# Secondo User Manual*

Version 4.1, September 20, 2007

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(*) This work was partially supported by a grant Gu 293/8-2 from the Deutsche Forschungsgemeinschaft (DFG), project “Datenbanken für bewegte Objekte” (Databases for Moving Objects).

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## 1 Introduction and Overview

The goal of SECONDO is to provide a "generic" database system frame that can be filled with implementations of various DBMS data models. For example, it should be possible to implement relational, object-oriented, temporal, or XML models and to accomodate data types for spatial data, moving objects, chemical formulas, etc. Whereas extensibility by data types is common now (e.g. as data blades, cartridges, etc.), the possibility to change the core data model is rather special to SECONDO.

The strategy to achieve this goal is the following:

- Separate the data model independent components and mechanisms in a database system (the *system frame*) from the data model dependent parts.
- Provide a formalism to describe the implemented data model, in order to be able to provide clean interfaces between system frame and "contents". This formalism is *second-order signature*, explained below.
- Structure the implementation of a data model into a collection of algebra modules, each providing specific data structures and operations.

SECONDO was intended originally as a platform for implementing and experimenting with new kinds of data models, especially to support spatial, spatio-temporal, and graph database models. We now feel, SECONDO has a clean architecture, and it strikes a reasonable balance between simplicity and sophistication. In addition, the central parts are well documented, with a technique developed specifically for this system (the so-called PD system). Since all the source code is accessible and to a large extent comprehensible for students, we believe it is also an excellent tool for teaching database architecture and implementation concepts.

SECONDO uses BerkeleyDB as a storage manager, runs on Windows, Linux[1], and Mac OS X platforms, and consists of three major components written in different languages:

- The SECONDO kernel implements specific data models, is extensible by algebra modules, and provides query processing over the implemented algebras. It is implemented on top of BerkeleyDB and written in C++.
- The optimizer provides as its core capability conjunctive query optimization, currently for a relational environment. Conjunctive query optimization is, however, needed for any kind of data models. In addition, it implements the essential part of SQL-like languages, in a notation adapted to PROLOG. The optimizer is written in PROLOG.
- The graphical user interface (GUI) is on the one hand an extensible interface for an extensible DBMS such as SECONDO. It is extensible by *viewers* for new data types or models. On the other hand, there is a specialized viewer available in the GUI for spatial types and moving objects, providing a generic and rather sophisticated spatial database interface, including animation of moving objects. The GUI is written in Java.

The three components can be used together or independently, in several ways. The SECONDO kernel can be used as a single user system or in a client-server mode. As a stand-alone system, it can be linked together with either a simple command interface running in a shell, or with the opti-

1. It should also run on other UNIX platforms.

mizer. In client-server mode, the kernel can serve clients running the command interface, an optimizer client, or the GUI. The optimizer can be used separately to transform SQL-like queries into query plans that would be executable in SECONDO. The GUI can be used separately to browse spatial or spatio-temporal data residing in files. All three components can be used together in a configuration shown in Figure 1.

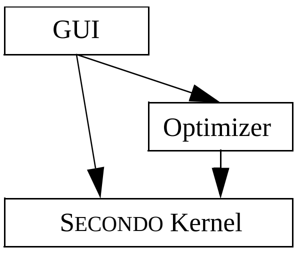


Figure 1: Cooperation of SECONDO Components

In this configuration, the GUI can ask the kernel directly to execute commands and queries (queries written as query plans, i.e., terms of the implemented algebras). Or it can call the optimizer to get a plan for a given SQL query. The optimizer when necessary calls the SECONDO kernel to get information about relation schemas, cardinalities of relations, and selectivity of predicates. Here the optimizer acts as a server for the GUI and as a client to the kernel.

A very rough description of the architecture of the SECONDO kernel is shown in Figure 2. A data model is implemented as a set of data types and operations. These are grouped into *algebras*.

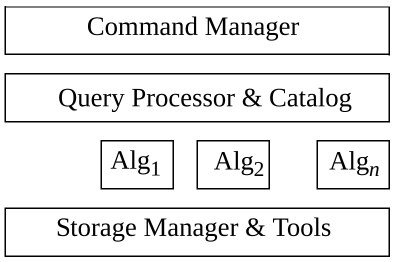


Figure 2: Rough architecture of the kernel

The definition of algebras is based on the concept of *second-order signature* [Gü93]. The idea is to use two coupled signatures. Any signature provides sorts and operations. Here in the first signature the sorts are called *kinds* and represent collections of types. The operations of this signature are *type constructors*. The signature defines how type constructors can be applied to given types. The available types in the system are exactly the terms of this signature.

The second signature defines operations over the types of the first signature.

An algebra module provides a collection of type constructors, implementing a data structure for each of them. A small set of support functions is needed to register a type constructor within an algebra. Similarly, the algebra module offers operators, implementing support functions for them such as type mapping, evaluation, resolution of overloading, etc.

The query processor evaluates queries by building an operator tree and then traversing it, calling operator implementations from the algebras. The framework allows algebra operations to have parameter functions and to handle streams. More details can be found in [DG00].

The SECONDO kernel manages *databases*. A database is a set of SECONDO objects. A SECONDO object is a triple of the form (*name*, *type*, *value*) where *type* is a type term of the implemented algebras and *value* a value of this type. Databases can be created, deleted, opened, closed, exported to and imported from files. In files they are represented as nested lists (like in LISP) in a text format.

Currently there exist about thirty algebras implemented within SECONDO. All algebras include appropriate operations. Some examples are:

- StandardAlgebra. Provides data types int, real, bool, string.
- RelationAlgebra. Relations with all operations needed to implement an SQL-like relational language.
- BTreeAlgebra. B-Trees.
- RTreeAlgebra. R-Trees.
- SpatialAlgebra. Spatial data types point, points, line, region.
- DateAlgebra. A small algebra providing a *date* type.
- MidiAlgebra. Providing a data type to represent the contents of Midi files including interesting operations like searching for a particular sequence of keys.

As a conclusion of this introduction, an example is shown in order to demonstrate how SECONDO can be used to formulate queries on spatial objects. This example involves some objects in the open database: (i) a relation `Kreis` with type (schema) `rel(tuple([KName: string, ..., Gebiet: region]))` containing the regions of 439 counties (“Kreise”) in Germany, (ii) an object `magdeburg` of type region, containing the geometry of county “Magdeburg”, and (iii) an object `kreis_Gebiet` of type `rtree(tuple([KName: string, ..., Gebiet: region]))` which is an R-tree on the `Gebiet` attribute of relation `Kreis`.

The following query finds neighbour counties of `magdeburg`:

```
query kreis_Gebiet Kreis
  windowintersects[bbox(magdeburg)]
  filter[.Gebiet adjacent magdeburg]
  project[KName] consume
```

The query uses the R-tree index to find tuples for which the bounding box (MBR) of the `Gebiet` attribute overlaps with the bounding box of the `magdeburg` region. The qualifying stream of tuples is filtered by the condition that the region of the tuple is adjacent to the region of `magdeburg`. Tuples are then projected on their `KName` attribute and the stream is collected into a result relation.

The following sections of this manual describe the use of SECONDO in detail.

# 2 Command Syntax

## 2.1 Overview

SECONDO offers a fixed set of commands for database management, catalog inquiries, access to types and objects, queries, and transaction control. Some of these commands require type expression, value expression, or identifier arguments (used for object names, database names, etc.). Whether a type expression or value expression is valid or not is determined by means of the specifications provided by the active algebra modules, while validity of an identifier depends on the content of the actual database (see Chapter 3 for details).

The SECONDO kernel accepts two different syntax levels for entering commands and queries: *nested list syntax* and *text syntax*. Nested list syntax is directly processed by the SECONDO kernel, and it is uniform over all operators. However, queries in nested list syntax tend to contain a lot of parentheses, thereby getting hard to formulate and read. This is the motivation for offering the second level of query syntax with two important features:

- Reading and writing type expressions is simplified.
- For each operator of an algebra module, the algebra implementor can specify syntax properties like infix or postfix notation. If this feature is used carefully, value expressions can be much more understandable.

## 2.2 Nested List Syntax

Using nested list syntax, each command is a single nested list. For short, the textual representation of a nested list consists of a left parenthesis, followed by an arbitrary number of elements, terminated by a right parenthesis. Elements are either nested lists again or atomic elements like numbers, symbols, etc. The list expression `(a b ((c)(d e)))` represents a nested list of 3 elements: `a` is the first element, `b` is the second one, and `((c)(d e))` is the third one. Thus the third element of the top-level list in turn is a nested list. Its two elements are again nested lists, the first one consisting of the single element `c`, the other one containing the two elements `d` and `e`.

Since a single user command must be given as a single nested list, a command like `list type constructors` has to be transformed to a nested list before it can be passed to the system: `(list type constructors)`. In addition to commands with fixed contents, there are also commands containing identifiers, type expressions, and value expressions. While identifiers are restricted to be atomic symbols, type expressions and value expressions may either be atomic symbols or nested lists again.

For instance, assuming there are type constructors `rel` and `tuple` and attribute data types `int` and `string`, the nested list term `(rel (tuple ((name string)(pop int))))` is a valid type expression, defining a relation type consisting of tuples whose attributes are called `name` of type `string` and `pop` of type `int`. Additionally SECONDO supports the definition of new types. Consider the new type `cityrel` defined as `(rel (tuple ((name string)(pop int))))`: now the symbol `cityrel` is a valid type expression, too. Writing `cityrel` has exactly the same effect as writing its complete definition.

Value expressions are *constants*, object *names*, or *terms* of the query algebra defined by the current collection of active algebra modules. Constants, in general, are two-element lists of the form `(<type> <value>)`. For standard data types (`int`, `real`, `bool`, `string`) just giving the value is sufficient:

```
17, 3.14159, TRUE, "Secondo"
```

Thus, `5`, `cities`, `(+ 4 5)`, `(count(head (feed cities) 4))`, or the constant relation

```
( (rel (tuple ((name string) (pop int)))
  (("New York" 7322000) ("Paris" 2175000) ("Hagen" 212000)))
```

are valid value expressions (provided an object with name `cities` and appropriate operators `feed`, `head` and `count` exist. Prefix notation is mandatory for specifying operator application in nested list syntax.

## 2.3 User Level Syntax

The user level syntax, also called *text syntax*, is more comfortable to use. It is implemented by a tool called the SECONDO *parser* which just transforms textual commands into the nested list format in which they are then passed to execution. This parser is not aware of the contents of a database; so any errors with respect to a database (e.g. objects referred to do not exist) are only discovered at the next level, when lists are processed. However, the parser knows the SECONDO commands described in Section 2.3; it implements a fixed set of notations for type expressions, and it also implements for each operator of an active algebra a specific syntax defined by the algebra implementor.

### 2.3.1 Commands

Commands can be written without parentheses, for example

```
list type constructors
query cities
```

which is translated to

```
(list type constructors)
(query cities)
```

### 2.3.2 Constants

Constants are written in text syntax in the form

```
[const <type expression> value <value expression>]
```

This is translated to the list

```
(<type expression> <value expression>)
```

which is the list form of constants explained above. Of course, simple constants for integers etc. can be written directly. For example,

```
[const int value 5] or 5
[const string value "secondo"] or "secondo"
[const bool value TRUE] or TRUE
[const rectangle value (12.0 16.0 2.5 50.0)]
```

might be notations for constants.

### 2.3.3 Type Expressions

Type constructors can be written in prefix notation, that is

```
<type constructor>(<arg_1>, ..., <arg_n>)
```

This is translated into the nested list format

```
(<type constructor> <arg_1> ... <arg_n>)
```

An example type expression is

```
rel(tuple([name: string, pop: int]))
```

This example uses notations for lists and pairs, which are translated by the parser as follows

```
[elem_1, ..., elem_n] -> (elem_1, ..., elem_n)
x: y -> (x y)
```

translated by the parser into

```
(elem_1 ... elem_n)
(x y)
```

So the expression `rel(tuple([name: string, pop: int]))` is transformed into the nested list form shown in Section 2.2. The relation constant can now be written as

```
[const rel(tuple([name: string, pop: int]))
value (("New York" 7322000) ("Paris" 2175000) ("Hagen" 212000))]
```

### 2.3.4 Value Expressions

Value expressions are terms consisting of operator applications to database objects or constants. For each operator a specific syntax can be defined. The parser is built at compile time taking these specifications into account. The syntax for an operator can be looked up in a running system by one of the commands

```
list operators
list algebra <algebra name>
```

These commands provide further information such as the meaning of the operator. For example, the entry appearing on `list operators` for the operator `year_of` is

```
     Name: year_of
Signature: instant -> int
   Syntax: year_of ( _ )
  Meaning: return the year of this instant
  Example: query year_of(T1)
```

This specifies prefix syntax for the operator `year_of`. Be aware that what appears in such a listing is a comment written by the algebra implementor which occasionally may be wrong. More details on the specification of an operator can be found in the SECONDO *Programmer's Guide*.

## Parameter Functions

The following operator demonstrates another general concept for query formulation: anonymous function definition. Its main purpose is to define predicate functions for operators like `filter`, taking a stream of tuples and a boolean function as parameters[1]. The function is applied to each tuple and `filter` lets the tuple pass if the function returns `true`.

```
filter [fun (tuple1: TUPLE) attr(tuple1, no) > 5]
```

In this example, `fun` is the keyword for the function, `tuple1` is the name which is assigned to the current tuple of the stream. By using this name, a tuple can be accessed. `attr` is an operator which extracts from the tuple passed as first argument the value of the attribute whose name is given in the second argument. Finally, the > operator is the binary infix operator which returns a boolean value that decides whether the tuple is passed through or not. For the given example, on a relation with an attribute `no` that contains numbers, the `filter` expression lets pass all tuples which have a `no` attribute with a value greater than 5.

However, this expression is a bit lengthy to write. For parameter functions, SECONDO allows one to use an abbreviated form. When using this form, a variable name and the correct type are generated automatically. This allows one to write the expression above as follows:

```
filter [attr(., no) > 5]
```

The parser translates this to the form shown above (and translates it then to the appropriate nested list form). Of course, when writing the expression one does not know which parameter name is generated by the parser (in particular, the parser assigns distinct numbers); hence there must be another way to refer to it, and that is the “.” symbol. The same mechanism is available for operators with parameter functions taking two arguments (e.g. for implementing `join` operators referring to the tuple types of the first and the second argument separately, i.e. two input streams); in that case the symbol “..” can be used to refer to the second argument. Instead of the symbol “.” one can also write `tuple` or `group` as this makes sense for many operators; it is translated by the parser in the same way as the “.” symbol.

Finally, attribute access is very frequently needed, therefore notations

```
.<attrname>
..<attrname>
```

are provided equivalent to the expressions

1. How a stream of tuples is created from a relation will be the subject of the subsequent chapter.

```
attr(., <attrname>)
attr(.., <attrname>)
```

So the use of the `attr` operator has been hard-coded into the parser. Finally, we can write the application of `filter` as

```
filter [.no > 5]
```

## 3 SECONDO Commands

There is a fixed set of commands implemented at the SECONDO application programming interface. These commands can be called from one of the user interfaces described in Section 5. An overview is given in Table 1.

| **Basic Commands** | **Inquiries** |
|---|---|
| `type` *<identifier>* `=` *<type expression>*<br>`delete type` *<identifier>*<br>`create` *<identifier>* `:` *<type expression>*<br>`update` *<identifier>* `:=` *<value expression>*<br>`let` *<identifier>* `=` *<value expression>*<br>`derive` *<identifier>* `=` *<value expression>*<br>`delete` *<identifier>*<br>`query` *<value expression>* | `list type constructors`<br>`list operators`<br>`list algebras`<br>`list algebra` *<identifier>*<br>`list databases`<br>`list types`<br>`list objects` |
| **Databases** | **Transactions** |
| `create database` *<identifier>*<br>`delete database` *<identifier>*<br>`open database` *<identifier>*<br>`close database` | `begin transaction`<br>`commit transaction`<br>`abort transaction` |
| **Import and Export** | |
| `save database to` *<file>*<br>`restore database` *<identifier>* `from` *<file>*<br>`save` *<identifier>* `to` *<file>*<br>`restore` *<identifier>* `from` *<file>* | |

Table 1: SECONDO Commands

An identifier is defined by the regular expression `[a-z,A-Z]([a-z,A-Z]|[0-9]|_)*` with a maximal length of 48 characters, e.g. `lineitem`, `employee`, `cities_pop` but not `_x_` or `10times`.

### 3.1 Inquiries

**Inquiry commands** are used to inspect the actual system and database configuration. They can be called even without a database.

- `list type constructors`
  Displays all names of type constructors together with their specification and an example in a formatted mode on the screen.
- `list operators`
  Nearly the same as the command above, but information about operations is presented instead.
- `list algebras`
  Displays a list containing all names of active algebra modules.
- `list algebra` *<identifier>*
  Displays type constructors and operators of the specified algebra.

- `list databases`
  Displays a list of names for all known databases.
- `list types`
  Displays a list of type names defined in the currently opened database.
- `list objects`
  Displays a list of objects present in the currently opened database.

## 3.2 Databases

**Database commands** are used to manage entire databases.

- `create database <`*`identifier`*`>`
  Creates a new database. A database name may have only up to 15 characters and no distinction between uppercase and lowercase letters is made.
- `delete database <`*`identifier`*`>`
  Destroys the database `<`*`identifier`*`>`.
- `open database <`*`identifier`*`>`
  Opens the database `<`*`identifier`*`>`.
- `close database`
  Closes the currently open database.

The state diagram in Figure 3 shows how database commands are related to the two states OPEN and CLOSED of a database.

## 3.3 Import and Export

An entire database can be exported into an ASCII file and loaded from such a file. Similarly, a single object within a database can be saved to a file or restored from a file.

A database file is a nested list with four elements of the following structure:

```
(DATABASE <identifier>
  (TYPES <a sequence of types>)
  (OBJECTS <a sequence of objects>))
```

Each of the mentioned sequences may be an empty list. Each type is a list of the form

```
(TYPE <identifier> (<type expression>))
```

and each object is a list of length five with the following structure

```
(OBJECT <identifier>
  (<type identifier>)
  (<type expression>)
  (<value expression>))
```

An object does not need to have a named type. In that case the third element is an empty list. A file storing a single object contains only one object list.

- `save database to <file>`
  Write the entire contents of the currently open database in nested list format into the file `<file>`. If the file exists, it will be overwritten, otherwise it will be created.

- `restore database <identifier> from <file>`
  Read the contents of the file `<file>` into the database `<identifier>`. Previous contents of the database are lost. If the database is not yet present, it will be created.

- `save <identifier> to <file>`
  Writes the object list for object `<identifier>` to file `<file>`. The content of an existing file will be deleted.

- `restore <identifier> from <file>`
  Creates a new object with name `<identifier>`, possibly replacing a previous definition. Type and value of the object are read from file `<file>`.

In the commands above a `<file>` can be an identifier or a nested list text atom which can hold character sequences of arbitrary length and is recognized by the nested list parser by enclosing it with the tags `<text>` and `</text--->` or in single quotes (’’). Moreover, it is possible to use environment variables. Examples:

```
save cities to cities_obj
save cities to '$(HOME)/cities.obj'
save cities to <text>/media/usb/memorystick/cities.obj<text--->
```

On a MS-Windows system you will need to use the backslash as directory separator, e.g.

```
save database to 'C:\msys\mydb.db'
```

## 3.4 Database States

Figure 3 shows how commands depend on and change the state of a database. The commands referred to all have the keyword `database` in their syntax. All commands accessing objects only work in an open database.

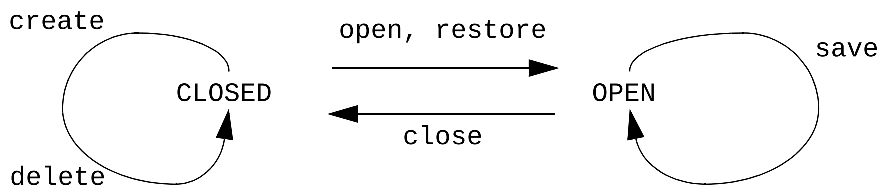


Figure 3: Database Commands and States

## 3.5 Basic Commands

These are the fundamental commands executed by SECONDO. They provide creation and manipulation of types and objects as well as querying, within an open database.

- `type <identifier> = <type expression>`
  Creates a new type named `<identifier>` for the given type expression.

- `delete type <identifier>`
  Deletes the user defined type named `<identifier>`.

- `create <identifier> : <type expression>`
  Creates an object called `<identifier>` of the type given by `<type expression>`. The value is still undefined.

- `update <identifier> := <value expression>`
  Assigns the result value of the right hand side to the object `<identifier>`.

- `let <identifier> = <value expression>`
  Assign the result value right hand side to a new object called `<identifier>`. The object is not allowed to exist yet; it is created by this command and its type is defined as the one of the value expression. The main advantage vs. using `create` and `update` is that the type is determined automatically.

- `derive <identifier> = <value expression>`
  This is a variant of the let command which can be useful to construct objects which use other objects as input and have no external list representation, e.g. indexes. When restoring a database those objects are reconstructed automatically.

- `delete <identifier>`
  Destroys the object whose name is `<identifier>`.

- `query <value expression>`
  Evaluates the given value expression  and returns the result object. If the user interface provides no special display functions for the object’s type it will be displayed as a nested list.

Some example commands:

```
type myrel = rel(tuple([Name: string, Age: int]))
create x : int
update x := 5
let place = “Hagen“
let rel2 = [const myrel value ((“Peter“ 17)(“Klaus“ 31))]
derive rel2_Age = rel2 createbtree[Age]
query (x * 7) + 5
query rel2 feed filter[.Age > 20] project[Name] consume
delete type myrel
delete rel2
```

## 3.6 Transactions

Each of the basic commands of SECONDO is encapsulated into its own transaction and committed automatically. If you want to put several commands into one single transaction the following commands have to be used.

- `begin transaction`
  Starts a new transaction; all commands until the next commit command are managed as one common unit of work.

- `commit transaction`
  Commits a running transaction; all changes to the database will be effective.

- `abort transaction`
  Aborts a running transaction; all changes to the database will be revoked.

## 3.7 Avoiding Name Conflicts

Currently, the optimizer uses the underscore symbol to encode additional information about objects into their names; for example, an object named `myrel_Attr` will be considered to be an index for attribute `Attr` in relation `myrel`. Therefore we recommend to use attribute names and relation names which are short enough and to avoid usage of the underscore.

Another problem can be name conflicts between database objects and identifiers which may be parameters for operators, e.g.:

```
let pop = FALSE;
query cities feed project[pop] consume
```

Now we have a conflict between the `bool` object called `pop` and the attribute `pop` of the relation `citites`. This will result in an type map error since `pop` will be replaced by `bool` during the query analysis, the error message will be

```
Type map error for operator project!
----------------------------------------------------------------------
Input: ((stream (tuple ((name string) (pop int)))) (bool))
----------------------------------------------------------------------
Error Message(s):
----------------------------------------------------------------------
RelationAlgebra: Operator project: Attributename 'bool' is not a known
    attributename in the tuple stream.
```

To avoid such name conflicts we recommend to follow the following convention:

- Attribute names start with an upper case letter.
- Object identifers including relation names start with a lower case letter.

Type constructors and operators in the system should start with a lower case letter anyway.

Moreover, as usual in programming languages, the usage of object or attribute identifiers which are keywords used in commands, or operator names, or the boolean constants `TRUE` or `FALSE`, will result in a parse error. For example the command

```
let myrel1 = [const rel(tuple([TRUE: bool])) value ((FALSE))]
```

returns

```
parse error, unexpected ZZBOOLEAN in line 1
```

# 4 Configuration Issues

## 4.1 Algebra Module Configuration

As described in Section 1, a running SECONDO system consists of the kernel extended by several algebra modules. These algebra modules can arbitrarily be included or excluded when compiling and linking the system by running the `make` utility.

The file `makefile.algebras` contains two entries for every algebra. The first defines the directory name and the second the name of the algebra module like in the example below:

```
...
ALGEBRA_DIRS += Polygon
ALGEBRAS     += PolygonAlgebra

ALGEBRA_DIRS += BTree
ALGEBRAS     += BTreeAlgebra
...
```

Currently, there is no mechanism which detects dependencies between algebra modules. Hence read the comments in the file. In case of trouble you have to switch on or off more algebras than the single one you wanted to change. Finally you need to recompile the system by calling the `make` command.

## 4.2 Startup Configuration

The SECONDO applications SECONDOTTY, SECONDOPL, SECONDOTTYCS, SECONDOMONITOR will read their configuration parameters from a file called `SecondoConfig.ini` which is searched for in the current directory. Optionally, if the environment variable `SECONDO_CONFIG` is defined, its value will be used as an absolute file name for the configuration file instead. On most installations this will be already defined as `$HOME/secondo/bin/SecondoConfig.ini`.

There are many possible options which are documented in the file itself, hence only some important options will be mentioned here. The parameter

```
SecondoHome=/home/databases1
```

defines the node in the directory tree where Secondo could store its databases. If this parameter is not defined or if it points to a non-existing directory the directory `$HOME/secondo-databases` is used. When you plan to restore big databases, you should switch off the usage of transactions, since otherwise mega- or giga-bytes of log files - Berkeley-DB does physical logging after each write operation on a page - are written to disk. This can be done by uncommenting the line

```
RTFlags += SMI:NoTransactions
```

If you have already produced gigabytes of log files and want to get rid of them, call the script

```
rmlogs
```

in the `secondo/bin` directory. This will delete all log files that are not needed for recovery any more.

# 5 User Interfaces

## 5.1 Overview

SECONDO comes with five different user interfaces, `SecondoTTYBDB`, `SecondoTTYCS`, `SecondoPL`, `SecondoPLCS` and `Javagui`. For testing, a further programm named `TestRunner` is available. The shell-based interfaces without optimizer support can be found in the `bin` directory. All programs related to the optimizer are in the `Optimizer` directory. `Javagui` is located in the `Javagui` directory.

`SecondoTTYBDB` is a simple single-user textual interface, implemented in C++. It is directly linked with the system frame. It is mainly used for debugging and testing the system without relying on client-server communication. `SecondoPL` is the single-user version of the optimizer. `SecondoTTYCS`, `SecondoPLCS` and `Javagui` are multi-user client-server interfaces. They exchange messages with the system frame running as a server process via TCP/IP. Provided that the database server process has been started, multiple user interface clients can access a SECONDO database concurrently.

## 5.2 Single-Threaded User Interfaces

### 5.2.1 SecondoTTYBDB

`SecondoTTYBDB` is a straightforward interface implementation. Both, input and output are textual. Since `SecondoTTYBDB` materializes in the shell window from which it has been started, existence and usage of features like scrolling, cut, copy and paste etc. depend on the shell and window manager environment. A command ends with a “`;`” or an empty line. Thus, multi-line commands are possible. `SecondoTTYBDB` provides some special commands described in the following table:

| **Command** | **Description** |
|---|---|
| `? or HELP` | Displays all user interface commands. |
| `@<filename>` | Starts batch processing of the specified file. The file must be in the `bin` directory. All lines are subsequently passed to the system, just as if they were typed in manually by the user. After the last command line was executed, `SecondoTTYBDB` returns to the interactive mode. |
| `DEBUG {0\|1\|2}` | Sets the debug mode. See online help for further information. |
| `q or quit` | Quits the session. A final `abort transaction` is executed automatically. After that, `SecondoTTYBDB` is terminated. |

Table 2: Commands of SecondoTTYBDB

For the algebra modules, `SecondoTTYBDB` is extended by support functions for pretty printed output of tuples and relations. Note that the implementation of these functions is optional. As a consequence, there might be algebra modules having types for which no pretty printing can be performed. In this case, objects having such a type are displayed in nested list format.

If the readline functionality is enabled (see Installation Guide), some additional features are available: The command history can be stepwise passed by pressing the `cursor-up` and `cursor-down` keys, respectively. The history remains available even after termination of SECONDO. By pressing the `tab` key, the input is extended to the next matching keyword. Keywords are all words from the SECONDO commands (`list`, `database,` etc.) and some frequently used operators (`feed`, `consume`). A double `tab` prints out all possible extensions of the current word.

### 5.2.2 SecondoPL

`SecondoPL` is the text-based interface of the SECONDO optimizer. To start this interface, navigate into the `Optimizer` directory of SECONDO and enter `SecondoPL`. At the first run of `SecondoPL` some error messages regarding non-existing files are shown. They can be ignored. On Linux machines you will have the advantages of the readline library if it is installed.

### 5.2.3 TestRunner

The `TestRunner` can be used for automatic testing of operators including checks for the correct (expected) results. For using the TestRunner, navigate into SECONDO's `bin` directory and enter

```
TestRunner -i <inputfile>
```

The format of the inputfile is described in the file `example.test` which is located in the `bin` directory as well.

## 5.3 Multi-User Operation

### 5.3.1 SecondoMonitor and SecondoListener

Before the client-server user interfaces can be used, the database server process (`SecondoListener)`waiting for client requests must be started. The host name and the port address can be changed in the file `SecondoConfig.ini`. Start the `SecondoListener` by typing `SecondoMonitor`. At the prompt, `startup` should be entered. By using the `-s` option with the `SecondoMonitor` command, the `SecondoListener` is started automatically without the additional `startup` command. After `SecondoListener` is started, it waits for requests from clients. `HELP` shows a list of additional commands.

### 5.3.2 OptimizerServer

If one intends to use the optimizer within `Javagui`, also an optimizer server has to be started. Because this server acts as a client for SECONDO, the `SecondoListener` has to be started before executing the optimizer server. To start the optimizer server, navigate into the `Optimizer` directory of SECONDO and enter `StartOptServer [Port]`. Without any argument, the default port

1235 is used. Ensure to use the same port in the optimizer settings of `Javagui`. The available commands of the optimizer server are:

| Command | Description |
|---|---|
| `help` | Prints out the available commands. |
| `quit` | Quits the server. |
| `clients` | Prints out the number of connected clients. |
| `trace-on`, `trace-off` | Enables (disables) tracing. If tracing is enabled, the query, the used database and the computed query plan are printed out. |

Table 3: Commands of the optimizer server

### 5.3.3 SecondoTTYCS

`SecondoTTYCS` is a client version of the single-threaded `SecondoTTYBDB` described in Section 5.2. The main difference is that all user queries are transmitted to the database server via TCP/IP, which is capable to serve multiple clients simultaneously, rather than calling system frame procedures directly. For the user of a `SecondoTTYCS` client, appearance and functionality are pretty much the same as those of `SecondoTTYBDB`. All commands work in the same way as with the single-threaded user interface.

To start `SecondoTTYCS`, change to the `bin` directory, and type `SecondoTTYCS`. Remember that `SecondoListener` (Section 5.3.1) must be running.

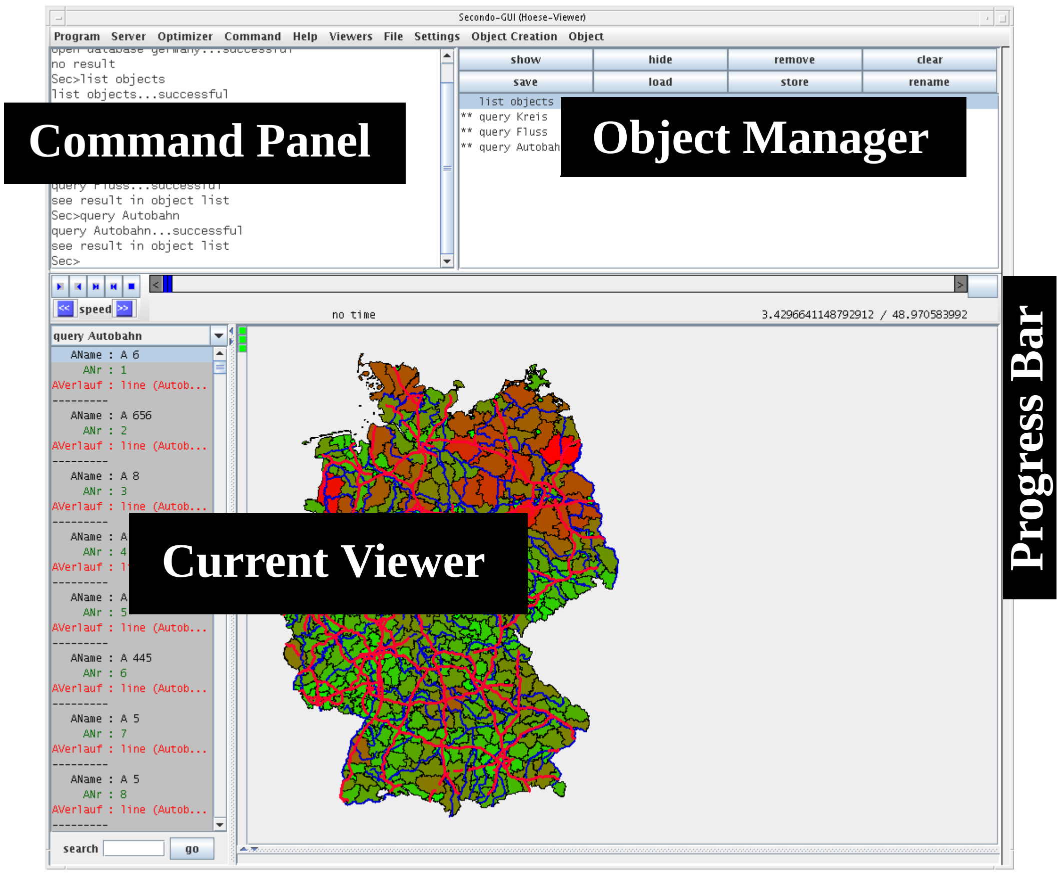
### 5.3.4 SecondoPLCS

The text-based client version of the optimizer of SECONDO is `SecondoPLCS`. It is started by entering `SecondoPLCS` in the `Optimizer` directory of SECONDO. The functionality is the same as in `SecondoPL`. Because the optimization is done within this client, the optimizer server is not required for using `SecondoPLCS`. However, the `SecondoListener` (Section 5.3.1) must be running.

### 5.3.5 Javagui

`Javagui` is a window-oriented user interface implemented in Java. Among its main features are:

- Javagui can be executed in any system in which a Java virtual machine (Ver. 1.4.2 or higher) is installed.
- It provides a large set of viewers to display a lot of different types (e.g. spatial data types).
- Data of different formats can be imported.
- Query results can be saved into a file.
- New viewers can be added.
- Javagui supports the SECONDO optimizer.



```
no result
Sec>list objects
list objects...successful
```

```
see result in object list
Sec>query Autobahn
query Autobahn...successful
see result in object list
Sec>
```

```
  list objects
** query Kreis
** query Fluss
** query Autobah
```

```
   AName : A 6
     ANr : 1
AVerlauf : line (Autob...
---------
   AName : A 656
     ANr : 2
AVerlauf : line (Autob...
---------
   AName : A 8
     ANr : 3
AVerlauf : line (Autob...
---------
   AName : A
     ANr : 4
AVerlauf : l
---------
   AName : A
     ANr : 5
AVerlauf : line (Autob...
---------
   AName : A 445
     ANr : 6
AVerlauf : line (Autob...
---------
   AName : A 5
     ANr : 7
AVerlauf : line (Autob...
---------
   AName : A 5
     ANr : 8
AVerlauf : line (Autob...
---------
```

Figure 4: The four Parts of Javagui

### The Configuration File

In the configuration file, variables used by `Javagui` can be changed to non-default values. In a standard SECONDO installation it is not necessary to change this file.

### Starting the Javagui

The easiest way to start `Javagui` is to call the `sgui` script. Remember to start the `SecondoListener` process before executing the script (see Section 5.3.1). For optimizer functionality, ensure that the OptimizerServer is also running (see Section 5.3.2).

After some licence information, a window will appear on the screen. This window has four main parts: the current viewer, the object manager, the command panel, and a progress bar (see Figure 4).

## The Menubar

The `Javagui` menubar consists of two parts: one depending on the current viewer and another one which is independent from it. The following description includes only viewer-independent parts.

| Menu | Submenu / Menuitem | Description |
|---|---|---|
| `Program` | `New` | Clears the history and removes all objects from `Javagui`. The state of SECONDO (opened databases etc.) is not changed. |
| | `Fontsize` | Here, the fontsize of the command panel and object manager can be changed. |
| | `Execute File` | Opens a file input dialog to choose a file. Then the batch mode is started to process the content of the selected file. It can be chosen how errors are handled. Note, there exist two different script styles which are described and can be selected in the configuration file. |
| | `History` | In this menu the current history can be manipulated. |
| | `Snapshot` | Stores a Picture of the `Javagui` window into a file as `png` image. The key combination `<alt C>` can also be used to make a snapshot. |
| | `Screen snapshot` | Works similar to the `Snapshot` menu entry but creates a snapshot of the whole screen instead of only the `Javagui` window. |
| | `Exit` | Closes the connection to SECONDO and quits `Javagui`. |
| `Server` | `Connect` | Connects `Javagui` to SECONDO. |
| | `Disconnect` | Disconnects the user interface from SECONDO. |
| | `Settings` | Shows a dialog to change the address and port used for communication with SECONDO. For a permanent change of these values, the configuration file should be used. |
| | `User settings` | If authorization is enabled (off by default), the username and the password can be entered here. |
| `Optimizer` | `Enable` | Connects `Javagui` to an OptimizerServer. |
| | `Disable` | Closes the connection to an OptimizerServer. |
| | `Command` | In this menu, the update functions of the optimizer for relations and indexes can be called. |

Table 4: Menubar of Javagui

| Menu | Submenu / Menuitem | Description |
|---|---|---|
| | `Settings` | Opens a dialog to change the settings of hostname and portnumber of the OptimizerServer. |
| `Command` | | This menu contains all available SECONDO commands. Menu entries beginning with a ~ require additional information. If such an entry is selected, a template of the command is printed out to the command panel. Other commands are processed directly without further user input. |
| `Help` | `Show gui commands` | Opens a new window containing all Gui commands (see Table 5). |
| | `Show secondo commands` | Shows a list of all known SECONDO commands. |
| `Viewers` | `<name list>` | All known (loaded) viewers are listed here. By choosing a new viewer the current viewer is replaced by the selected one. |
| | `Set priorities` | Opens a dialog to define priorities for the loaded viewers (see Figure 5). |
| | `Add Viewer` | Opens a file input dialog for adding a new viewer at runtime. |
| | `Show only viewer` | Hides the command panel and the object manager to have more space to display objects. The menu entry is replaced by `show all`, which displays all hidden components. |

Table 4: Menubar of Javagui

## Setting Viewer Priorities

There are different viewers which can display the same data type(s). To select one of these viewers, priorities are used. In the priority dialog you can define priorities of the loaded viewers depending on your personal preferences. The viewer at the top has the highest priority. To change the position of a viewer, select it and use the `up` or `down` button. `Javagui` ask the viewers about their display capabilities for a specific object and uses this information if `depending from`

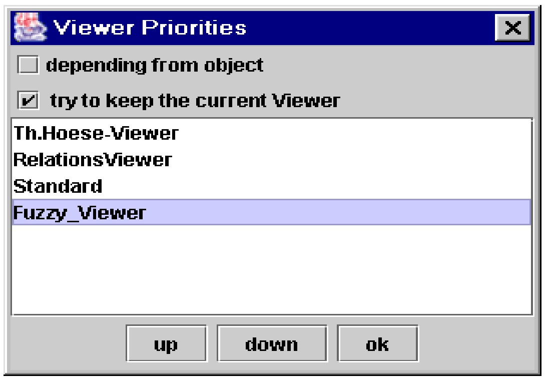


Figure 5: The Priority Dialog

`object` is selected. The Viewer with the highest value is used to display an object. If you have selected the box `try to keep the current viewer`, the current viewer is only replaced by another one if it cannot display the object.

### The Command Panel

Using the command panel, the user can communicate with the `SecondoServer` and the `OptimizerServer`. After the prompt `Sec>`, commands terminated by `return` can be entered. The command is stored in the history. A history entry can be selected by `cursor-up` and `cursor-down` keys. All SECONDO commands are available. Additionally, some Gui commands exist to control the behaviour of `Javagui`:

| Command | Description |
|---|---|
| `gui exit` | Closes the connection to SECONDO and quits `Javagui`. |
| `gui clearAll` | Removes all objects from `Javagui` and clears the history. |
| `gui addViewer <viewer name>` | Adds a new viewer at runtime. If the viewer was already loaded, then the current viewer is replaced by this viewer. |
| `gui selectViewer <viewer name>` | Replaces the current viewer by the viewer with the given name. |
| `gui clearHistory` | Removes all entries from the history. |

Table 5: Gui Commands

| Command | Description |
|---|---|
| `gui loadHistory [-r]` | Shows a file input dialog and reads the history from this file.<br><br>Used with the `-r` option this command replaces the current history with the file content. Without the `-r` option this command appends the file content to the current history. |
| `gui saveHistory` | Opens a file dialog to save the content of the current history. |
| `gui showObject <ObjectName>` | Shows an object from the object manager in a viewer. The viewer is determined by the priority settings. |
| `gui showAll` | Shows all objects listed in the object manager in the current viewer, whose types are supported by this viewer. |
| `gui hideObject <ObjectName>` | Removes the object with the specified name from the current viewer. |
| `gui hideAll` | Removes all objects from the current viewer. |
| `gui removeObject <ObjectName>` | Removes the object with the given name from the object manager and from all viewers. |
| `gui clearObjectList` | Removes all objects from the object manager. |
| `gui saveObject <ObjectName>` | Opens a file dialog to save the object with the given object name. |
| `gui loadObject` | Opens a file dialog to load an object. |
| `gui setObjectDirectory <directory>` | Sets the object directory.<br><br>This directory is initially shown when a `load` or `save` command is executed. |
| `gui loadObjectFrom <Filename>` | Loads the object with the specified filename.<br><br>The file must be located in the `objectdirectory`. |
| `gui storeObject <ObjectName>` | Stores an object into the currently open database.<br><br>The object name must not contain spaces. |
| `gui connect` | Connects `Javagui` to SECONDO. |
| `gui disconnect` | Disconnects `Javagui` from SECONDO. |
| `gui serverSettings` | Opens the server setting dialog to change the default settings for host name and port. |

Table 5: Gui Commands

| Command | Description |
|---|---|
| `gui renameObject <old name> -> <new name>` | Renames an object. |
| `gui onlyViewer` | Hides the command panel and the object manager. To show the hidden components use the `Viewers` entry in the menubar. |
| `gui executeFile [-i] <filename>` | Batch processing of the file.<br><br>If `-i` is set then file processing is continued even if an error occured. |
| `gui status` | Prints out information about the connection to SECONDO as well as the name of currently open database. |
| `gui set` | Can be used for changing the values of some `Javagui` settings. The complete list of the variables can be obtained by the `help` menu entry. The effect of the variables is described in the configuration file of `Javagui`. |

Table 5: Gui Commands

Each non-empty query result requested in the command panel is sent to the object manager and shown in a viewer according to the priority settings. If no viewer is found, which is capable to display the requested object, a message is shown to inform the user about this. If the `StandardViewer` is loaded, this case will never occur.

If the optimizer is enabled, queries in SQL syntax are possible. All queries beginning with `select` or `sql` are send to the OptimizerServer to get a query plan. Embedded SQL queries can be used for a postprocessing of the result of such a query. An example is

```
query (select sname from staedte where bev>500000) feed head[3] consume
```

Each `select`-clause in brackets is optimized separately. Note that the result of an optimized query is always a relation (exceptions are `count` queries). For this reason, the `feed` operator is required in the example. In contrast to an embedded `select`-clause, a single `select`-clause adds the leading `query` automatically.

The keyword `optimizer` enables communication with the OptimizerServer at a lower level. The text after this keyword is transfered to the OptimizerServer, converted into a Prolog predicate and evaluated afterwards. For example, you can type

```
optimizer current_prolog_flag(version, Version)
```

to get the currently used Prolog version.

## The Object Manager

This window manages all objects resulting from queries or file input operations. The manager provides a set of buttons described below:

| Button | Description |
|---|---|
| `show` | Shows the selected object in the viewer depending on priority settings. |
| `hide` | Removes the selected object from the current viewer. |
| `remove` | Removes the selected object from all viewers and from the object manager. |
| `clear` | Removes all objects from all viewers and also from the object manager. |
| `save` | Opens a file dialog to save the selected object to a file.<br><br>If the selected object is a valid SECONDO object [consisting of a nested list (type value)] and the chosen file name ends with `obj` then the object is saved as a SECONDO object. |
| `load` | Opens a file dialog to load an object.<br><br>Supported file formats are nested list files, shape files or dbase3 files.<br><br>In the current version, restrictions for shape and dbf files exist. |
| `store` | Stores the selected object into the currently open database. |
| `rename` | Replaces the object manager with a dialog to rename the selected object. |

## Using Javagui for Test Purposes

`Javagui` can be used to make tests including client server communication and the optimizer. The different test modes provided by `Javagui` are presented in this section. Remember to start the `SecondoListener` and the optimizer server if needed.

### *The Simple Test Mode*

The simple test mode is used if `Javagui` is started with the option(s) `--testmode [<filename>]`. Here, all user interaction is switched off. If the optional `filename` is given, it will be executed, as if a script is executed via the `file` menu.

### *The Extended Test Mode*

The extended test mode is started using the `--testmode2 <filename>` arguments. The test file has to contain a nested list with the commands to execute as well as the expected results. The format is described in detail in the `GuiTestmodes.pdf` file which is part of a standard SECONDO distribution. After executing this file, Javagui will halt for 5 seconds and then exit.

*The Testrunner mode*

This test mode is enabled by adding the `--testrunner <filename>` arguments to the `sgui` script. The file has to be in the same format as the `TTY`-based `TestRunner` files. The only difference is that in `Javagui` testfiles also queries in `SQL`-like (Optimizer-) syntax are allowed.

## The Viewers

In this section, some of the available viewers are presented.

*The Standard Viewer*

The `StandardViewer` simply shows a SECONDO object as a string representing the nested list of this object. In the text area only one object is displayed at the same time. To show another object in this viewer it must be selected in the combobox at the top of this viewer. You can remove the current (or all) object(s) in the extension of the menubar. Make sure to load the `StandardViewer` by default to be able to display any SECONDO object.

*The Relation Viewer*

This viewer displays SECONDO relations as a table. The relation that shall be displayed can be selected in the combobox at the top of this viewer. The viewer is not suitable for displaying relations with many attributes or relations containing large objects.

*The Formatted Viewer and the Inquiry Viewer*

The `Formatted Viewer` shows the results of inquiries sent to SECONDO in a similar way as the `SecondoTTY` does. The `Inquiry Viewer` shows objects of the same types as a colorized table. In the default configuration file, this viewer is not included. It has to be loaded first by using by the `gui addViewer` command.

*The Hoese Viewer*

This viewer is very powerful and is able to display a lot of different SECONDO object types.

The viewer consists of several different parts to display textual, graphical and temporal data. If an object in the textual part is selected, then the corresponding graphical representation is also selected (if it exists) and vice versa.

The Textual Representation of an Object

Using the combobox at the top of the text panel you can choose another object (query result) to display. A string in the text representation of the selected object can be searched by entering the search string in the field at the bottom of the text panel and clicking on the `go` button. If the end of text is reached, the search continues at the beginning of the text.

The Graphical Representation of Objects

The graphic panel contains geometric/spatial objects. Press the right mouse button and drag the mouse holding the right mouse button for zoom in. Stepwise zoom in (zoom out) is available in the `Settings` menu or by pressing `Alt +` (`Alt -`). To get an overview of all objects click on `Zoom out` in the `Settings` menu or press `Alt z`.

Each query result is displayed in a single layer. Using layers, the order in which the objects are displayed can be changed. To hide/show a layer use the green/gray buttons on the left of the graphic panel. The order of the layers can be set in the layer management located in the `Settings` menu. A selected object can be moved to another layer using the `Object` menu. Here, the user also can change the display settings for a single selected object.

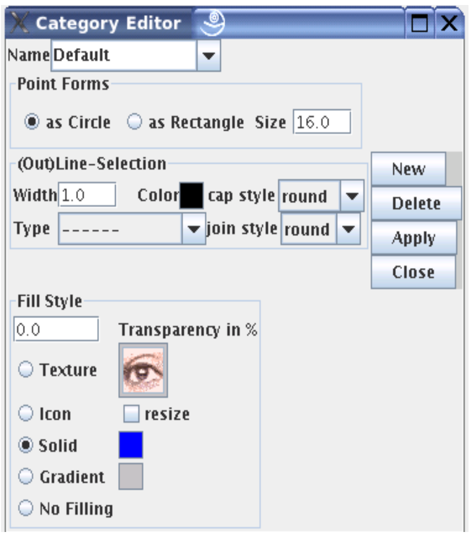
The menu `Settings->Projections` offers the possibility to enable one of a set of projections. This is helpful, if data containing geographical coordinates (longitude, latitude) should be displayed. The usual view of such data is obtained using the Mercator or the Gauss-Krueger projection.

Sessions

A session is a snapshot of the viewer's state. It contains all objects and the display settings. You can save, load or start an empty session in the `File` menu.

Categories

A category contains information how an object is to be displayed. Such information is color or texture of the interior, color and thickness of the borderline, or size and shape of a point. Catego-



Name: Default

Point Forms: [✓ as Circle] as Rectangle; Size: 16.0

(Out)Line-Selection: Width: 1.0; Color: ■; cap style: round; Type: ------; join style: round

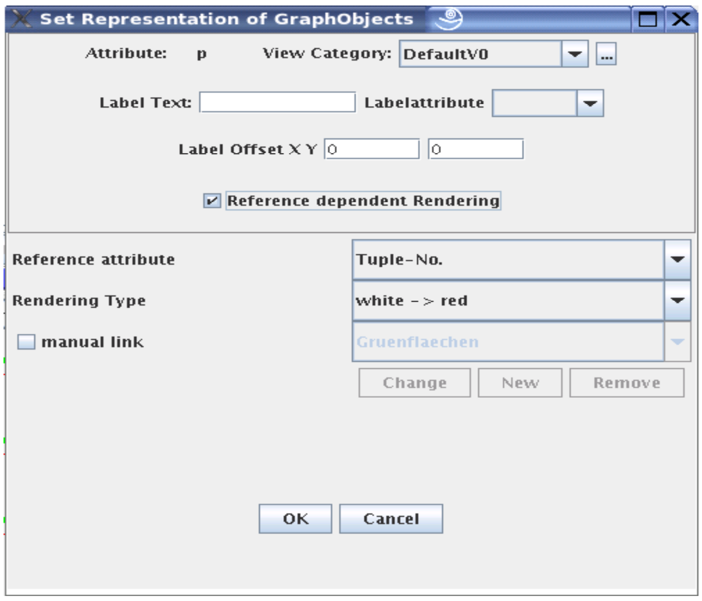
Fill Style: 0.0 Transparency in %; Texture; Icon; resize ☐; [✓ Solid] 🟦; Gradient; No Filling

Figure 6: Category Editor

ries can be loaded and saved via the `File` menu. To edit an exististing category, the category editor available via the `Settings` menu has to be invoked. There are several possibilities to assign a category to an object or to attributes of a relation. The method can be chosen in the `Settings` menu. If the manual selection is choosen, for each object (or for each graphical attribute of a relation), a selection window pops up. Auto selection creates for each graphical object a new random category. If the selection by name is used, two cases are distinguished. First, if the name of the object (attribute) is equal to the name of a category, this category is chosen automatically. Otherwise, the user is asked for a category.

Query Representation

In this window the user can make settings for displaying a query result with graphical content. This can be a single graphical object or a relation with one or more graphical attributes. At the top


Set Representation of GraphObjects

Attribute: p View Category: DefaultV0

Label Text: Labelattribute

Label Offset X Y 0 0

☑ Reference dependent Rendering

Reference attribute Tupel-No.

Rendering Type white -> red

☐ manual link Gruenflaechen

Figure 7: Query Representation

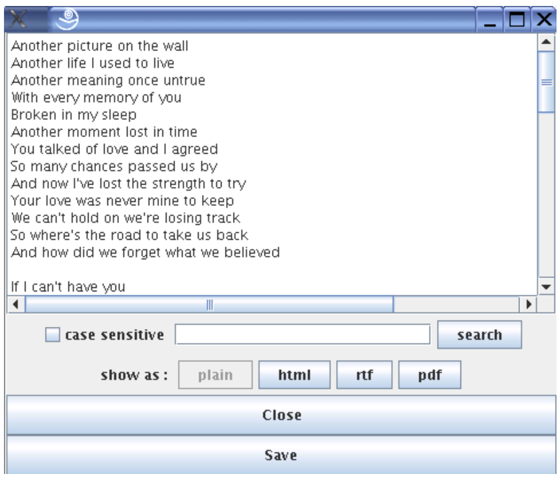
the user can choose an existing category for all graphical objects of this query with the same (attribute) name. The button labeled with “`...`” invokes the category editor to create or change categories. A graphical object may have a label. The label content can be entered as `Label Text`. If the object is part of a relation, the value of another attribute can be used as label. This feature is available in the `Labelattribute` combobox. In this case, the user can also make graphical settings for objects contained in the relation. If `Single Tuple` is selected, for each single tuple in the relation an own category can be chosen. Another possibility is to choose the category depending on an attribute in the relation. Thus, the points ize, the line width or the color can be chosen to be dependent on the value of another attribute. The possible values for these features are distributed in a linear way over the values of the selected attribute. For a non-linear distribution or for attribute values which do not support this function, a manual link between value and used category can be created.

Animating Temporal Objects

If a spatial-temporal object is loaded, you can start the animation by clicking on the `play` button left of the time line. The speed can be chosen in the `Settings` menu. The speed can also be halved (doubled) by clicking on the `[<<]speed[>>]` buttons. The other buttons are `play`, `play backwards`, `go start`, `go end` and `stop`. You can also use the time scrollbar to select a desired point in time.

Displaying Special Objects

Some objects can be displayed in a separate window. These objects are marked by a special color in the textual representation. By double clicking on the object, an additional window is opened and the selected object is displayed. Figure 8 shows such a window for the `text` type.



Another picture on the wall
Another life I used to live
Another meaning once untrue
With every memory of you
Broken in my sleep
Another moment lost in time
You talked of love and I agreed
So many chances passed us by
And now I've lost the strength to try
Your love was never mine to keep
We can't hold on we're losing track
So where's the road to take us back
And how did we forget what we believed

If I can't have you

Figure 8: Special representation of the text type

Managing Backgrounds

The background of the graphic window can be changed by the user. The color can be chosen via the `Settings` menu. This color is used if no background image is given and for all areas not covered by the background image. A background image can be used to show the context of other objects. For positioning the image, the bounding box of this image must be defined together with the image. For simplifying the positioning, so-called `tfw` files can be used. Such files are also used in geographic information systems. Another possibility to set the background is to capture the current display as background. This may be useful if many non-moving objects are displayed and additional moving objects are animated. After capturing the static objects as background, these objects can removed from the display to reduce the computation effort during the animation.

Creating Objects

The HoeseViewer offers the possibility to create simple graphical objects. An object type can be chosen in the `Object Creation` menu. After pressing the empty labeled button (right of the time line) the object creation starts. For creating a rectangle, the rectangle can be drawn by holding the left mouse button pressed and dragging the mouse. A point is created just by clicking on its location. For the creation of other objects, a sequence of points has to be created by left mouse button clicks. To finish the creation of such more complex objects, the object creation button has to be pressed again. If an object is defined, it is stored into the currently open database and inserted into the object manager.

# 6 Algebra Modules

## 6.1 Overview

Included in the full SECONDO release is a large set of different algebra modules. Three of these algebras are somehow fundamental and therefore are described here in detail. They are:

- the standard algebra (StandardAlgebra in the algebra list)
- the relation algebra (RelationAlgebra in the algebra list)
- an extension to the relation algebra (ExtRelationAlgebra in the algebra list)

All three algebras are located in the *Algebras*-directory of the SECONDO installation. Algebra modules can be activated and deactivated by changing the configuration of SECONDO (`makefile.algebras`, see Section 4.1). However, the denoted three algebras are activated by default.

## 6.2 Standard Algebra

### 6.2.1 Standard Type Constructors

The standard algebra module provides four constant type constructors (thus four types) for standard data types:

- *int* (for integer values): The domain is that of the *int* type implemented by the C++ compiler, typically -2147483648 to 2147483647.
- *real* (for floating point values): The domain is that of the *float* type implemented by the C++ compiler.
- *bool*: The value is either TRUE or FALSE.
- *string*: A value consisting of a sequence of up to 48 characters.

Each data type contains an additional flag determining whether the respective value is *defined* or not. Thus, for instance, integer division by zero does not cause a runtime error, but the result is an undefined integer value.

### 6.2.2 Standard Operators

Table 6 shows the most important operators provided by the standard algebra module. Most of the operations (like +, -, *, /) are overloaded and work for both types, *int* and *real*. For more information about specific operations type `list algebra StandardAlgebra` in your SECONDO interface.

In Table 6 we use the following notations. For signatures, an expression like `int || real` means that either of the types *int* or *real* can be used as an argument. In the *syntax* column, “_” denotes an argument, and “#” the operator; parentheses have to be put as shown.

| Operator | Signature | Syntax | Semantics |
|---|---|---|---|
| `+, -, *` | `int x int -> int`<br>`int x real -> real`<br>`real x int -> real`<br>`real x real -> real` | `_ # _` | addition, subtraction, multiplication |
| `/` | `(int \|\| real) x (int \|\| real) -> real` | `_ # _` | division |
| `div, mod` | `int x int -> int` | `_ # _` | integer division and modulo operation |
| `<, <=,`<br>`>, >=,`<br>`=, #` | `(int \|\| real) x (int \|\| real) -> bool`<br>`string x string -> bool` | `_ # _` | comparison operators |
| `starts` | `string x string -> bool` | `_ # _` | TRUE if $arg_1$ begins with $arg_2$ |
| `contains` | `string x string -> bool` | `_ # _` | TRUE if $arg_1$ contains $arg_2$ |
| `not` | `bool -> bool` | `# ( _ )` | logical not |
| `and, or` | `bool x bool -> bool` | `_ # _` | logical and |

Table 6: Standard Operators

### 6.2.3 Query Examples (Standard Algebra)

Notice that queries can only be processed after a database was opened by the user. In the query command

```
query <value expression>
```

`value expression` is a term over the active algebra(s). Some examples for queries using the standard algebra are given in Table 7. Note that no operator takes priority over another operator. Therefore a multiplication is not computed before an addition as the examples 3 and 4 show. Parentheses must be used in this case.

| Text Syntax | Nested List Syntax |
|---|---|
| `query 5;` | `(query 5);` |
| `query 5.0 + 7;` | `(query (+ 5.0 7));` |
| `query 3 * 4 + 9;` | `(query (* 3 (+ 4 9)));` |
| `query (3 * 4) + 9;` | `(query (+ (* 3 4) 9));` |
| `query 6 < 8;` | `(query (< 6 8));` |
| `query (“Secondo” contains “cond”)`<br>`and TRUE;` | `(query`<br>`  (and`<br>`    (contains “Secondo” “cond”)`<br>`    TRUE));` |

Table 7: Query Examples (Standard Algebra)

## 6.3 Relation Algebra

### 6.3.1 Relation Algebra Type Constructors

The relational algebra module provides two type constructors `rel` and `tuple`. The structural part of the relational model can be described by the following signature:

**kinds** IDENT, DATA, TUPLE, REL

**type constructors**

| | | |
|---|---|---|
| | $\rightarrow$ DATA | *int*, *real*, *string*, *bool* (from standard algebra) |
| $(\text{IDENT} \times \text{DATA})^+$ | $\rightarrow$ TUPLE | *tuple* |
| TUPLE | $\rightarrow$ REL | *rel* |

Therefore a tuple is a list of one or more pairs (identifier, attribute type). A relation is built from such a tuple type. For instance

```
rel(tuple([name: string, pop: int]))
```

is the type of a relation containing tuples consisting of two attribute values, namely `name` of type `string` and `pop` of type `int`. A valid value of this type in nested list representation is a list containing lists of attributes of values, e.g.

```
(
  (“New York” 732200)
  (“Paris” 2175000)
  (“Hagen” 212000)
)
```

### 6.3.2 Relation Operators

Table 8 shows a selection of the operators provided by the relational algebra module. Some of the operators are overloaded. For more information about the operators and a full list of operators type `list algebra RelationAlgebra` in the SECONDO user interface.

Here in the description of signatures, type constructors are denoted in lower case whereas words starting with a capital denote type variables. Note that type variables occurring several times in a signature must be instantiated with the same type.

| **Operator** | **Signature** | **Syntax** | **Semantics** |
|---|---|---|---|
| `feed` | `rel(Tuple) -> stream(Tuple)` | `_ #` | Produces a stream of tuples from a relation. |
| `consume` | `stream(Tuple) -> rel(Tuple)` | `_ #` | Produces a relation from a stream of tuples. |
| `filter` | `stream(Tuple) x (Tuple -> bool) -> stream(Tuple)` | `_ # [ _ ]` | Lets pass those input tuples for which the parameter function evaluates to TRUE. |

Table 8: Relation Operators

| | | | |
|---|---|---|---|
| attr | `tuple([a1:t1, ..., an:tn]) x ai -> ti` | `# (_ , _)` | retrieves an attribute value from a tuple |
| project | `stream(Tuple1) x attrname+ -> stream(Tuple2)` | `_ # [ _ ]` | relational projection operator (on streams); no duplicate removal |
| product | `stream(Tup1) x stream(Tup2) -> stream(Tup3)` | `_ _ #` | relational Cartesian product operator on streams |
| count | `stream(Tuple) -> int`<br>`rel(Tuple) -> int` | `_ #` | Counts the number of tuples in a stream or a relation. |
| rename | `stream(Tuple1) x id -> stream(Tuple2)` | `_ { _ }`<br><br>(special syntax, operator name not needed) | Changes only the type, not the value of a stream by appending the characters supplied in arg$_2$ to each attribute name. The first character of arg$_2$ must be a letter. Used to avoid name conflicts, e.g. in joins. |

Table 8: Relation Operators

Examples for the use of the operators listed in Table 8 are given in Section 6.4.2.

## 6.4 Extended Relation Algebra

### 6.4.1 Extended Relation Operators

Beyond the operators provided by the relational algebra module a set of more sophisticated operators for relations is contained in the Extended Relation Algebra. This module adds no new types, but operators for modification, extension, sorting and grouping of relations instead. The operator table is structured similarly to the table above.

| **Operator** | **Signature** | **Syntax** | **Semantics** |
|---|---|---|---|
| extract | `stream(tuple([a1:t1, ..., an:tn])) x ai -> ti` | `_ # [ _ ]` | Returns the value of a specified attribute of the first tuple in the input stream. |
| extend | `stream(tuple([a1:t1, ..., an:tn]) x [(b1 x (Tuple -> u1)) ... (bj x (Tuple -> uj))] -> stream(tuple([a1:t1, ..., an:tn, b1:u1, ..., bj:uj]))` | `_ # [ _ ]` | Extends each input tuple by new attributes. The second argument is a list of pairs; each pair consists of a name for a new attribute and an expression to compute the value of that attribute. Result tuples contain the original attributes and the new attributes. Refer to example 2 in Table 10. |

Table 9: Extended Relation Operators

| | | | |
|---|---|---|---|
| `loopjoin` | `stream(Tuple1) x (Tuple1 ->`<br>`stream(Tuple2)))`<br>`-> stream(Tuple3)` | _ # [ _ ] | Join operator performing a nested loop join. Each tuple of the outer stream is passed as an argument to the second argument function which computes an inner stream of tuples. The operator returns the concatenation of each tuple of the outer stream with each tuple produced in the inner stream. |
| `mergejoin` | `stream(Tuple1) x stream(Tuple2)`<br>`x attr1 x attr2`<br>`-> stream(Tuple3)` | _ _ #<br>[ _ , _ ] | Join operator performing merge join on two streams w.r.t. `attr1` of the first and `attr2` of the second stream. Each argument stream must be ordered (ascending) by the respective attribute. |
| `sortmerge-`<br>`join` | `stream(Tuple1) x stream(Tuple2)`<br>`x attr1 x attr2`<br>`-> stream(Tuple3)` | _ _ #<br>[ _ , _ ] | Join operator performing merge join on two streams w.r.t. `attr1` of the first and `attr2` of the second stream. |
| `hashjoin` | `stream(Tuple1) x stream(Tuple2)`<br>`x attr1 x attr2 x int`<br>`-> stream(Tuple3)` | _ _ # [ _<br>, _ , _ ] | Join operator performing hash join on two streams w.r.t. `attr1` of the first and `attr2` of the second stream. The number of buckets used is specified by the fifth argument. |
| `symmjoin` | `stream(tuple(a1 ... an)) x`<br>`  stream(tuple(b1 ... bm)) x`<br>`  (tuple(a1 ... an) x`<br>`   tuple(b1 ... bm) -> bool)`<br>`-> stream tuple(a1 ... an b1`<br>`... bm)` | _ _ #<br>[ _ ] | Join operator performing symmetric join on two streams by computing a Cartesian product stream from its argument streams and filtering by the third argument. |
| `concat` | `stream(Tuple) x stream(Tuple)`<br>`-> stream(Tuple)` | _ _ # | Concatenates two streams. Can be used to implement relational union (without duplicate removal). |
| `mergesec` | `stream(Tuple) x stream(Tuple)`<br>`-> stream(Tuple)` | _ _ # | Intersection. Both streams must be ordered (lexicographically by all attributes, achieved by applying a `sort` operator before). |
| `mergediff` | `stream(Tuple) x stream(Tuple)`<br>`-> stream(Tuple)` | _ _ # | Difference on two ordered streams. |

Table 9: Extended Relation Operators

| | | | |
|---|---|---|---|
| `aggregate` | `stream(tuple((a1 t1) ... (an tn))) x ai x (ti x ti -> ti) x ti`<br>`-> ti` | `_ # [ _ ; _ ; _ ]` | Given an input stream, aggregates all values of a selected attribute `ai` of all tuples of that stream using the given aggregation function and an initial value. See also `aggregateB` in the operator list in the system and the example in Table 10. |
| `groupby` | `stream(Tuple) x`<br>`  [a1 ... ai] x`<br>`  [(b1 x (rel(Tuple) -> u1))...`<br>`   (bj x (rel(Tuple) -> uj))]`<br>`-> stream(tuple([a1:t1, ..., ai:ti, b1:u1, ..., bj:uj]))` | `_ #`<br>`[ _ ; _ ]` | Groups a stream by the attributes given in the second argument. The third argument is a list of pairs; each pair consists of a name for a new attribute and an expression to compute the value of that attribute from a subrelation obtained by grouping. Result tuples contain the grouping attributes and the new attributes. See the example in Table 10. |
| `sortby` | `stream(Tuple) x`<br>`  (attr_i x dir_i)+`<br>`-> stream(Tuple)` | `_ # [ _ ]` | Operator for sorting a stream lexicographically by one or more attributes. For each attribute, the “direction” of sorting can be specified as either ascending (`asc`) or descending (`desc`). |
| `sort` | `stream(Tuple) -> stream(Tuple)` | `_ #` | Sorts the input tuple stream lexicographically by all attributes. |
| `rdup` | `stream(Tuple) -> stream(Tuple)` | `_ #` | Removes duplicates from a totally ordered input stream. |
| `min, max, sum` | `stream(Tuple) x intattrname`<br>`-> int`<br>`stream(Tup) x realattrname`<br>`-> real` | `_ # [ _ ]` | Returns the minimum, maximum, or sum value of the specified column. The second argument must be the name of an integer or real attribute. |
| `avg` | `stream(Tuple) x numattrname`<br>`-> real` | `_ # [ _ ]` | Returns the average value of the specified column. The second argument must be the name of an integer or real attribute. |
| `head` | `stream(Tuple) x int -> stream(Tuple)` | `_ # [ _ ]` | Returns the first n elements of the input stream. |

Table 9: Extended Relation Operators

### 6.4.2 Query Examples (Relation Algebra and Extended Relation Algebra)

To make it easier to understand how to use the operations of the relational algebra, a small database is available for this purpose. It is called `testqueries` and can be created and loaded as follows (from the `secondo/bin` directory):

```
create database testqueries;
restore database testqueries from testqueries;
```

Now the database is loaded. It provides (among others) the following simple relations:

```
tenTest:        rel(tuple([no: int]))
twentyTest:     rel(tuple([no: int]))
EmployeeTest:   rel(tuple([EName: string, EmpNr: int, DeptNr: int]))
DeptTest:       rel(tuple([Leader: string, DeptNr: int]))
StaedteTest:    rel(tuple([SName: string, Bev: int,
                  PLZ: int, Vorwahl: string, Kennzeichen: string]))
```

A first query example (in text syntax) is the following:

```
query tenTest feed filter [.no > 5] consume;
```

`query` is the keyword to start a query. Next, `tenTest` selects the relation used in the query. `feed` and `consume` are operators to produce a stream of tuples from a relation and produce a relation from a stream of tuples, respectively. The `filter` operation has a parameter function `[.no > 5]` and removes all tuples from the stream which evaluate to `FALSE`.

As we can see, the query in text syntax can be read from the beginning to the end: first, the relation is selected and a tuple stream is generated. For every single tuple the `filter` operation is evaluated. After that, the remaining tuples are collected and a new relation is built.

As a second example we take

```
query tenTest feed twentyTest feed {A} product project[no_A] sort
  rdup count;
```

Now we use two different relations (`tenTest` and `twentyTest`). Since the attribute names of both relations are the same (they both have the attribute `no`), we have to use the `rename` operation, which renames the attribute in the second relation by appending the attribute's name with the passed character string. After that the `product` of both relations is computed. An attribute name (the new name `no_A`) is passed to the `project` operator; after the projection to this attribute the tuples of the stream are sorted and duplicates are removed. Finally the number of tuples is counted by the `count` operation. The accurate result is 20.

Some more example queries are given in Table 10.

| **Text Syntax** | **Nested List Syntax** |
|---|---|
| `query StaedteTest feed avg[Bev];` | `(query (avg (feed StaedteTest) Bev));` |
| `query tenTest feed extend[mod2: .no mod 2] head[3] consume;` | `(query (consume (head (extend (feed tenTest) ( (mod2 (fun (tuple1 TUPLE) (mod (attr tuple1 no) 2))))) 3)));` |
| `query StaedteTest feed filter [.SName contains "burg"] project [SName,Kennzeichen] consume;` | `(query (consume (project (filter (feed StaedteTest) (fun (tuple1 TUPLE) (contains (attr tuple1 SName) "burg"))) (SName Kennzeichen))));` |
| `query EmployeeTest feed sortby[DeptNr asc] groupby[DeptNr; anz: group feed count] consume;` | `(query (consume (groupby (sortby (feed EmployeeTest) ( (DeptNr asc))) (DeptNr) ( (anz (fun (group1 GROUP) (count (feed group1))))))));` |
| `query StaedteTest feed max[SName];` | `(query (max (feed StaedteTest) SName));` |
| `query tenTest feed aggregate[no; fun(i1: int, i2: int) i1 * i2; 1]` | `(query (aggregate (feed tenTest) no (fun (i1 int) (i2 int) (* i1 i2)) 1))` |

Table 10: Query Examples (Relation Algebra)

## 7 Functions and Function Objects

A fundamental facility in SECONDO is the possibility to treat functions as values. We have already seen anonymous parameter functions to operators such as `select` or `filter`. The type of a function

```
fun (<arg_1>: <type_1>, ..., <arg_n>: <type_n>) <expr>
```

is

```
map(<type1>, ..., <type_n>, <resulttype>)
```

where `<resulttype>` is the type of `<expr>`. For example, the type of the function

```
fun (n: int) n + 1
```

is

```
map(int, int)
```

It is possible to create named SECONDO objects whose values are functions; technically the type constructor `map` is provided by the `FunctionAlgebra`. Hence we can say:

```
create double: map(int,int)
update double := fun (n: int) n + n
```

It is easier to create a function object through the `let` command:

```
let prod = fun (n: int, m: int) m * n
```

We can ask for the value of a function object:

```
query prod
```

As a result, the type and the value of the function are displayed in nested list syntax:

```
Function type:
(map int int int)
Function value:
(fun
    (n int)
    (m int)
    (* m n))
```

Function objects can be applied to arguments in the usual syntax and mixed with other operations:

```
query prod(5, double(7 * 6)) + 50
```

It is also possible to apply anonymous functions to arguments (this works only in nested list syntax):

```
(<anonymous function> <arg1> ... <arg_n>)
```

For example, we can write

```
(query ((fun (n int) (+ n 1)) 70))
```

and get as a result 71. It is allowed to define function objects with zero arguments; this can be used to define views. For example, given a relation `Staedte` similar to `StaedteTest` from Section 6.3 we can define a view to get cities with more than 500000 inhabitants:

```
let Grossstaedte = fun () Staedte feed filter[.Bev > 500000] consume
```

Then the command

```
query Grossstaedte
```

yields the definition of the function:

```
Function type:
(map
    (rel
        (tuple
            (
                (SName string)
                (Bev int)
                (PLZ int)
                (Vorwahl string)
                (Kennzeichen string)))))
Function value:
(fun
    (consume
        (filter
            (feed Staedte)
            (fun
                (tuple1 TUPLE)
                (>
                    (attr tuple1 Bev)
                    500000)))))
```

Observe that the `map` constructor has only one argument, the result type. The function is applied (evaluated) by writing

```
query Grossstaedte()
```

Such a view can be used in further processing, for example:

```
query Grossstaedte() feed project[SName] consume
```

and it can even be used in further views:

```
let Grosse = fun () Grossstaedte() feed project[SName] consume
```

As a final example, let us define a function that for a given string argument returns the number of cities starting with that string:

```
let Staedte_with = fun (s: string) Staedte feed filter[.SName starts s]
count
```

Then

```
query Staedte_with(“B”)
```

returns on our little example relation the value 7.

# 8 The Optimizer

The optimizer component of SECONDO is written in PROLOG and allows one to formulate SECONDO commands as well as queries in an SQL-like language within a PROLOG environment. Commands are passed directly to the SECONDO kernel for execution. Queries are translated to query plans which are then also sent to the kernel for exection. One can also experiment with the optimizer and just see how queries are translated without executing them.

In the following sections after some preparations we discuss the PROLOG environment, the query language, hybrid queries (combining SQL with SECONDO operations) and creation of objects from query results, the optimizer's knowledge about databases, and how the optimizer can be informed about new operators available in SECONDO.

## 8.1 Preparations

In the following examples, we work with the database `opt`. Hence, enter at any of the user interfaces (e.g. in `SecondoTTYBDB`) the commands:

```
create database opt
restore database opt from opt
```

Now the database is in good shape. When you type `list objects`, you can see that it has the following relations:[1]

```
Orte(Kennzeichen: string, Ort: string, Vorwahl: string, BevT: int)
Staedte(SName: string, Bev: int, PLZ: int Vorwahl: string,
  Kennzeichen: string)
plz(PLZ: int, Ort: string)
ten(no: int)
thousand(no:int)
```

Furthermore, there are the two indexes `plz_Ort` and `plz_PLZ` which index on the `plz` relation the attributes `Ort` and `PLZ`, respectively. All relations are small except for `plz` which is a bit larger, having 41267 tuples.

## 8.2 Using SECONDO in a PROLOG environment

In Section 5 it was already discussed how the optimizer can be called. In this section, we assume that the single user version `SecondoPL` is used; the client-server interface `SecondoPLCS` behaves similarly. Hence, switch to the directory `Optimizer` and call the optimizer by the command:

```
SecondoPL
```

After some messages, there appears a PROLOG prompt:

```
1 ?-
```

1. There is also a further relation SEC_DERIVED_OBJ used internally to restore indexes and other derived objects, and some more system tables starting SEC2... System tables can be queried like any relation, but they are not persistent and will get lost between two sessions.

When the optimizer is used for the first time after installing SECONDO, some error messages appear; these can safely be ignored. The reason is that some files generated by the running optimizer are not yet there.

We now have a PROLOG interpreter running which understands an additional predicate:

```
secondo(Command, Result) :- execute the Secondo command Command and get
the result in Result.
```

So at the command line, one can type:

```
1 ?- secondo('open database opt', Res).
```

This is executed, some SECONDO messages appear, and then the PROLOG interpreter shows the result of binding variable `Res`:

```
Res = []
```

This is the empty list that SECONDO returns on executing successfully such a command, converted to a PROLOG list. As usual with a PROLOG interpreter we can type `<return>` to accept the first solution, or `;<return>` to see more solutions (if any exist). After typing `<return>`, the interpreter responds

```
Yes
2 ?-
```

Let us try another command:

```
2 ?- secondo('query Staedte feed filter[.Bev > 500000] head[3]
|    consume', R), R = [First, _].
```

Here at the end of the first line we typed `<return>`, the interpreter then put “`|    `“ at the beginning of the next line. The PROLOG goal is complete only with the final “.” symbol, only then interpretation is started. Here as a result we get after some SECONDO messages the result of the query shown in variable `R` and the first element in variable `First`. This illustrates that, of course, we can process SECONDO results further in the PROLOG environment.

By the way, when you later want to quit the running `SecondoPL` program, just type at the prompt either

```
.. ?- halt.
```

or

```
.. ?- quit.
```

The first is the standard PROLOG termination, the second has been introduced to be consistent with other SECONDO interfaces. In the sequel, we omit the PROLOG prompt in the examples.

There is also a version of the `secondo` predicate that has only one argument:

```
secondo(Command) :- execute the Secondo command Command and pretty-print
the result, if any.
```

Hence we can say:

```
secondo(’query Staedte’).
```

The result is printed in a similar format as in `SecondoTTYBDB` or `SecondoTTYCS`.

In addition, a number of predicates are available that mimic some frequently used SECONDO commands, namely

```
open
create
update
let
delete
query
```

They all take a character string as a single argument, containing the rest of the command, and are defined in PROLOG to be prefix operators, hence we can write:

```
secondo('close database').
open 'database opt'.
create 'x: int'.
update 'x := Staedte feed count'.
let 'double = fun(n: int) 2 * n'.
query 'double(x)'.
delete 'x'.
```

In the remainder of this chapter, we assume that the “standard” version of the optimizer is active. To ensure this, type

```
setOption(standard).
```

after starting `SecondoPL`. This command will do some output and finally print an overview of all available options. A marked checkbox in front of option “standard” indicates, that it is active.

## 8.3 An SQL-like Query Language

The optimizer implements a part of an SQL-like language by a predicate `sql`, to be written in prefix notation, and provides some operator definitions and priorities, e.g. for `select`, `from`, `where`, that allow us to write an SQL query directly as a PROLOG term. For example, one can write (assuming database `opt` is open):

```
sql select * from staedte where bev > 500000.
```

Note that in this environment all relation names and attribute names are written in lower case letters only. Remember that words starting with a capital are variables in PROLOG; therefore we cannot use such words. The optimizer on its own gets information from the SECONDO kernel about the spellings of relation and attribute names and sends query plans to SECONDO with the correct spelling.

Some messages appear that tell you something about the inner workings of the optimizer. Possibly the optimizer sends by itself some small queries to SECONDO, then it says:

```
Destination node 1 reached at iteration 1
Height of search tree for boundary is 0

The best plan is:

Staedte feed filter[.Bev > 500000] consume

Estimated Cost: 120.64
```

After that appear evaluation messages and the result of the query. If you are interested in understanding how the optimizer works, please read the paper [GBA+04]. If you wish to understand the working of the optimizer in more detail, you can also read the source code documentation, that is, say in the directory `Optimizer`:

```
pdview optimizer.pl
```

Almost all prolog sourcefiles (having filename extension `.pl`) from the `Optimizer` directory can be processed in this way. In the following, we describe the currently implemented query language in detail. Whereas the syntax resembles SQL, no attempt is made to be consistent with any particular SQL standard.

## Basic Queries

The SQL kernel implemented by the optimizer basically has the following syntax:

```
select <attr-list>
from <rel-list>
where <pred-list>
```

Each of the lists has to be written in PROLOG syntax (i.e., in square brackets, entries separated by comma). If any of the lists has only a single element, the square brackets can be omitted. Instead of an attribute list one can also write “`*`”. Hence one can write (don’t forget to type `sql` before all such queries and end them with a “`.`”):

```
select [sname, bev]
from staedte
where [bev > 270000, sname starts “S”]
```

To avoid name conflicts, one can introduce explicit variables. In this case one refers to attributes in the form `<variable>:<attr>`. For example, one can perform a join between relations `Orte` and `plz`:

```
select * from [orte as o, plz as p]
where [o:ort = p:ort, o:ort contains "dorf", (p:plz mod 13) = 0]
```

In the sequel, we define the syntax precisely by giving a grammar. For the basic queries described so far we have the following grammar rules:

```
query           ->  select distinct-clause sel-clause
                    from rel-clause
                    where-clause

distinct-clause ->  all | distinct | ε

sel-clause      ->  *
                  | result | [result-list]
                  | count(distinct-clause *)

result          ->  attr | attr-expr as newname

result-list     ->  result | result, result-list

attr            ->  attrname | var:attrname

attr-list       ->  attr | attr, attr-list

attrname        ->  id
```

```
rel            ->  relname | relname as var
rel-clause     ->  rel | [rel-list]
rel-list       ->  rel | rel, rel-list
relname        ->  id
var            ->  id
where-clause   ->  where [pred-list] | where pred | ε
pred           ->  attr-boolexpr
pred-list      ->  pred | pred, pred-list
```

We use the following notational conventions. Words written in normal font are grammar symbols (non-terminals), words in bold face are terminal symbols. The symbols "`->`" and "`|`" are meta-symbols denoting derivation in the grammar and separation of alternatives. "ε" denotes the empty word. Other characters like "`*`" or "`:`" are also terminals. „**id**" is any valid SECONDO identifier (spelled in lower case letters).

The notation `X-`*`list`* refers to a non-empty PROLOG list with elements of type `X`; as mentioned already, the square brackets can be omitted if the list has just one element.

The notation `X-`*`expr`* refers to an expression built from elements of type `X`, constants, and operations available on `X`-values. Hence `attr-`*`expr`* is an expression involving attributes denoted in one of the two forms `attrname` or `var:attrname`. Similarly a predicate (`pred`) is a boolean expression over attributes (`attr-`*`boolexpr`*).

`X-`*`constant`* denotes a SECONDO constant of type `X`.

Finally, "ε" denotes the empty alternative. Hence the where-clause or the distinct keyword are optional.

From the grammar, one can see that it is also possible to compute derived attributes in the select-clause. For example:

```
select [sname, bev div 1000 as bevt] from staedte
```

## Order

One can add an orderby-clause (and a first-clause, see below), hence the syntax of a query is more completely:

```
query           ->  select distinct-clause sel-clause
                    from rel-clause
                    where-clause orderby-clause first-clause
orderby-clause  ->  orderby [orderattr-list] | orderby orderattr | ε
orderby-clause  ->  orderby [orderattr-list] | orderby orderattr | ε
orderattr       ->  attrname | attrname asc | attrname desc
orderattr-list  ->  orderattr | orderattr, orderattr-list
```

For example, we can say:

```
select [o:ort, p1:plz, p2:plz]
from [orte as o, plz as p1, plz as p2]
```

```
    where [o:ort = p1:ort, p2:plz = (p1:plz + 1), o:ort contains "dorf"]
    orderby [o:ort asc, p2:plz desc]
```

It is possible to mention derived attributes in the orderby-clause.

## Taking Only the First *n* Elements

Sometimes one is interested in only the first few tuples of a query result. This can be achieved by using a first-clause:

```
    first-clause    ->  first int-constant | ε
```

For example:

```
    select * from plz orderby ort desc first 3
```

This is also a convenient way to see the beginning of a large relation. Only the first few tuples are processed.

## Grouping and Aggregation

Aggregation queries have a groupby-clause in addition to what is known already and a different form of the select-clause.

```
    query            ->  select aggr-clause from rel-clause
                         where-clause
                         groupby-clause
                         orderby-clause first-clause

    aggr-clause      ->  aggr2 | [aggr2, aggr-list]

    aggr2            ->  count(distinct-clause *) as newname
                       | aggrop(ext-attr-expr) as newname
                       | arbitrary-aggr as newname

    aggr             ->  groupattr | groupattr as newname | aggr2

    aggr-list        ->  aggr | aggr, aggr-list

    aggrop           ->  min | max | sum | avg | extract | count

    aggr-fun         ->  (*) |  (+) |  union_new |  intersection_new |
                         % any name fun of a binary SECONDO-operator or
                           function object with syntax fun: T x T -> T
                           which should be associative and commutative. Infix-
                           operators must be inclosed in round paranthesis.

    arbitrary-aggr   ->  aggregate(ext-attr-expr, aggrfun, datatype,
                         datatype-constant)

    datatype           ->  int | real | bool | string | line | points
                         | mpoint | uregion |
                           % any name of a SECONDO-datatype

    groupattr        ->  attr

    groupattr-list   ->  groupattr | groupattr, groupattr-list

    groupby-clause   ->  groupby [groupattr-list] | groupby groupattr
```

For example, one can say:

```
select [ort, min(plz) as minplz, max(plz) as maxplz, count(*) as cntplz]
from plz
where plz > 40000
groupby ort
orderby cntplz desc
first 10
```

Entries in the select-clause are either attributes used in the grouping or definitions of derived attributes which are obtained by evaluating aggregate functions on the group. Again one can order by such derived values. An aggregate operator like `sum` cannot only be applied to an attribute name, but also to an expression built over attributes.

There is one restriction imposed by the current implementation and not visible in the grammar: the select-clause in an aggregate query must contain a derived attribute definition. Hence

```
select ort from plz groupby ort
```

will not work. This will be optimized but not executed by SECONDO.

### Union and Intersection

It is possible to form the union or intersection of a set of relations each of which is the result of a separate query. The queries are written in a PROLOG list. All result relations must have the same schema.

```
mquery          ->  query
                  | union [query-list]
                  | intersection [query-list]
query-list      ->  query | query, query-list
```

For example:

```
union [
  select * from plz where ort contains “dorf”,
  select * from plz where ort contains “stadt”]
```

Note that in this case, each of the subqueries in the list is optimized separately. One interesting application is to find tuples in a relation fulfilling a very large set of conditions. The optimizer’s effort in optimizing a single query is exponential in the number of predicates. It works fine roughly up to 10 predicates. Beyond that optimization times get long. However, it is no problem to use, for example, an intersection query on 30 subqueries each of which has only one or a few conditions.

The query processed by the optimizer is an `mquery`, i.e., the query command is of the form

```
sql mquery.
```

The complete grammar can be found in Appendix B.

## 8.4 Further Ways of Querying

The basic form of querying is using the `sql` predicate in prefix notation, as explained in the previous section, hence

```
sql Term.
```

### Hybrid Queries

A second form of the `sql` predicate allows one to further process the result of a query by SECONDO operators:

```
sql(Term, SecondoQueryRest).
```

Here `SecondoQueryRest` contains a character string with SECONDO operators, applicable to a stream of tuples returned by the optimized and evaluated `Term`. For example:

```
sql(select * from orte where bevt > 300, 'project [Ort] consume').
```

Note that in the second argument, attribute names have to be spelled correctly as in writing executable queries to the SECONDO kernel. In this example, the same effect could have been achieved by a pure SQL query, but there are cases when this facility is useful.

### Creating Objects

The `let` command of SECONDO allows one to create SECONDO objects as the result of an executable query. There is a `let` predicate in the optimizer that allows one to do the same for the result of an optimized query. There are two forms, the second one corresponding to a hybrid query.

```
let(ObjectName, Term).
let(ObjectName, Term, SecondoQueryRest).
```

For example:

```
let(orte2, select ort from [orte, plz as p] where ort = p:ort orderby ort,
'rdup consume').
```

This query creates a relation `orte2` with the names of places (“Orte”) that also occur in the postal code relation `plz`. Here duplicate removal was done at the executable level. However, it can also be done directly, by saying:

```
let(orte3, select distinct ort from [orte, plz as p] where ort = p:ort
orderby ort).
```

### Just Optimizing

For experimenting with the optimizer it is useful to optimize queries without executing them. This is provided by the `optimize` predicate.

```
optimize(Term).
```

This returns the query plan and the expected cost.

## 8.5 The Optimizer's Knowledge of Databases

The optimizer and the SECONDO kernel are only loosely coupled. In particular, one can use the kernel independently, create and delete databases and objects within databases out of control of the optimizer.

The optimizer maintains knowledge about the existing database contents within a number of "dynamic predicates" while the optimizer is running, and in files between sessions. It obtains such knowledge from the SECONDO kernel by sending commands or queries to it, for example, `list objects`. Currently there are the following such predicates and corresponding files:

- *storedRels* - relations and their attributes
- *storedSpells* - spellings of relation and attribute names
- *storedIndexes* - for which attributes do and do not exist indexes
- *storedCards* - cardinalities of relations
- *storedTupleSizes* - average tuple sizes (in bytes) of relations
- *storedSels* - selectivities of selection and join predicates
- *storedPETs* - predicate evaluation times for selection and join predicates
- *storedAttrSizes* - average sizes of attributes in bytes
- *storedTypeSizes* - the size of SECONDO datatypes[2]
- *storedOrderings* - known orderings within stored relations

The optimizer distinguishes between different databases by saving the database name with all facts of its knowledge base.

The general principle is that the optimizer retrieves information from SECONDO when it is needed and then stores it for later use. For example, when a relation is mentioned for the first time in a query, the optimizer sends "`list objects`" to the kernel to check whether the relation exists and to get attribute names with their spelling. It also determines whether there are indexes available and creates a small sample relation if there is none yet. It sends a query "`<relname> count`" to get the cardinality and another "`<relname> tuplesize`" to get the average tuple size in byte. It also gets average attribute sizes by queries of the form "`<relname> attrsize[<attrname>]`".

When in a query a selection or join predicate occurs for which the selectivity is not yet known, the optimizer sends a corresponding query on the small sample relation(s) to determine the selectivity and predicate evaluation time (PET).

**Note**: The optimizer recognizes indexes by a name convention. The name of the index must have the form `<relation name>_<attribute name>`. These names must be spelled as in the SECONDO kernel except that the first letter must be in lower case (due to its use in PROLOG). Hence an index on attribute `Bev` of relation `Staedte` must be called `staedte_Bev` to be recognized by the optimizer. Such an index can be created by the command:

```
let 'staedte_Bev = Staedte createbtree[Bev]'.
```

2. Created by the SECONDO kernel, this refers to the fixed size part of a data type representation.

## Inquiries on the Optimizer's Knowledge Base

The optimizer provides several commands for inquiries on its knowledge base:

- `showStoredRels` - lists all known relations and their attributes
- `showStoredAttrSizes` - lists types and sizes for known attributes
- `showStoredOrders` - list known orderings
- `showSels` - lists the known selectivities
- `showPETs` - lists all known PETs

The command

- `showDatabase`

will show a summary of all relation-based information gathered for the open database, including information on attribute types and sizes, cardinalities and average tuple sizes, known indexes and orderings. Last, the command

- `showDatabaseSchema`

will list all relations available in the open database (not only the ones known to the optimizer from past queries) together with their attributes and attribute types.

## Reinitializing

One can reinitialize the optimizer's knowledge of databases by deleting the files `storedRels` etc. mentioned above from the directory `Optimizer` (when the optimizer is not running). In this case, all information needed will be collected afresh on further queries.

If you somehow run into unexplainable problems with the optimizer, it is usually a good idea to quit the optimizer, delete all these `stored*.pl` files and restart the optimizer.

## Creating and Deleting Relations

When new relation objects are created, the optimizer should recognize them automatically as soon as they are used in a query. However, the optimizer will not automatically be aware that a relation has been deleted and will still create query plans for it which will then be refused by the SECONDO kernel. We explain below how the optimizer can be informed about the deletion.

## Creating and Deleting Indexes

The optimizer checks for indexes when a relation is mentioned for the first time in a query. Hence, it automatically recognizes indexes created together with a relation before querying. However, once it has been determined that for a given attribute of a relation no index exists, the optimizer will not check further for an index on that attribute. The optimizer also does not notice when an index is deleted.

## Informing the Optimizer

Two commands (predicates) are available to explicitly inform the optimizer about changes to relations and indexes.

```
updateRel(Rel)
```

A call of this predicate causes the optimizer to delete all information it has about the relation `Rel`, including selectivities of predicates. An existing sample is also destroyed. A query afterwards involving this relation collects all information from scratch. Existing or non-existing indexes are also discovered. For example:

```
updateRel(plz).
```

resets all information for relation `plz`. The second predicate is:

```
updateIndex.
```

This predicate lets the optimizer check whether any indexes have been added or removed to update its knowledge base. Hence this can be used after creating or destroying an index, without losing all the other information collected for relation `Rel`. For example, after deleting the index `plz_Ort` one should inform the optimizer by saying `updateIndex` once.

## Creating Sample Relations Manually

As mentioned above, the optimizer uses small sample relations to determine selectivities of selection or join predicates before actually optimizing the query. These sample relations are normally created automatically, with default sizes. There is one sample relation called `<relname>_sample_s` and another one called `<relname>_sample_j`, to be used for selection and join predicates, and with default sizes 2000 and 500 tuples, respectively. If a relation has less tuples than that, the sample will be the full relation.

However, in some cases this default value is not appropriate. This is mainly the case when a relation has few tuples containing large objects. For example, in the `germany` example database that comes with SECONDO, there is a relation `Kreis` with 439 tuples, each containing a *region* value with several hundred or thousand edges. In this case a sample with 10% of the tuples is quite sufficient and preferable, as on the geometries often expensive predicates are evaluated. hence in such a case one would like to have samples of size 50, say, for both selection and joins.

Unfortunately it is difficult to build a general rule for such samples into the optimizer, and this has not been done. Instead, the optimizer complains if by default it would create a sample relation of size more than 2 MB, and asks the user to manually create samples. This can be done as follows. The predicate

```
createSamples(RelName, SizeSel, SizeJoin)
```

creates samples with the desired sizes. Note that here the relation name has to be given in quotes as the real Secondo name is used (rather than the lower case version used in queries). For example:

```
createSamples(’Kreis’, 50, 50)
```

In some configurations of the optimizer, also so-called *small* relations are created, named `<rel-name>_small`. The optimizer will create small relations automatically. If the automatically chosen size of a small relation is not suitable, one can create it manually by a predicate

```
createSmall(Rel, Size)
```

In this case, however, the relation name has to be spelled as in queries, that is:

```
createSmall(kreis, 50)
```

## 8.6 Operator Syntax

In queries given to the optimizer one uses atomic operators in predicates and expressions in the select-clause like

```
<, >, <=, #, starts, contains, +, *, div, mod
```

In this section we explain how new operators of this kind can be made available in the optimizer. For using operators in queries, there are two conditions:

1. We must be able to write the operator in PROLOG.
2. The optimizer must know how to translate the operator application to SECONDO syntax.

### PROLOG Syntax

Any operator can be written in PROLOG in prefix syntax. For example:

```
length(X), theDate(2004, 5, 9)
```

These are just standard terms in PROLOG. If we want to write a (binary) operator in infix notation, either this operator is defined already in PROLOG. This is the case for standard operators like `+, *, <`, etc. Otherwise one can explicitly define it in the file `opsyntax.pl` in directory `Optimizer`. For example, in the file we find definitions:

```
:- op(800, xfx, inside).
:- op(800, xfx, intersects).
:- op(800, xfx, adjacent).
:- op(800, xfx, or).
:- op(800, fx, not).
```

Here `inside`, `intersects`, `adjacent`, and `or` are defined to be binary infix operators, and `not` is defined to be a unary prefix operator. New operators can be made available in the same way.

### SECONDO Syntax

Translation to SECONDO is controlled firstly, by a few defaults, depending on the number of arguments:

- one argument: translated to prefix notation
  `op(arg)`
- two arguments: translated to infix notation
  `arg1 op arg2`

- three arguments: translated to prefix notation
  ```
  op(arg1, arg2, arg3)
  ```

If a binary operator is to be translated to prefix notation instead, one can place a fact into the file `opsyntax.pl` of the form

```
secondoOp(Op, prefix, 2)
```

For example, to define a `distance` operator with two arguments to be written in prefix notation we can specify:

```
secondoOp(distance, prefix, 2).
```

Reload the file after modifying it:

```
[opsyntax].
```

The current contents of the file are shown in Appendix A. For example, we can now use the `distance` operator in a query (on a database `germany`):

```
select [sname, distance(ort, s2:ort) as dist]
from [stadt, stadt as s2]
where [s2:sname = "Dortmund", distance(ort, s2:ort) < 0.3]
```

## A Operator Syntax

```
/*
[File ~opsyntax.pl~]

*/

:-
  op(800, xfx, =>),
  op(800, xfx, <=),
  op(800, xfx, #),
  op(800, xfx, div),
  op(800, xfx, mod),
  op(800, xfx, starts),
  op(800, xfx, contains),
  op(200, xfx, :).

:- op(800, xfx, inside).
:- op(800, xfx, insideold).
:- op(800, xfx, intersects).
:- op(800, xfx, adjacent).
:- op(800, xfx, attached).
:- op(800, xfx, overlaps).
:- op(800, xfx, onborder).
:- op(800, xfx, ininterior).
:- op(800, xfx, touchpoints).
:- op(800, xfx, intersection).
:- op(800, xfx, commonborder).
:- op(800, xfx, commonborderscan).

:- op(800, xfx, or).
:- op(800,  fx, not).

:- op(800, xfx, present).
:- op(800, xfx, passes).
:- op(800, xfx, atinstant).
:- op(800, xfx, atperiods).
:- op(800, xfx, at).

:- op(800, xfx, satisfies).
:- op(800, xfx, when).

:- op(800, xfx, simpleequals).

:- op(800, xfx, intersects_new).
:- op(800, xfx, p_intersects).


/*

----secondoOp(?Op, ?Syntax, ?NoArgs) :-
----

~Op~ is a Secondo operator written in ~Syntax~, with ~NoArgs~ arguments.
Currently implemented:

  * postfix, 1 or 2 arguments: corresponds to \_ \# and \_ \_ \#

  * postfixbrackets, 2 or 3 arguments, of which the last one is put into
```

```
the brackets: \_ \# [ \_ ] or \_ \_ \# [ \_ ]

  * prefix, 2 arguments: \# (\_, \_)

  * prefix, either 1 or 3 arguments, does not need a rule here, is
translated by default.

  * infix, 2 arguments: does not need a rule, translated by default.

For all other forms, a plan\_to\_atom rule has to be programmed expli-
citly.

*/

secondoOp(distance, prefix, 2).
secondoOp(intersection_new, prefix, 2).
secondoOp(intersection, prefix, 2).
secondoOp(theperiod, prefix, 2).
secondoOp(union_new, prefix, 2).
secondoOp(minus_new, prefix, 2).
secondoOp(feed, postfix, 1).
secondoOp(consume, postfix, 1).
secondoOp(count, postfix, 1).
secondoOp(pdelete, postfix, 1).
secondoOp(product, postfix, 2).
secondoOp(filter, postfixbrackets, 2).
secondoOp(puse, postfixbrackets, 2).
secondoOp(pfeed, postfixbrackets, 2).
secondoOp(pcreate, postfixbrackets, 2).
secondoOp(loopjoin, postfixbrackets, 2).
secondoOp(exactmatch, postfixbrackets, 3).
secondoOp(leftrange, postfixbrackets, 3).
secondoOp(rightrange, postfixbrackets, 3).
secondoOp(remove, postfixbrackets, 2).
secondoOp(sortby, postfixbrackets, 2).
secondoOp(loopsel, postfixbrackets, 2).
secondoOp(sum, postfixbrackets, 2).
secondoOp(min, postfixbrackets, 2).
secondoOp(max, postfixbrackets, 2).
secondoOp(avg, postfixbrackets, 2).
secondoOp(tuplesize, postfix, 1).
secondoOp(exttuplesize, postfix, 1).
secondoOp(attrsize, postfixbrackets, 2).
secondoOp(head, postfixbrackets, 2).
secondoOp(windowintersects, postfixbrackets, 3).
secondoOp(windowintersectsS, postfixbrackets, 2).
secondoOp(gettuples, postfix, 2).
secondoOp(sort, postfix, 1).
secondoOp(rdup, postfix, 1).
secondoOp(bbox, prefix, 1).
secondoOp(box3d, prefix, 2).
secondoOp(symmproduct, postfix, 2).
```

## B Grammar of the Query Language

We use the following notational conventions. Words written in normal font are grammar symbols (non-terminals), words in bold face are terminal symbols. The symbols “`->`” and “`|`” are meta-symbols denoting derivation in the grammar and separation of alternatives. Other characters like “*” or “:” are also terminals.

The notation `X-`*`list`* refers to a PROLOG list with elements of type `X`; as mentioned already, the square brackets can be omitted if the list has just one element. The notation `X-`*`expr`* refers to an expression built from elements of type `X`, constants, and operations available on `X`-values. Hence `attr-`*`expr`* is an expression involving attributes denoted in one of the two forms `attrname` or `var:attrname`. Similarly a predicate (`pred`) is a boolean expression over attributes. `X-`*`constant`* denotes a SECONDO constant of type `X`. Finally, “ε” denotes the empty alternative. For example, the where-clause is optional. „**id**“ is any valid SECONDO identifier.

```
sql-clause        ->  let objectname mquery.
                    | let(objectname, mquery, secondo-rest-query).
                    | sql mquery.
                    | sql(mquery, secondo-rest-query).

aggr              ->  groupattr | groupattr as newname | aggr2

aggr2             ->  count(distinct-clause *) as newname
                    | aggrop(ext-attr-expr) as newname
                    | aggregate(ext-attr-expr, aggrfun, datatype,
                      datatype-constant) as newname

aggrop            ->  min | max | sum | avg | extract | count

aggr-clause       ->  aggr | [aggr, aggr-list]

aggr-fun          ->  (*) | (+) | union_new | intersection_new |
                      % any name fun of a binary SECONDO-operator or
                        function object with syntax fun: T x T --> T
                        which should be associative and commutative.
                        Infix-operators must be inclosed in round
                        paranthesis.

aggr-list         ->  aggr | aggr, aggr-list

attr              ->  attrname | var:attrname

attr-list         ->  attr | attr, attr-list

attrname          ->  id

datatype          ->  int | real | bool | string | line | points
                    | mpoint | uregion |
                      % any name of a SECONDO-datatype

distinct-clause   ->  all | distinct | ε

ext-attr          ->  distinct-clause attr

ext-attr-expr     ->  distinct-clause attr-expr

first-clause      ->  first int-constant | ε

groupattr         ->  attr

groupattr-list    ->  groupattr | groupattr, groupattr-list | ε

groupby-clause    ->  groupby [groupattr-list] | groupby groupattr

mquery            ->  query
                    | union [query-list]
                    | intersection [query-list]

newname           ->  id

orderattr         ->  attrname | attrname asc | attrname desc
```

```
orderattr-list     ->  orderattr | orderattr, orderattr-list

orderby-clause     ->  orderby [orderattr-list] | orderby orderattr | ε

pred               ->  attr-boolexpr

pred-list          ->  pred | pred, pred-list

query              ->  select distinct-clause sel-clause from rel-clause
                       where-clause orderby-clause first-clause
                     | select aggr-clause from rel-clause where-clause
                       groupby-clause orderby-clause first-clause

query-list         ->  query | query, query-list

rel                ->  relname | relname as var

rel-clause         ->  rel | [rel-list]

rel-list           ->  rel | rel, rel-list

relname            ->  id

result             ->  attr | attr-expr as newname

result-list        ->  result | result, result-list

secondo-rest-query  ->  'text'
                       % any valid subexpression in
                         Secondo executable language

sel-clause         ->  *
                     | result | [result-list]
                     | count(distinct-clause *)
                     | aggrop(ext-attr-expr)
                     | aggregate(ext-attr-expr, aggrfun, datatype,
                       datatype-constant)

text               ->  id

var                ->  id

where-clause       ->  where [pred-list] | where pred | ε
```

## C References

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