
Use the `zed` package. You can only use the commands defined in `zed`.
- b) `oz-zed` compatible mode.
Use the `oz` package. You can use all the commands defined in `oz` and `zed`. Incompatibilities are resolved in favor of `zed`.
- c) `oz` native mode.
Use the `oz` package. You can only use the commands defined in `oz`.

The incompatible commands in `zed` and `oz` are listed in Figure 1.

symbol	zed command	oz command
\emptyset	<code>\empty</code>	<code>\emptysetset</code>
$\hat{=}$	<code>\defs</code>	<code>\sdef</code>
<code>==</code>	<code>==</code>	<code>\defs</code>

Figure 1: Incompatible commands between `zed` and `oz`.

In the L^AT_EX preamble, you must

1. *indicate whether zed or oz package is used;*
2. *use the ztc package included in the distribution; (ztc must follow zed or oz.)*
3. *inform ZTC about your package selection decision using ZTC pragmas:*
 - *zed mode:*
None. This is the default mode.
 - *oz-zed compatible mode:*
`\zedcompatible`
`%% oz`
 - *oz native mode:*
`%% oz-native`

Here are some examples of L^AT_EX preamble.

1. Using zed with L^AT_EX2.09.

```
\documentstyle[zed,ztc]{article}
```

2. Using oz-zed compatible mode with L^AT_EX2 ϵ .

```
\documentclass{article}
\usepackage{oz,ztc}
\zedcompatible
%% oz
```

3. Using oz native mode with L^AT_EX2 ϵ .

```
\documentclass{article}
\usepackage{oz,ztc}
%% oz-native
```

Note that, the oz and oz-native pragmas must be in the preamble for them to take effect.

3.2 Lexical conventions

The lexical elements of L^AT_EX input form can be classified into the following categories:

- a) *L^AT_EX commands*, which begin with a backslash (\), such as `\begin`, `\power_1`.
- b) *Keywords*, such as `schema`, `zed`;
- c) *Identifiers*, such as `DataDictionary`, `name?`;

- d) *Integers*, such as 0, 65535;
- e) *Symbols*, which consists of one or more non-alphanumeric characters, such as: :, ==, :: =.

The \LaTeX input form is case sensitive.

The rules for forming identifiers in the \LaTeX input form are the following:

- An identifier consists of a word followed by a possibly empty decoration.
- A word can be in one of the following forms:
 - a letter followed by zero or more letters, digits, or underscores (\backslash);
 - a \LaTeX command, i.e., a back slash (\backslash) followed by letters.
- A decoration is sequence of zero or more stroke characters, ', ?, !, or subscriptions.

Here are some examples of legal identifiers in \LaTeX input form:

<code>ident1</code>	<code>ident1</code>
<code>ident₂</code>	<code>ident_2</code>
<code>ident'₀</code>	<code>ident'_0</code>
ε	<code>\varepsilon</code>
<code>max_size</code>	<code>max_size</code>

The only primitive data type Z supports is the integer type. ZTC recognizes signed and unsigned decimal integers.

The mnemonic names of Z symbols are listed in Appendix A.

3.3 Structure of specifications

ZTC can directly type check \LaTeX source files containing Z specifications.

Each specification must be enclosed by one of the following environments:

- `\begin{spec} ... \end{spec}`
- `\begin{document} ... \end{document}`

Everything outside these environments are ignored by ZTC.

The `spec` environment can occur multiple times and can be nested. This is useful when you want to put several specifications in a single document, or to divide a large specification into separate files and type check them separately. The `document` environment can occur only once in a \LaTeX document, and must be the outer-most environment. The `document` environment is retained for backward compatibility with version 1.3.

3.4 Formal and informal text

A Z specification consists of formal and informal text. ZTC will type check the formal text and ignore the informal text.

3.4.1 Formal environments

Formal text must be enclosed in one of the following formal environments:

- `\begin{axdef}... \end{axdef}`
- `\begin{gendef}... \end{gendef}`
- `\begin{schema}... \end{schema}`
- `\begin{syntax}... \end{syntax}`
- `\begin{zed}... \end{zed}`

Anything outside these formal environments are considered informal text and ignored.

Note!

Specifically, formulae enclosed in \dots , $\langle \dots \rangle$, and $[\dots]$ are considered informal text and ignored.

Usage of these formal environments are briefly illustrated below.

The `axdef` environment is used to define the *axiom boxes*.

<code>\begin{axdef}</code>	$MaxSize : \mathbb{N}$
<code> MaxSize: \nat</code>	
<code>\where</code>	$MaxSize \leq 65535$
<code> MaxSize \leq 65535</code>	
<code>\end{axdef}</code>	

The `gendef` environment is used to define the *generic boxes*.

<code>\begin{gendef}{X,Y}</code>	$[X, Y]$
<code> First: X \cross Y \fun X</code>	$First : X \times Y \rightarrow X$
<code>\where</code>	
<code> \forall x: X; y: Y @ First(x,y) = x</code>	$\forall x : X; y : Y \bullet First(x,y) = x$
<code>\end{gendef}</code>	

The `schema` environment is used to define the *schema boxes*.

```

\begin{schema}{InsertOk}
  \Delta DataDictionary \\  

  name? : NAME \\  

  info? : INFO \\  

  resp! : Response
\where
  name? \notin defined \\  

  \# defined < MaxSize \\  

  dict' = dict \cup \{  

    name? \mapsto info? \} \\  

  resp! = Success
\end{schema}

```

$InsertOk$ $\Delta DataDictionary$ $name? : NAME$ $info? : INFO$ $resp! : Response$
$name? \notin defined$ $\#defined < MaxSize$ $dict' = dict \cup \{name? \mapsto info?\}$ $resp! = Success$

The `syntax` environment is used to define *free types*.

A `syntax` environment contains a sequence of syntax rules separated by the `\also` command.

```

\begin{syntax}
  OP & ::= & plus | minus | times | divide
\also
  EXP & ::= & const \ldata \nat \rdata \\  

  & | & binop \ldata OP \cross \\  

  & EXP \cross EXP \rdata
\end{syntax}

```

$$OP ::= plus \mid minus \mid times \mid divide$$

$$EXP ::= const\langle\mathbb{N}\rangle$$

$$\mid binop\langle OP \times EXP \times EXP \rangle$$

The `zed` environment is used to define other paragraphs in Z , including *given sets*, *schema definitions*, *equivalence definitions*, and *predicates*. Short free type definitions can also be included in the `zed` environment. A `zed` environment may contain several paragraphs. The paragraphs in a `zed` environment must be separated by the `\also` command.

```

\begin{zed}
  [ADDR, PAGE]
\also
  DataDictInit \defs [ DataDictionary' | \\  

  \t3   defined' = \empty ]
\also
  DATABASE == ADDR \fun PAGE
\also
  \exists n: NAME @ birthday(n) \in December
\also
  REPORT ::= ok | unknown \ldata NAME \rdata
\end{zed}

```

$$[ADDR, PAGE]$$

$$DataDictInit \hat{=} [DataDictionary' \mid defined' = \emptyset]$$

$$DATABASE == ADDR \rightarrow PAGE$$

$$\exists n : NAME \bullet birthday(n) \in December$$

$$REPORT ::= ok \mid unknown\langle NAME \rangle$$

The formal environments may not be nested.

Note!

You may use either `syntax` and `zed` environments to define free types, but they not inter-changeable. Use the `syntax` environment for the vertical format, and use the `zed` environment for the horizontal format.

3.4.2 Comments inside formal environments

Sometimes, you may want to put comments inside the formal environments. This can be accomplished by using `\comm` or `\remark` commands

Informal comments or remarks inside formal environments can be introduced as follows:

- `\comm{ informal text };`
- `\remark{ informal text };`

ZTC ignores the arguments of these two commands.

These two commands are synonymous.

3.4.3 Ignore formal environments

Sometimes, you may want ZTC to ignore some formal text without deleting them. Formal text can be commented out using `comment` or `nocheck` environments.

Anything enclosed in the following environments, including formal environments, will be ignored by ZTC.

- `\begin{comment} ... \end{comment}`
- `\begin{nocheck} ... \end{nocheck}`

Note!

It is no longer necessary to comment out informal text outside formal environments.

3.5 White spaces

ZTC recognizes some commonly used L^AT_EX spacing commands and ignores them.

ZTC ignores the following L^AT_EX commands inside formal environments:

- *spacing commands:* `~`, `\,`, `\!`, `\:`, `\;`, `{}`
- *blank lines.*

3.6 Separators

Separator are used to separate between declarations or predicates in the axiom, generic, and schema boxes.

ZTC treats the following commands as separators in `axdef`, `gendef`, and `schema` environments:

- *semi-colon* (`;`)
- *the `\also` command, and*
- *the L^AT_EX linebreaking commands, `\` and `\linebreak`.*

Omission of separators between declarations or predicates will cause syntax and/or typing errors. However, extra separators cause no harm.

The following two examples are equivalent semantically, but differ in their printout.

a) Linebreak as separators:

```
\begin{schema}{InsertOk}
  \Delta DataDictionary \\ name? : NAME \\
  info? : INFO \\ resp! : Response
\where
  name? \notin defined \\
  \# defined < MaxSize \\
  dict' = dict \cup
  \{ name? \mapsto info? \} \also
  resp! = Success
\end{schema}
```

<i>InsertOk</i> Δ <i>DataDictionary</i> <i>name? : NAME</i> <i>info? : INFO</i> <i>resp! : Response</i>
<i>name? \notin defined</i> <i>#defined < MaxSize</i> <i>dict' = dict \cup {name? \mapsto info?}</i> <i>resp! = Success</i>

b) Semi-colon as separators:

```
\begin{schema}{InsertOk}
  \Delta DataDictionary; name? : NAME \\
  info? : INFO; resp! : Response
\where
  name? \notin defined ;
  \# defined < MaxSize \\
  dict' = dict \cup
  \{ name? \mapsto info? \} \\
  resp! = Success
\end{schema}
```

<i>InsertOk</i> Δ <i>DataDictionary; name? : NAME</i> <i>info? : INFO; resp! : Response</i>
<i>name? \notin defined; #defined < MaxSize</i> <i>dict' = dict \cup {name? \mapsto info?}</i> <i>resp! = Success</i>

Note!

The separator rule above does not apply to the `syntax` and `zed` environments.

Paragraphs in a zed environment and free type definitions in a syntax environment must be separated by the `\also` command.

3.7 Line continuing command

Sometimes, you may want to break a line without terminating the current declaration or predicate, e.g., when you have a long predicate that can not fit into a single line. You can accomplish this by using the *line continuing command*.

A line continuing command is a linebreaking command followed by a TAB command, which is one of the following:

`\t0, \t1, \t2, \t3, \t4, \t5, \t6, \t7, \t8, \t9.`

Line continuing commands are treated as white spaces by ZTC.

When you print out specifications, a continuation command will cause a linebreak and an indentation of the continuing line. The amount of space indented is determined by the TAB command, with

`\t1` indents the least and `\t9` the most amount of space. The TAB command is not only necessary for ZTC to perform type-checking properly, but also desirable for enhancing the readability of specifications. The following example shows the proper use of the line continuing command.

```
\begin{gendef}{X,Y}
  First: X \cross Y \fun X
\where
  \forall x: X; y: Y @ \
\t1   First(x,y) = x
\end{gendef}
```

$[X, Y]$ $First : X \times Y \rightarrow X$
$\forall x : X; y : Y \bullet$ $First(x, y) = x$

When the indentation is not desired, you can use `\t0` as in the example below. It is equivalent to the previous one, however the continuing line is not indented and the printout is less readable.

```
\begin{gendef}{X,Y}
  First: X \cross Y \fun X
\where
  \forall x: X; y: Y @ \
\t0   First(x,y) = x
\end{gendef}
```

$[X, Y]$ $First : X \times Y \rightarrow X$
$\forall x : X; y : Y \bullet$ $First(x, y) = x$

The continuation commands can also be used in the zed environment to break a long paragraph as in the following example.

```
\begin{zed}
Insert \defs InsertOk \lor InsertOverflow \
\t1 \lor InsertAlreadyDefined
\end{zed}
```

$$Insert \hat{=} InsertOk \vee InsertOverflow \\ \vee InsertAlreadyDefined$$

3.8 File inclusion

ZTC allows you to break a long specification into several input files and then include them into a master file.

You may use either of the following commands to include a file:

- `\input{ filename }`
- `\include{ filename }`

The complete filename must be specified in the file inclusion commands. The file inclusion commands can be nested. The maximum depth of inclusion is 16.

4 The ZSL Input — Basics

4.1 Lexical conventions

The lexical elements of ZSL can be classified into following categories:

- *Keywords*, such as `schema`, `where`;
- *Identifiers*, such as `DataDictionary`, `name?`;
- *Integers*, such as `0`, `65535`;
- *Bars*, which are used in the box style, such as `=====`, `|`;
- *Symbols*, which consists of one or more non-alphanumeric characters, such as `:`, `==`, `::=`.

ZSL is case sensitive.

The rules for forming identifiers are the following:

- *An identifier consists of a word followed by a possible empty decoration.*
- *A word must begin with a letter and followed by letters, digits, or underscores (`_`).*
- *A decoration consists of one or more stroke characters, `'`, `?`, `!`, or subscriptions.*
- *A subscription consists of an underscore followed by a digit.*

Here are some examples of legal identifiers in ZSL:

```
ident1  ident_2  ident'_0
```

The only primitive data type Z supports is the integer type. ZTC recognizes signed and unsigned decimal integers.

The bars are used in the box style to form axiom, generic, and schema boxes. There are three types of bars:

- *vertical bars*: `|`;
- *horizontal single bars*: `-----`;
- *horizontal double bars*: `=====`.

The length of a horizontal bar must be at least 3. The actual length of a horizontal bar is insignificant.

ZSL defines ASCII equivalents for all the mathematical symbols used in Z. They are listed in Appendix A.

4.2 Structure of specifications

A Z specification consists of a sequence of paragraphs.

A ZSL input file consists of a sequence of paragraphs enclosed by one of the following specification environment

- *specification... end specification, or*
- *spec ... end spec*

The paragraphs must be separated one or more blank lines.

You can have multiple specification environments in a ZSL file. Specification environments can also be nested. Everything outside specification environments are ignored.

A complete ZSL input is shown earlier in Section 2 (page 3.)

Paragraphs can be classified into box or non-box paragraphs. A *box paragraph* is either an axiom box, a generic box, or a schema box. All other paragraphs are called *non-box paragraphs*.

4.3 Informal text and comments

ZSL allows mixed informal text and formal specifications in ZSL input files. Unlike most programming languages, in which indentation and vertical alignment are insignificant, in ZSL, indentation and vertical alignment are used to distinguish formal text from informal text.

ZTC treats any line beginning with a TAB as formal text, and any line not beginning with a TAB as informal text.
ZTC also treat anything following a percentage sign (%) up to the end of the line as informal text and ignores them.

The following example shows a ZSL schema with comments:

```

schema DataDictionary
  dict : NAME +-> INFO;
  defined : P NAME
where
  defined = dom dict;
  # defined <= MaxSize
end schema
defined is the set of all terms defined in the
data dictionary.
```

4.4 Box paragraphs

The plain text style and box style of ZSL are only different for box paragraphs, and they are identical for all other syntactical structures. For the box paragraphs, the text style uses keywords, such as

schema ... where ... end schema, to define the syntactical structures, whereas the box style uses horizontal and vertical bars to define the syntactical structures.

An axiom box can be written in the following forms:

```
Plain text style:   global
                   MaxSize : N
                   axiom
                   MaxSize <= 65535
                   end axiom

Box style:         | MaxSize : N
                   |-----
                   | MaxSize <= 65535
```

A generic box can be written in the following forms:

```
Plain text style:   generic [X,Y]
                   First: X & Y --> X
                   where
                   forall x: X; y: Y @ First(x,y) = x
                   end generic

Box style:         === [X,Y] =====
                   | First: X & Y --> X
                   |-----
                   | forall x: X; y: Y @ First(x,y) = x
                   |-----
```

A schema box can be written in the following forms:

```
Plain text style:   schema InsertOk
                   Delta DataDictionary;
                   name? : NAME;
                   info? : INFO;
                   resp! : Response
                   where
                   name? notin defined;
                   # defined < MaxSize;
                   dict' = dict || { name? -> info? };
                   resp! = Success
                   end schema

Box style:         --- InsertOk -----
                   | Delta DataDictionary;
                   | name? : NAME;
                   | info? : INFO;
                   | resp! : Response
                   |-----
                   | name? notin defined;
                   | # defined < MaxSize;
                   | dict' = dict || { name? -> info? };
                   | resp! = Success
                   |-----
```

When using the plain text style, spaces following the leading TAB of each line are allowed and they are ignored. However, when using the box style, spaces following the leading TAB are not allowed.

When using the box style, each line must begin with a TAB, and the box must immediately follow the TAB. No space in between is allowed.

This ensures that all the boxes are aligned vertically. The length of horizontal bars must be at least that 3. Other than that the length of the horizontal bars is insignificant.

4.5 Non-box paragraphs and expressions

The text and box styles of ZSL are identical for non-box paragraphs and expressions. The non-box paragraphs include given sets, schema definition, equivalence definition, predicates, and free types. Non-box paragraphs can be written as follows:

```
[ADDR, PAGE]

DataDictInit is [ DataDictionary' |
                  defined' = {} ]

DATABASE == ADDR --> PAGE

exists n: NAME @ birthday(n) in December

OP ::= plus | minus | times | divide

EXP ::= const << N >>
       | binop << OP & EXP & EXP >>
```

Consult Appendix A for the syntactical structures of non-box paragraphs. ZSL defines ASCII equivalents for all the mathematical symbols used in Z. They are also listed in Appendix A.

4.6 Separators

Separator are used to separate between declarations or predicates in a sequence of declarations or predicates in the axiom, generic, and schema boxes. Omission of separators between declarations or predicates will cause syntax and/or typing errors.

A sequence of declarations and predicates must be separated by semi-colons (;).

The example on the left is incorrect, since a new line is not considered as a separator in ZSL. The correct input is shown on the right.

```
schema InsertOk
  Delta DataDictionary
  name? : NAME
  info? : INFO
  resp! : Response
where
  name? notin defined
  # defined < MaxSize
  dict' = dict || { name? -> info? }
  resp! = Success
end schema

schema InsertOk
  Delta DataDictionary;
  name? : NAME;
  info? : INFO;
  resp! : Response
where
  name? notin defined;
  # defined < MaxSize;
  dict' = dict || { name? -> info? };
  resp! = Success
end schema
```

4.7 File inclusion

ZSL allows you to break a long specification into several input files and then include them into a master file.

You may use either of the following commands to include a file:

- a) *input filename*
- b) *include filename*

The complete filename must be specified in the file inclusion commands. The file inclusion commands can be nested. The maximum depth of inclusion is 16.

5 Advanced Features

All the features described in this section are new in version 2.0. Most of them apply to both input forms.

5.1 ZTC pragmas

ZTC recognizes a number of *pragmas* to support non-standard extension to Z and allow you to exert fine control over the behavior of ZTC.

A pragma *begins with double percentage signs* (%%) followed by a single space and the pragma name. Zero or more arguments separated by spaces may follow.

Anything following a pragma on the same line will be considered parameters of the pragma, not part of formal text.

We have already seen the `oz` and `oz-native` in section 3.1.

```
%% oz
%% oz-native
```

Neither of them has arguments.

5.2 User-defined symbols

ZTC allows user-defined symbols. You can define

- infix relational symbols,
- prefix relational symbols,
- infix generic symbols,
- prefix generic symbols, and
- infix function symbols.²

²Postfix function symbols can be defined using L^AT_EX macros discussed in the next section.

User-defined relational and generic symbols are defined as follows:

- *infix relational symbol:*
%% inrel symbol
- *prefix relational symbols:*
%% prerel symbol
- *infix generic symbols:*
%% ingen symbol
- *prefix generic symbols:*
%% pregen symbol

A symbol is either a word or 1 to 4 character combinations of the following characters:

```
\ @ / < > = & | - + * : . _ { } ( )
[ ]
~ (ZSL only)
```

Here are some examples of user-defined relational and generic symbols.

```
%% inrel \prec
%% prerel \odd
%% pregen \smallpower
```

When define a infix function symbol, ZTC also allow you to specify its priority and associativity.

User-defined infix function symbols are defined as follows:

```
%% infun<associativity><priority> symbol
```

where

- *<associativity> is either l, for left associative, or r, for right associative.*
- *<priority> is a digit from 0 to 7 indicating the priority of the symbol.*

Priority 0 is the lowest and 7 the highest. The priority of the pre-defined infix function symbols are shown in Figure 2. All the pre-defined infix function symbols are left-associative.

Here are some examples of user-defined infix function symbols.

```
%% infunl4 \times
%% infunr0 \myop
```

Note!

The inrel, prerel, ingen, pregen, and infun pragmas only define the lexical categories of the user-defined symbols. You have to define the type and meaning of the symbols before you can

Priority 1	\mapsto
Priority 2	\dots
Priority 3	$+ - \cup \setminus \hat{\ } \# \#$
Priority 4	$* \text{div} \text{mod} \cap \uparrow \downarrow \S \circ \otimes$
Priority 5	$\oplus \#$
Priority 6	$\triangleleft \triangleright \triangleleft \triangleright$

Figure 2: The priority of the pre-defined infix function symbols

use them. You may also have to define their visual appearances using `\def` or `\newcommand`, if they are not already defined.

Figure 3 shows an example of user-defined symbols.

Any identifier *Rel* that denotes a relation can be converted to a infix relational symbol *Rel*.

The infix relational symbol corresponding to *Rel* is written as
`\inrel{Rel}`

Here is an example.

```
\begin{axdef}
  divides: \nat_1 \rel \nat_1
\where
  \forall x, y : \nat_1 @ x \inrel{divides} y
  \iff x \bmod y = 0
\end{axdef}
```

$$\frac{\text{divides} : \mathbb{N}_1 \leftrightarrow \mathbb{N}_1}{\forall x, y : \mathbb{N}_1 \bullet x \text{ divides } y \Leftrightarrow x \bmod y = 0}$$

5.3 Using \LaTeX macros

ZTC allows Z expressions to be written in \LaTeX macro syntax, so that they can be typeset in anyway you like.

The following \LaTeX macro
`\xyz{exp1}{exp2}...{expn}`
 is interpreted by ZTC as
`\xyz (exp1, exp2, ..., expn)`

This feature can be used to define so-called *outfix* or *surround-fix* symbols as shown below:

```

%% inrel \prec
%% prerel \odds
%% pregen \smallpower
%% infunl4 \times
\def \odds {\mathsf{Odd}~}
\def \smallpower {\boldsymbol{S}~}

\begin{axdef}
\_ \prec \_ : \num \rel \num \\
\odds \_ : \power \num \\
\_ \times \_ : \nat_1 \cross \nat_1
  \pfun \nat_1
\where
\forall x, y : \num @
  x \prec y \iff x + 1 < y \\
\forall x : \num @
  \odds x \iff x \mod 2 = 1 \\
\forall x, y : \nat_1 @
  x \times y = x * y
\end{axdef}

\begin{zed}
\smallpower X ==
  \{ S : \power X | \# S \leq 10 \}
\end{zed}

```

$$\begin{array}{l}
 \prec : \mathbb{Z} \leftrightarrow \mathbb{Z} \\
 \text{Odd } _ : \mathbb{P} \mathbb{Z} \\
 \times : \mathbb{N}_1 \times \mathbb{N}_1 \rightarrow \mathbb{N}_1 \\
 \hline
 \forall x, y : \mathbb{Z} \bullet x \prec y \Leftrightarrow x + 1 < y \\
 \forall x : \mathbb{Z} \bullet \text{Odd } x \Leftrightarrow x \bmod 2 = 1 \\
 \forall x, y : \mathbb{N}_1 \bullet x \times y = x * y \\
 \hline
 \mathbb{S} X == \{S : \mathbb{P} X \mid \#S \leq 10\}
 \end{array}$$

Figure 3: User-defined symbols.

```

\def \abs#1 {\sim|#1|\sim}

\begin{axdef}
\abs{\_} : \num \fun \nat
\where
\forall x : \num @
\abs{x} = \zif x \geq 0 \zthen x \\
\t4 \zelse -x
\end{axdef}

```

$$\begin{array}{l}
 | _ | : \mathbb{Z} \rightarrow \mathbb{N} \\
 \hline
 \forall x : \mathbb{Z} \bullet |x| = \text{if } x \geq 0 \text{ then } x \\
 \qquad \qquad \qquad \text{else } -x
 \end{array}$$

This feature can also be used to define postfix function symbols and fractions, etc.

The `ignore` and `null-token` pragmas will make \LaTeX commands disappear.

The effect of the following ignore pragma

```
%% ignore \xyz
```

is to make

$$\backslash\text{xyz}\{exp_1\}\{exp_2\}\dots\{exp_n\}$$

equivalent to

$$(exp_1, exp_2, \dots, exp_n)$$

```

\def\ace {\mathsf{A}}
\def\king {\mathsf{K}}
...
\def\two {\mathsf{2}}
Suppose we ...
\begin{zed}
SUIT ::= \spadesuit | \heartsuit |
         \diamondsuit | \clubsuit
\also
RANK ::= \ace | \king | \queen | \jack |
         \ten | \nine | \eight | \seven | \t2
\also
Cards == SUIT \cross RANK
\end{zed}
Thus, we can say
\begin{zed}
(\spadesuit, \ace) \in Cards
\end{zed}
Or we can say
\def\card#1#2{#1#2}
%% ignore \card
\begin{zed}
\card{\spadesuit}{\ace} \in Cards
\end{zed}
Is this more fun?

```

Suppose we are specifying a deck of playing cards. Each card consists of a suit and a rank. It can be specified as follows:

$$\begin{aligned}
 \text{SUIT} &::= \spadesuit | \heartsuit | \diamondsuit | \clubsuit \\
 \text{RANK} &::= \text{A} | \text{K} | \text{Q} | \text{J} | 10 | 9 | 8 | 7 | \\
 &\quad 6 | 5 | 4 | 3 | 2 \\
 \text{Cards} &== \text{SUIT} \times \text{RANK}
 \end{aligned}$$

Thus, we can say

$$(\spadesuit, \text{A}) \in \text{Cards}$$

Or we can say

$$\spadesuit \text{A} \in \text{Cards}$$

Is this more fun?

Figure 4: The Ignore pragma.

Figure 4 shows an example of using the ignore pragma.

The effect of the null-token pragma is to discard a parameterless \LaTeX command.

The null-token pragma is useful in situations such as you want to customize the layout of the schemas. The example in Figure 5 shows how to center the predicates in schemas.

5.4 Liberal mode

ZTC 2.0 introduces the *liberal mode*, which is a deviation from the Z notation defined in ZRM. However, I believe that it is quite reasonable.

In the liberal mode, declarations of variables can be omitted as long as their types can be deduced from the context up to and including the current paragraph.

By default, ZTC is in the *strict mode* that follows the strict rules given in ZRM.

```

\def \bstack {\begin{array}{c}}
\def \estack {\end{array}}
%% null-token \bstack
%% null-token \estack

\begin{schema}{S}
  x, y, z : \nat
\where
  \bstack
  x \geq 0 \\\
  y \geq x \geq z
  \estack
\end{schema}

```

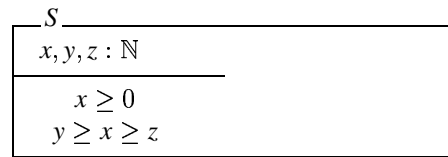


Figure 5: Null-token pragma.

You can switch between the strict and liberal modes using the following pragmas:

- %% liberal: to enter the liberal mode.
- %% strict: to enter the strict mode.

You can also use the `-L` switch from the command line to set the default mode to the liberal mode.

A trivial example of using the liberal mode is the following:

```

%% liberal

\begin{zed}
x = 2 \also
y = x + 1 \also
u = v \cup \{ 1 \} \also
s = \{ x, y \} \also
f ( x, y ) = s
\end{zed}

```

$$x = 2$$

$$y = z + 1$$

$$u = v \cup \{1\}$$

$$s = \{x, y\}$$

$$f(x, y) = s$$

This specification is illegal in strict mode but legal in liberal mode. The variables are used without declaration but their types can be easily deduced from the context.

The following is a more sensible use of liberal mode. This is an excerpt from Susan Stepney's *High Integrity Compilation*[10], in which she specified the semantics of compilers using Z. She wrote:

The definitions of the semantics functions are quantified over all the variables appearing on the left-hand side of the equation. ...

The continual occurrence of such quantifications tends to clutter the specification. So this is abbreviated, by omitting the declarations of all the arguments of the meaning functions, whose types can easily be deduced. (p. 23)

In fact, such abbreviations are not only reasonable, but also very common and widely accepted in literatures. This example also illustrates the \LaTeX macro feature of ZTC. Using `[...]` instead of `(...)` to enclose the arguments is a standard convention when writing denotation semantics. Using

the strict syntax required by Z will be less straightforward and socially unacceptable. With the \LaTeX macros, you can follow the accepted conversions in the printout, and still type-check your specifications.

So instead of writing the following semantic function in the strict mode:

$$\begin{array}{|l} \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[-] : \mathit{EXPR} \rightarrow \mathit{State} \rightarrow \mathbb{Z} \\ \hline \forall \chi : \mathbb{Z}; \xi : \mathit{NAME}; \epsilon, \epsilon_1, \epsilon_2 : \mathit{EXPR}; \omega : \mathit{OP}; \sigma : \mathit{State} \bullet \\ \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\mathit{number} \chi]\sigma = \chi \\ \wedge \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\mathit{variable} \xi]\sigma = \sigma\xi \\ \wedge \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\mathit{negate} \epsilon]\sigma = -(\mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\epsilon]\sigma) \\ \wedge \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\mathit{operation}(\epsilon_1, \omega, \epsilon_2)]\sigma = \\ \mathcal{D}_{\mathcal{O}\mathcal{P}}[\omega](\mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\epsilon_1]\sigma, \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\epsilon_2]\sigma) \end{array}$$

we can write it in the liberal mode as follows:

```
%% liberal
```

```
\def\dop#1{\mathcal{D}_#\mathcal{OP}}%
\lbag #1 \rbag}
\def\dexpr#1{\mathcal{D}_#\mathcal{EXPR}}%
\lbag #1 \rbag}
\begin{axdef}
\dexpr{\_} : \mathit{EXPR} \to \mathit{State} \to \mathit{num}
\where
\dexpr{number~\chi} \sigma = \chi \ \backslash
\dexpr{variable~\xi} \sigma = \sigma \xi \ \backslash
\dexpr{negate~\epsilon} \sigma =
- (\dexpr{\epsilon} \sigma) \ \backslash
\dexpr{operation(\epsilon_1, \omega,
\epsilon_2)}
\sigma = \ \backslash
\tl \dop{\omega}(\dexpr{\epsilon_1} \sigma,
\dexpr{\epsilon_2} \sigma)
\end{axdef}
```

$$\begin{array}{|l} \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[-] : \mathit{EXPR} \rightarrow \mathit{State} \rightarrow \mathbb{Z} \\ \hline \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\mathit{number} \chi]\sigma = \chi \\ \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\mathit{variable} \xi]\sigma = \sigma\xi \\ \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\mathit{negate} \epsilon]\sigma = -(\mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\epsilon]\sigma) \\ \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\mathit{operation}(\epsilon_1, \omega, \epsilon_2)]\sigma = \\ \mathcal{D}_{\mathcal{O}\mathcal{P}}[\omega](\mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\epsilon_1]\sigma, \mathcal{D}_{\mathcal{E}\mathcal{X}\mathcal{P}\mathcal{R}}[\epsilon_2]\sigma) \end{array}$$

A more complete version of this example is included in the ZTC distribution.

5.5 Forward declaration of types

ZTC allows you to forward declare a type as a given set and then redefine it later.

A warning message will be issued for each redefinition.

5.6 Obtain type information

ZTC allows you to obtain type information of any expression.

The `typeof` macro will print out the type of the its argument.

```
\typeof{ exp }
```

This feature is enabled by the `-T` switch and only available in the \LaTeX input.

5.7 Verbosity control

You can control the verbosity of ZTC using the `verbose` pragma or the `V` switch from the command line.

The `verbose` pragma sets the verbosity value from 0 to 9.

```
%% verbose [0-9]
```

Verbosity value 0 is the least verbose and 9 is the most verbose. The default verbosity is 5.

6 Running ZTC

ZTC supports a number of command line options.

```
ztc [-I [ t1 ] ] infile [ options ]
```

On extended MS-DOS, use `ztc32` instead of `ztc`.

The input file name is required. It is no longer necessary to specify the input form when the full file name is given. ZTC will determine the input form automatically. You can still specify the input form explicitly with the `-I` switch, then the extension of the input file name may be omitted:

`-It` L^AT_EX form, the default extension is `zed`.

`-I1` ZSL form, the default extension is `zsl`.

The options of ZTC are:

- `-F` Enable the flying-erase mode
This switch instructs ZTC to erase the paragraphs from the memory as soon as they have been type checked. It is particularly useful when you are running the standard DOS version. It increases the capacity of ZTC.
- `-L` Set the default mode to the liberal mode.
- `-M[0-9]` Select mathematical toolkit library.
`-Mn` instructs ZTC to load `mathn.zed` for L^AT_EX input and `mathn.zbx` for ZSL input. The default mathematical toolkit library is `math1.zed` and `math1.zbx`.
Library `math0` contains the basic mathematical toolkit defined in ZRM. Library `math1` contains additional declarations of `float`, `boolean`, `char`, and `string`, see Appendix B.
- `-Mlibfile` Select mathematical toolkit library.
This switch instructs ZTC to load `libfile.zed` for L^AT_EX input and `libfile.zbx` for ZSL input.
- `-M-` Disable mathematical toolkit library.
This switch instructs ZTC not to load any mathematical toolkit library.
- `-O[t1b] outfile` Translate the input file into a given output form and save the result to outfile. The extension of the output filename may be omitted
 - `-Ot` translate the input file to the L^AT_EX form, the default extension is `zed`.
 - `-O1` translate the input file to the ZSL plain text form, the default extension is `zsl`.
 - `-Ob` translate the input file to the ZSL box form, the default extension is `zbx`.

When the translation is performed, only the formal text is translated, and all the informal text is deleted.
- `-S` Suppress type-checking.

- T Generate a type report:
This switch generates a type report that contains the type information of all the names in the specification. The type report will be written in a file whose name is the same as the input file name with extension `.typ`.
- V[0-9] Set verbosity
The default verbosity is 5. 0 is the least verbose and 9 the most.

The single-letter options, `F`, `L`, `S`, and `T`, can be grouped together, such as `-LT`.

Every time ZTC is invoked, a log file will be written. It contains all the messages sent to the standard output. The name of the log file is the same as the input file name with the extension `.log`.

Common usages:

1. `ZTC spec.zed`
Type-checking \LaTeX input file `spec.zed`.
2. `ZTC spec.zsl -T`
Type-checking ZSL input file `spec.zsl`, and requesting a type report.
3. `ZTC spec.zed -Ob spec`
Translating \LaTeX input file `spec.zed` to ZSL box style. The output file will be named `spec.zbx`, and type-checking is performed on the input file.
4. `ZTC spec.zsl -Ot spec -S`
Translating ZSL input file `spec.zsl` to \LaTeX style. The output file will be named `spec.zed`, and type-checking is suppressed.

7 Installation

ZTC runs on the following platforms:

- Microsoft Windows 9x, NT, 2000, and XP, and
- Linux

7.1 The distribution package

The ZTC 2.1 distribution package contains the following files:

Documentation (all platforms)

README, a brief overview
 guide.ps, this guide in PostScript
 ztc.1, a man page

Executable files (one of the following sets)

ztc, for Linux
 ZTC.EXE, for Windows/MS-DOS

Library files (all platforms)

math0.zed, for \LaTeX input
 math0.zbx, for ZSL input
 mathoz.zed, for \LaTeX input using oz package

\LaTeX style file (all platforms)

ztc.sty, for \LaTeX input

Sample Z specification files (all platforms)

datadict.zed, datadict.zsl, datadict.zbx

A simple *data dictionary* in three different input styles: \LaTeX ZSL plain text style, and ZSL box style.

liberal.zed

A more complete version of the example on page 24 illustrating the liberal mode and \LaTeX macro syntax for Z expressions.

bridge.zed

Some basic rules of bidding in contract bridge.

Registration form (all platforms)

register.txt, please send this in via e-mail.

7.2 Installing Windows/MS-DOS version

Step 1. Create a new directory on your hard drive for ZTC, say `C:\ZTC`.

Step 2. Copy the executable file `ZTC.EXE` to `\ZTC`.

Step 3. Copy the data files `MATH0.ZED`, `MATH0.ZBX`, and `MATHOZ.ZED` to `\ZTC`. (Alternatively, you can put them in the same directory where your specifications resides. Then you don't need to set `ZLIBPATH`.)

Step 4. If you use the \LaTeX input form, copy the \LaTeX style file `ZTC.STY` to the \TeX input directory. If you use $\text{Em}\TeX$ it will be `C:\EMTEX\TEXINPUT`. You need to have `zed` or `oz` style package installed as well. (Alternatively, you can put it in the same directory where your specifications reside.)

Step 5. Update `AUTOEXEC.BAT` file by appending the following lines:

```
SET PATH=%PATH%;C:\ZTC;
SET ZLIBPATH=C:\ZTC
```

7.3 Installing Linux version

Assume that the executable directory is `/usr/local/bin`, and the data directory is usually `/usr/local/lib`.

Step 1. Copy the executable file `ztc` to `/usr/local/bin`.

Step 2. Copy the data file `math0.zed`, `math0.zbx`, and `mathoz.zed` to `/usr/local/lib`. (Alternatively, you can put them in the same directory where your specifications resides. Then you don't need to set `ZLIBPATH`.)

Step 3. If you use the \LaTeX input form, copy the \LaTeX style file `ztc.sty` to the \TeX input directory, probably `/usr/local/lib/texmf/tex/latex2e` depending on your \TeX installation and \LaTeX version. You need to have `zed` or `oz` style package installed as well. (Alternatively, you can put it in the same directory where your specifications reside.)

Step 4. Make sure `/usr/local/bin` is in your search path.

Step 5. Set the environment variable `ZLIBPATH` to `/usr/local/lib`.

In `csh` and `tcsh` do:

```
setenv ZLIBPATH /usr/local/lib
```

In `bash`, `ksh`, and `sh` do:

```
ZLIBPATH=/usr/local/lib; export ZLIBPATH
```

You may want to put this in your shell initialization script.

8 Registration and Bug Reports

Please fill out the *Registration Form* included in the distribution package, and email it to

`jia@cs.depaul.edu`

You will receive information regarding new releases of ZTC and other tools for Z.

Comments on ZSL and ZTC are greatly appreciated. Send your comments and bug reports to the same address above. When filing a bug report, please include the following information:

- a) hardware platform and operating system;
- b) version of ZTC;
- c) input file;
- d) command line used to invoke ZTC.

References

- [1] J.M. Spivey, *The Z Notation, A Reference Manual*, 2nd edition. Prentice Hall International, 1992.
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- [4] J.M. Spivey, “An Introduction to Z and Formal Specification,” *Software Engineering Journal*, Vol. 4, No. 1, January 1989, pp. 40-50.
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- [8] J.M. Spivey, *A guide to the zed style option*, 1990. Available via anonymous FTP at <ftp.comlab.ox.ac.uk>.
- [9] L. Lamport, *L^AT_EX: A Document Preparation System*, 2nd edition, Addison-Wesley, 1994.
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A L^AT_EX and ZSL Input Notations

A.1 Paragraphs

A.1.1 Axiom Box

$$\left| \begin{array}{l} D_1; \dots; D_m \\ \hline P_1; \dots; P_n \end{array} \right.$$

L^AT_EX input:

```
\begin{axdef}
  D_1; ... ; D_m
\where
  P_1; ... ; P_n
\end{axdef}
```

ZSL input – text style:

```
global
  D1; ... ; Dm
axiom
  P1; ... ; Pn
end axiom
```

ZSL input – box style:

```
| D1; ... ; Dm
|-----
| P1; ... ; Pn
```

$$\left| D_1; \dots; D_m \right.$$

L^AT_EX input:

```
\begin{axdef}
  D_1; ... ; D_m
\end{axdef}
```

ZSL input – text style:

```
global
  D1; ... ; Dm
end global
```

ZSL input – box style:

```
| D1; ... ; Dm
```

$$P_1; \dots; P_n$$
L^AT_EX input:

```
\begin{zed}
  P_1; ... ; P_n
\end{zed}
```

ZSL input

```
axiom
  P1; ... ; Pn
end axiom
```

A.1.2 Schema Box

S
$D_1; \dots; D_m$
$P_1; \dots; P_n$

L^AT_EX input:

```
\begin{schema}{S}
  D_1; ... ; D_m
\where
  P_1; ... ; P_n
\end{schema}
```

ZSL input – text style:

```
schema S
  D1; ... ; Dm
where
  P1; ... ; Pn
end schema
```

ZSL input – box style:

```
--- S -----
|  D1; ... ; Dm
|-----
|  P1; ... ; Pn
|-----
```

A.1.3 Generic Schema Box

$S[X_1, \dots, X_k]$
$D_1; \dots; D_m$
$P_1; \dots; P_n$

L^AT_EX input:

```
\begin{schema}{S[X_1, \dots X_k]}
  D_1; ... ; D_m
\where
  P_1; ... ; P_n
\end{schema}
```

ZSL input – text style:

```
schema S [X1, ... , Xk]
  D1; ... ; Dm
where
  P1; ... ; Pn
end schema
```

ZSL input – box style:

```
--- S [X1, ... , Xk] -----
|  D1; ... ; Dm
|-----
|  P1; ... ; Pn
|-----
```

A.1.4 Generic Box

$[X_1, \dots, X_k]$
$D_1; \dots; D_m$
$P_1; \dots; P_n$

\LaTeX input zed:

```
\begin{gendef}[X_1, \dots, X_k]
  D_1; ... ; D_m
\where
  P_1; ... ; P_n
\end{gendef}
```

\LaTeX input oz:

```
\begin{gendef}{X_1, \dots, X_k}
  D_1; ... ; D_m
\where
  P_1; ... ; P_n
\end{gendef}
```

ZSL input – text style:

```
generic [X1, ... , Xk]
  D1; ... ; Dm
where
  P1; ... ; Pn
end generic
```

ZSL input – box style:

```

=== [X1, ... , Xk] =====
|  D1; ... ; Dm
|-----
|  P1; ... ; Pn
|-----
    
```

A.1.5 Schema Definition

$S \hat{=} [D P]$	L ^A T _E X zed <code>S \defs [D P]</code>	ZSL <code>S ^= [D P]</code> <code>S is [D P]</code>
	L ^A T _E X oz <code>S \sdef [D P]</code>	

A.1.6 Given Set

$[T_1, \dots, T_n]$	L ^A T _E X <code>[T_1, ..., T_n]</code>	ZSL <code>[T1, ..., Tn]</code>
---------------------	---	-----------------------------------

A.1.7 Equivalence Definition

$id == Exp$	L ^A T _E X zed <code>id == Exp</code>	ZSL <code>id == Exp</code>
	L ^A T _E X oz <code>id \defs Exp</code>	

A.1.8 Free Type Definition

$ \begin{array}{l} T ::= c_1 \dots c_m \\ d_1 \langle\langle E_1[T] \rangle\rangle \\ \dots \\ d_n \langle\langle E_n[T] \rangle\rangle \end{array} $	L ^A T _E X input zed: <pre> \begin{syntax} T & ::= & c_1 ... c_m \\ & & d_1 \lldata E_1[T] \rdata \\ & & ... \\ & & d_n \lldata E_n[T] \rdata \end{syntax} </pre>
--	---

\LaTeX input oz:

```
\begin{syntax}
T & \ddef & c_1 | ... | c_m \\
  & | & d_1 \lang E_1[T] \rang \\
  & | & ... \\
  & | & d_n \lang E_n[T] \rang
\end{syntax}
```

ZSL input:

```
T ::= c1 | ... | cm
      | d1 << E1[T] >>
      | ...
      | dn << En[T] >>
```

A.1.9 Schema Expressions

	\LaTeX	ZSL
$\forall D P \bullet S$	<code>\forall D P @ S</code>	<code>forall D P @ S</code>
	oz only ▶ <code>\all D P \dot S</code>	
$\exists D P \bullet S$	<code>\exists D P @ S</code>	<code>exists D P @ S</code>
	oz only ▶ <code>\exi D P \dot S</code>	
$\exists_1 D P \bullet S$	<code>\exists_1 D P @ S</code>	<code>exists1 D P @ S</code>
	oz only ▶ <code>\exione D P \dot S</code>	
$[D P]$	<code>[D P]</code>	<code>[D P]</code>
ΔS	<code>\Delta S</code>	<code>Delta S</code>
ΞS	<code>\Xi S</code>	<code>Xi S</code>
$S[T_1, \dots, T_n]$	<code>S[T_1, \dots, T_n]</code>	<code>S[T1, \dots, Tn]</code>
$S[x_1/y_1, \dots, x_n/y_n]$	<code>S[x_1/y_1, \dots, x_n/y_n]</code>	<code>S[x1/y1, \dots, xn/yn]</code>
$\text{pre } S$	<code>\pre S</code>	<code>pre S</code>
$\neg S$	<code>\lnot S</code>	<code>not S</code>
$S_1 \wedge S_2$	<code>S_1 \land S_2</code>	<code>S1 and S2</code>
$S_1 \vee S_2$	<code>S_1 \lor S_2</code>	<code>S1 /\ S2</code>
$S_1 \Rightarrow S_2$	<code>S_1 \implies S_2</code>	<code>S1 implies S2</code>
	oz only ▶ <code>S_1 \imp S_2</code>	<code>S1 => S2</code>
$S_1 \Leftrightarrow S_2$	<code>S_1 \iff S_2</code>	<code>S1 iff S2</code>
		<code>S1 <=> S2</code>
$S_1 \upharpoonright S_2$	<code>S_1 \project S_2</code>	<code>S1 project S2</code>
		<code>S1 \ S2</code>
$S \setminus (v_1, \dots, v_n)$	<code>S \hide (v_1, \dots, v_n)</code>	<code>S hide (v1, \dots, vn)</code>
	oz only ▶ <code>S \zhide (v_1, \dots, v_n)</code>	<code>S \\ (v1, \dots, vn)</code>
$S_1 \circledast S_2$	<code>S_1 \semi S_2</code>	<code>S1 semi S2</code>
	oz only ▶ <code>S_1 \zcmp S_2</code>	<code>S1 // S2</code>
$S_1 \gg S_2$	<code>S_1 \pipe S_2</code>	<code>S1 pipe S2</code>
	oz only ▶ <code>S_1 \zpipe S_2</code>	

A.1.10 Predicates

	\LaTeX	ZSL
$\forall D \mid P \bullet Q$	<code>\forall D \mid P @ Q</code>	<code>forall D \mid P @ Q</code>
	oz only ▶ <code>\all D \mid P \dot S</code>	
$\exists D \mid P \bullet Q$	<code>\exists D \mid P @ Q</code>	<code>exists D \mid P @ Q</code>
	oz only ▶ <code>\exi D \mid P \dot S</code>	
$\exists_1 D \mid P \bullet Q$	<code>\exists_1 D \mid P @ Q</code>	<code>exists1 D \mid P @ Q</code>
	oz only ▶ <code>\exione D \mid P \dot S</code>	
let $v == e \bullet P$	<code>\zlet v==e @ P</code>	<code>let v==e @ P</code>
	oz only ▶ <code>\zlet v==e \dot P</code>	
$p \wedge q$	<code>p \land q</code>	<code>p and q</code>
$p \vee q$	<code>p \lor q</code>	<code>p /\ q</code>
$p \Rightarrow q$	<code>p \implies q</code>	<code>p or q</code>
	oz only ▶ <code>p \imp q</code>	<code>p \/ q</code>
$p \Leftrightarrow q$	<code>p \iff q</code>	<code>p implies q</code>
$\neg p$	<code>\lnot p</code>	<code>p => q</code>
<i>true</i>	<code>true</code>	<code>p iff q</code>
		<code>p <=> q</code>
<i>false</i>	<code>false</code>	<code>not p</code>
		<code>true</code>
		<code>TRUE</code>
		<code>false</code>
		<code>FALSE</code>

A.2 Expressions**A.2.1 Lambda Expression**

	\LaTeX	ZSL
$\lambda D \mid P \bullet E$	<code>\lambda D \mid P @ E</code>	<code>lambda D \mid P @ E</code>

A.2.2 Definite Description

	\LaTeX	ZSL
$\mu D \mid P \bullet E$	<code>\mu D \mid P @ E</code>	<code>mu D \mid P @ E</code>
	oz only ▶ <code>\mu D \mid P \dot E</code>	<code>unique D \mid P @ E</code>

A.2.3 Conditional expression

if P then E_1 else E_2	\LaTeX <code>\zif P \zthen E_1</code> <code>\zelse E_2</code>	ZSL <code>if P then E1 else E2</code>
--	---	--

A.2.4 Local definition

let $v == e \bullet E$	\LaTeX <code>\zlet v==e @ E</code> oz only ► <code>\zlet v==e \dot E</code>	ZSL <code>let v==e @ E</code>
--	---	----------------------------------

A.2.5 Sets

$\{x_1, \dots, x_n\}$ $\{D \mid P \bullet E\}$	\LaTeX <code>\{ x_1, \dots, x_n \}</code> <code>\{ D \mid P @ E \}</code> oz only ► <code>\{ D \mid P \dot E \}</code>	ZSL <code>{ x1, ..., xn }</code> <code>{ D \mid P @ E }</code>
$S_1 \times S_2$	<code>S_1 \cross S_2</code>	<code>S1 & S2</code>
$S_1 = S_2$	<code>S_1 = S_2</code>	<code>S1 = S2</code>
$S_1 \neq S_2$	<code>S_1 \neq S_2</code>	<code>S1 /= S2</code>
$x \in S$	<code>x \in S</code> oz only ► <code>x \mem S</code>	<code>x in S</code>
$x \notin S$	<code>x \notin S</code> oz only ► <code>x \nem S</code>	<code>x notin S</code>
\emptyset	<code>\empty</code>	<code>{ }</code>
$S_1 \subset S_2$	<code>S_1 \subset S_2</code> oz only ► <code>S_1 \psubs S_2</code>	<code>S1 subset S2</code>
$S_1 \subseteq S_2$	<code>S_1 \subseteq S_2</code> oz only ► <code>S_1 \subseq S_2</code>	<code>S1 subseq S2</code>
$\mathbb{P}S$	<code>\power S</code> oz only ► <code>\pset S</code>	<code>P S</code>
$\mathbb{P}_1 S$	<code>\power_1 S</code> oz only ► <code>\psetone S</code>	<code>P1 S</code>
$\mathbb{F}S$	<code>\finset S</code> oz only ► <code>\fset S</code>	<code>F S</code>
$\mathbb{F}_1 S$	<code>\finset_1 S</code> oz only ► <code>\fsetone S</code>	<code>F1 S</code>
$S_1 \cup S_2$	<code>S_1 \cup S_2</code> oz only ► <code>S_1 \uni S_2</code>	<code>S1 setunion S2</code> <code>S1 S2</code>
$S_1 \cap S_2$	<code>S_1 \cap S_2</code> oz only ► <code>S_1 \int S_2</code>	<code>S1 setint S2</code> <code>S1 && S2</code>
$S_1 \setminus S_2$	<code>S_1 \setminus S_2</code>	<code>S1 setminus S2</code> <code>S1 \ S2</code>
$\bigcup SS$	<code>\bigcup SS</code>	<code>Union SS</code>

$\bigcap SS$	<code>\bigcap SS</code>	Intersection SS
--------------	-------------------------	-----------------

A.2.6 Ordered Pairs

	L ^A T _E X	ZSL
$x \mapsto y$	<code>x \mapsto y</code>	<code>x mapsto y</code>
<i>first P</i>	<code>x \map y</code>	<code>x -> y</code>
<i>second P</i>	<code>first P</code>	<code>first P</code>
	<code>second P</code>	<code>second P</code>

A.2.7 Relations

	L ^A T _E X	ZSL
$A \leftrightarrow B$	<code>A \rel B</code>	<code>A <-> B</code>
$x \underline{R} y$	<code>x \inrel{R} y</code>	<code>A rel B</code>
$\text{dom } R$	<code>\dom R</code>	<code>x _R_ y</code>
$\text{ran } R$	<code>\ran R</code>	<code>dom R</code>
$\text{id } S$	<code>\id S</code>	<code>ran R</code>
$R_1 \circ R_2$	<code>R_1 \circ R_2</code>	<code>id S</code>
$R_1 \circlearrowleft R_2$	<code>R_1 \circ R_2</code>	<code>R1 \circ R2</code>
$R_1 \triangleleft R_2$	<code>R_1 \circ R_2</code>	<code>R1 \circ R2</code>
$R_1 \triangleleft\!\!\! \triangleleft R_2$	<code>R_1 \circ R_2</code>	<code>R1 \circ R2</code>
$R_1 \triangleright R_2$	<code>R_1 \circ R_2</code>	<code>R1 \circ R2</code>
$R_1 \triangleright\!\!\! \triangleright R_2$	<code>R_1 \circ R_2</code>	<code>R1 \circ R2</code>
$R_1 \oplus R_2$	<code>R_1 \circ R_2</code>	<code>R1 \circ R2</code>
$R(S)$	<code>R \lim S \ring</code>	<code>R1 \circ R2</code>
R^{\sim}	<code>R \inv</code>	<code>R1 \circ R2</code>
R^*	<code>R \star</code>	<code>R1 \circ R2</code>
R^+	<code>R \plus</code>	<code>R1 \circ R2</code>
R^k	<code>R \bsup k \esup</code>	<code>R1 \circ R2</code>

A.2.8 Functions

	L ^A T _E X	ZSL
$A \rightarrow B$	<code>A \pfun B</code>	<code>A +-> B</code> <code>A pfun B</code>
$A \rightarrow B$	<code>A \fun B</code>	<code>A --> B</code>
$A \twoheadrightarrow B$	oz only ► <code>A \tfun B</code>	<code>A fun B</code>
$A \mapsto B$	<code>A \pinj B</code>	<code>A >+> B</code> <code>A pinj B</code>
$A \hookrightarrow B$	<code>A \inj B</code>	<code>A >-> B</code>
$A \twoheadrightarrow B$	oz only ► <code>A \tinj B</code>	<code>A inj B</code>
$A \twoheadrightarrow B$	oz only ► <code>A \psurj B</code>	<code>A +>> B</code>
$A \rightarrow B$	oz only ► <code>A \psur B</code>	<code>A psurj B</code>
$A \rightarrow B$	oz only ► <code>A \surj B</code>	<code>A ->> B</code>
$A \twoheadrightarrow B$	oz only ► <code>A \tsur B</code>	<code>A surj B</code>
$A \twoheadrightarrow B$	<code>A \bij B</code>	<code>A >->> B</code> <code>A bij B</code>
$A \twoheadrightarrow B$	<code>A \ffun B</code>	<code>A ++> B</code>
$A \twoheadrightarrow B$	<code>A \finj B</code>	<code>A ffun B</code> <code>A >+>> B</code> <code>A finj B</code>

A.2.9 Numbers

	L ^A T _E X	ZSL
\mathbb{N}	<code>\nat</code>	<code>N</code>
\mathbb{N}_1	<code>\nat_1</code>	<code>Nat</code>
\mathbb{Z}	oz only ► <code>\natone</code>	<code>N1</code>
	oz only ► <code>\num</code>	<code>Nat1</code>
$n \dots m$	oz only ► <code>\integer</code>	<code>Z</code>
	<code>n \upto m</code>	<code>Int</code>
$x + y$	<code>x + y</code>	<code>n upto m</code> <code>n .. m</code>
$x - y$	<code>x - y</code>	<code>x + y</code>
$x * y$	<code>x * y</code>	<code>x - y</code>
$x = y$	<code>x = y</code>	<code>x * y</code>
$x \neq y$	<code>x \neq y</code>	<code>x = y</code>
$x \text{ div } y$	<code>x \div y</code>	<code>x /= y</code>
$x \text{ mod } y$	<code>x \mod y</code>	<code>x div y</code>
$x < y$	<code>x < y</code>	<code>x mod y</code>
$x \leq y$	<code>x \leq y</code>	<code>x < y</code>
$x > y$	<code>x > y</code>	<code>x <= y</code>
$x \geq y$	<code>x \geq y</code>	<code>x > y</code>
$\text{succ } x$	<code>succ x</code>	<code>x >= y</code> <code>succ x</code>

$\#S$	$\backslash\# S$	$\# S$
$\min S$	$\min\tilde{S}$	$\min S$
$\max S$	$\max\tilde{S}$	$\max S$

A.2.10 Sequences

	\LaTeX	ZSL
$\text{seq } X$	$\backslash\text{seq } X$	$\text{seq } X$
$\text{seq}_1 X$	$\backslash\text{seq}_1 X$	$\text{seq}_1 X$
	oz only \blacktriangleright $\backslash\text{seqone } X$	
$\text{iseq } X$	$\backslash\text{iseq } X$	$\text{iseq } X$
$\langle s_1, \dots, s_n \rangle$	$\backslash\langle s_1, \dots, s_n$ $\backslash\rangle$	$\langle\langle s_1, \dots, s_n \rangle\rangle$
	oz only \blacktriangleright $\backslash\text{lseq } s_1, \dots, s_n \backslash\text{rseq}$	
$s \hat{\ } t$	$s \backslash\text{cat } t$	$s \text{ concat } t$ $s \hat{\ } t$
$\text{head } s$	$\text{head}\tilde{s}$	$\text{head } s$
$\text{last } s$	$\text{last}\tilde{s}$	$\text{last } s$
$\text{tail } s$	$\text{tail}\tilde{s}$	$\text{tail } s$
$\text{front } s$	$\text{front}\tilde{s}$	$\text{front } s$
$\text{rev } s$	$\text{rev}\tilde{s}$	$\text{rev } s$
$s \upharpoonright X$	$s \backslash\text{filter } X$	$s \text{ filter } X$
	oz only \blacktriangleright $s \backslash\text{sres } X$	$s \text{ } - X$
$X \upharpoonright s$	$X \backslash\text{extract } s$	$X \text{ extract } s$
	oz only \blacktriangleright $X \backslash\text{ires } s$	$X \text{ }- s$
$\hat{\ }/ss$	$\backslash\text{dcat } ss$	$\hat{\ }/ ss$
$\text{disjoint } ss$	$\backslash\text{disjoint } ss$	$\text{disjoint } ss$
$ss \text{ partition } S$	$ss \backslash\text{partition } S$	$ss \text{ partition } S$
$s_1 \text{ in } s_2$	$s_1 \backslash\text{subseq } s_2$	$s_1 \text{ subseq } s_2$
	oz only \blacktriangleright $s_1 \backslash\text{inseq } s_2$	
$s_1 \text{ prefix } s_2$	$s_1 \backslash\text{prefix } s_2$	$s_1 \text{ prefix } s_2$
$s_1 \text{ suffix } s_2$	$s_1 \backslash\text{suffix } s_2$	$s_1 \text{ suffix } s_2$
$\text{squash } s$	$\text{squash}\tilde{s}$	$\text{squash } s$

A.2.11 Bags

	\LaTeX	ZSL
$\text{bag } X$	$\backslash\text{bag } X$	$\text{bag } X$
$[[a_1, \dots, a_n]]$	$\backslash\text{lbag } a_1, \dots, a_n \backslash\text{rbag}$	$[[a_1, \dots, a_n]]$
$x \in B$	$x \backslash\text{inbag } B$	$x \text{ inbag } B$
$\text{count } B$	$\text{count } B$	$\text{count } B$
$B_1 \sqsubseteq B_2$	$B_1 \backslash\text{subbag } B_2$	$B_1 \text{ subbag } B_2$
$B_1 \cup B_2$	$B_1 \backslash\text{bagdiff } B_2$	$B_1 \text{ bagdiff } B_2$

$n \otimes B$	<code>n \bagscale B</code>	<code>B1 -- B2</code>
$B \# x$	<code>B \bagcount x</code>	<code>n bagscale B</code>
$B_1 \uplus B_2$	<code>B_1 \uplus B_2</code>	<code>B bagcount x</code>
	oz only ► <code>B_1 \buni B_2</code>	<code>B1 bagunion B2</code>
$items\ s$	<code>items s</code>	<code>B1 ++ B2</code>
		<code>items s</code>

A.2.12 Binding

	\LaTeX	ZSL
θS	<code>\theta S</code>	<code>theta S</code>

A.2.13 Selection

	\LaTeX	ZSL
$S.x$	<code>S.x</code>	<code>S.x</code>

A.2.14 Operators

	\LaTeX	ZSL
$PreSym_$	<code>PreSym _</code>	<code>PreSym _</code>
$_InSym_$	<code>_ InSym _</code>	<code>_ InSym _</code>
$_PostSym$	<code>_ PostSym</code>	<code>_ PostSym</code>
$-(-)$	<code>_ \limg _ \ring</code>	<code>- (-)</code>

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