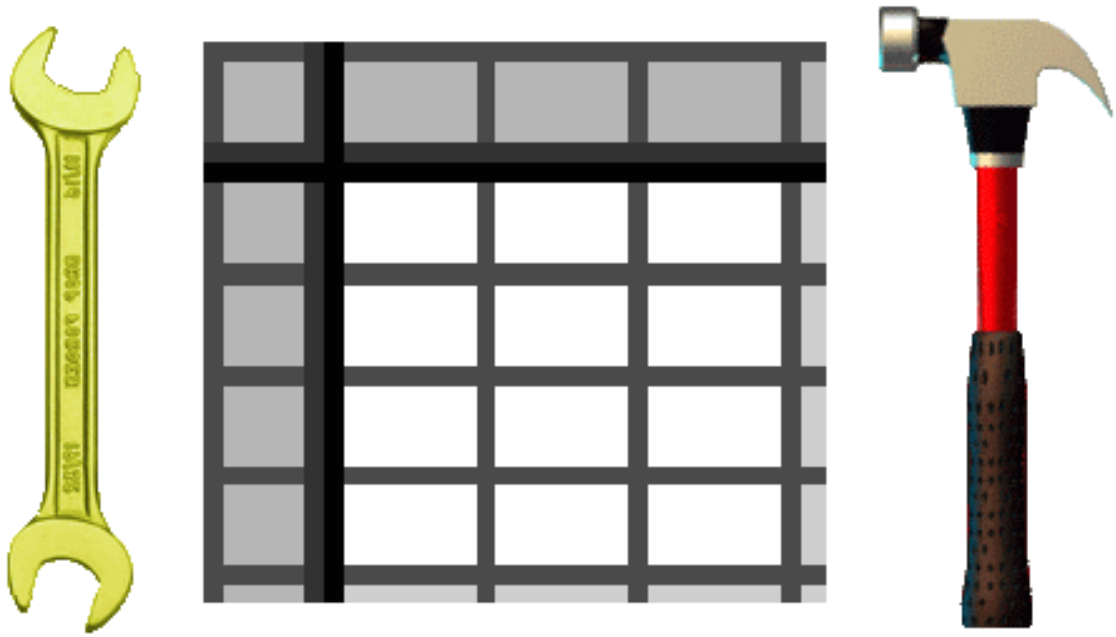
STILTS - Starlink Tables Infrastructure Library Tool Set

Version 1.3-5



Starlink User Note256
Mark Taylor
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Abstract

STILTS is a set of command-line tools for processing tabular data. It has been designed for, but is not restricted to, use on astronomical data such as source catalogues. It contains both generic (format-independent) table processing tools and tools for processing VOTable documents. Facilities offered include format conversion, format validation, column calculation and rearrangement, row selection, sorting, crossmatching, statistical calculations and metadata display. Calculations on cell data can be performed using a powerful and extensible expression language.

The package is written in pure Java and based on STIL, the Starlink Tables Infrastructure Library. This gives it high portability, support for many data formats (including FITS, VOTable, text-based formats and SQL databases), extensibility and scalability. Where possible the tools are written to accept streamed data so the size of tables which can be processed is not limited by available memory. As well as the tutorial and reference information in this document, detailed on-line help is available from the tools themselves.

Contents

1 Introduction

STILTS provides a number of command-line applications which can be used for manipulating tabular data. Conceptually it sits between, and uses many of the same classes as, the packages STIL, which is a set of Java APIs providing table-related functionality, and TOPCAT, which is a graphical application providing the user with an interactive platform for exploring one or more tables. This document is mostly self-contained - it covers some of the same ground as the STIL and TOPCAT user documents (SUN/252 and SUN/253 respectively).

Currently, this package consists of the following commands for generic table manipulation:

- `tcopy` (Appendix A.8): Converts between table formats
- `tpipe` (Appendix A.12): Performs pipeline processing on a table
- `tmatch2` (Appendix A.11): Crossmatches 2 tables
- `tcat` (Appendix A.6): Concatenates multiple similar tables
- `tcatn` (Appendix A.7): Concatenates multiple tables
- `tjoin` (Appendix A.10): Joins multiple tables side-to-side
- `tcube` (Appendix A.9): Calculates N-dimensional histograms

the following commands specifically for operating on VOTable files:

- `votcopy` (Appendix A.13): Transforms between VOTable encodings
- `votlint` (Appendix A.14): Validates VOTable documents

the following commands for accessing VO/database services:

- `regquery` (Appendix A.4): Queries the VO registry
- `multicone` (Appendix A.3): Makes multiple cone search queries to the same service
- `sqlcone` (Appendix A.5): Crossmatch between local table and table in SQL database

and the following general purpose utilities:

- `calc` (Appendix A.1): Evaluates expressions
- `funcs` (Appendix A.2): Browse functions used by algebraic expression langauage

More tools may be introduced in the future.

There are many ways you might want to use these tools; here are a few possibilities:

In conjunction with TOPCAT
: you can identify a set of processing steps using TOPCAT's interactive graphical facilities, and construct a script using the commands provided here which can perform the same steps on many similar tables without further user intervention.

Format conversion
: If you have a separate table processing engine and you want to be able to output the results in a somewhat different form, for instance converting it from FITS to VOTable or from TABLEDATA-encoded to BINARY-encoded VOTable, or to perform some more scientifically substantial operation such as changing units or coordinate systems, substituting bad values etc, you can pass the results through one of the tools here. Since on the whole operation is streaming, such conversion can easily and efficiently be done on the fly.

Server-side operations
: The tools provided here are suitable for use on servers, either to generate files as part of a web service (perhaps along the lines of the **Format conversion** item above) or as configurable components in a server-based workflow system.

Quick look
: You might want to examine the metadata, or a few rows, or a statistical summary of a table without having to load the whole thing into TOPCAT or some other table viewer application.

2 The `stilts` command

All the functions available in this package can be used from a single command, which is usually referred to in this document simply as "`stilts`". Depending on how you have installed the package, you may just type "`stilts`", or something like

```
java -jar some/path/stilts.jar
```

or

```
java -classpath topcat-lite.jar uk.ac.starlink.ttools.Stilts
```

or something else - this is covered in detail in Section 3.

In general, the form of a command is

```
stilts <stilts-flags> <task-name> <task-args>
```

The forms of the parts of this command are described in the following subsections, and details of each of the available tasks along with their arguments are listed in the command reference (Appendix A) at the end of this document. Some of the commands are highly configurable and have a variety of parameters to define their operation. In many cases however, it's not complicated to use them. For instance, to convert the data in a FITS table to VOTable format you might write:

```
stilts tcopy cat.fits cat.vot
```

2.1 Stilts flags

Some flags are common to all the tasks in the STILTS package, and these are specified after the `stilts` invocation itself and before the task name. They generally have the same effect regardless of which task is running. These generic flags are as follows:

`-help`
Prints a usage message for the `stilts` command itself and exits. The message contains a listing of all the known tasks.

`-version`
Prints the STILTS version number and exits.

`-verbose`
Causes more verbose information to be written during operation. Specifically, what this does is to boost the logging level by one notch. It may be specified multiple times to increase verbosity further.

`-disk`
Encourages the command to use temporary files on disk for caching large amounts of data rather than doing it in memory. This is a good flag to try if you are running out of memory. This flag is in most cases equivalent to specifying the system property `-Dstartable.storage=disk`.

`-debug`
Sets up output suitable for debugging. The most visible consequence of this is that if an error occurs then a full stacktrace is output, rather than just a user-friendly report.

`-prompt`
Most of the STILTS commands have a number of parameters which will assume sensible defaults if you do not give them explicit values on the command line. If you use the `-prompt` flag, then you will be prompted for every parameter you have not explicitly specified to give you an opportunity to enter a value other than the default.

`-batch`
Some parameters will prompt you for their values, even if they offer legal defaults. If you use the `-batch` flag, then you won't be prompted at all.

-bench
Outputs the elapsed time taken by the task to standard error on successful completion.

-checkversion <vers>
Requires that the version is exactly as given by the string `<vers>`. If it is not, STILTS will exit with an error. This can be useful when executing in certain controlled environments to ensure that the correct version of the application is being picked up.

-stdout <file>
Sends all normal output from the run to the given file. By default this goes to the standard output stream. Supplying an empty string or "`-`" for `<file>` will restore this default behaviour.

-stderr <file>
Sends all error output from the run to the given file. By default this goes to the standard error stream. Supplying an empty string or "`-`" for `<file>` will restore this default behaviour.

If you are submitting an error report, please include the result of running `stilts -version` and the output of the troublesome command with the `-debug` flag specified.

2.2 Task Names

The `<task-name>` part of the command line is the name of one of the tasks listed in Appendix A - currently the available tasks are:

- `calc`
- `funcs`
- `multicone`
- `regquery`
- `sqlcone`
- `tcat`
- `tcatn`
- `tcopy`
- `tcube`
- `tjoin`
- `tmatch2`
- `tpipe`
- `votcopy`
- `votlint`

2.3 Task Arguments

The `<task-args>` part of the command line is a list of parameter assignments, each giving the value of one of the named parameters belonging to the task which is specified in the `<task-name>` part.

The general form of each parameter assignment is

```
<param-name>=<param-value>
```

If you want to set the parameter to the null value, which is legal for some but not all parameters, use the special string "`null`". In some cases you can optionally leave out the `<param-name>` part of the assignment (i.e. the parameter is positionally determined); this is indicated in the task's usage description if the parameter is described like `[<param-name>=]<param-value>` rather than `<param-name>=<param-value>`. If the `<param-value>` contains spaces or other special characters, then in most cases, such as from the Unix shell, you will have to quote it somehow. How this is done depends on your platform, but usually surrounding the whole value in single quotes will do the trick.

Tasks may have many parameters, and you don't have to set all of them explicitly on the comand line. For a parameter which you don't set, two things can happen. In many cases, it will default to some sensible value. Sometimes however, you may be prompted for the value to use. In the latter case, a line like this will be written to the terminal:

```
matcher - Name of matching algorithm [sky]:
```

This is prompting you for the value of the parameter named `matcher`. "Name of matching algorithm" is a short description of what that parameter does. "`sky`" is the default value (if there is no default, no value will appear in square brackets). At this point you can do one of four things:

- Hit return - this will select the default value if there is one. If there is no default, this is equivalent to entering "`null`".
- Enter a value for the parameter explicitly. The special value "`null`" means the null value, which is legal for some, but not all parameters. If the value you enter is not legal, you will see an error message and you will be invited to try again.
- Enter "`help`" or a question mark "`?`". This will output a message giving a detailed description of the parameter and prompt you again.
- Bail out by hitting ctrl-C or whatever is usual on your platform.

Under normal circumstances, most parameters which have a legal default value will default to it if they are not set on the command line, and you will only be prompted for those where there is no default or the program thinks there's a good chance you might not want to use it. You can influence this however using flags to the `stilts` command itself (see Section 2.1). If you supply the `-prompt` flag, then you will be prompted for every parameter you have not explicitly set. If you supply `-batch` on the other hand, you won't be prompted for any parameters (and if you fail to set any without legal default values, the task will fail).

If you want to see the actual values of the parameters for a task as it runs, including prompted values and defaulted ones which you haven't specified explicitly, you can use the `-verbose` flag after the `stilts` command:

```
% stilts -verbose tcopy cat.fits cat.vot ifmt=fits
INFO: tcopy in=cat.fits out=cat.vot ifmt=fits ofmt=(auto)
```

Extensive help is available from `stilts` itself about task and its parameters, as described in the next section.

2.4 Getting help

As well as the command descriptions in this document (especially the reference section Appendix A) you can get help for STILTS usage from the command itself. Typing

```
stilts -help
```

results in this output:

```
Usage:
   stilts [-help] [-version] [-verbose] [-disk] [-debug] [-prompt] [-batch]
          [-bench] [-checkversion <vers>] [-stdout <file>] [-stderr <file>]
          <task-name> <task-args>

   stilts <task-name> help[=<param-name>]

   Known tasks:
      calc
      funcs
      multicone
      regquery
      sqlcone
      tcat
      tcatn
      tcopy
      tcube
      tjoin
```

```
        tmatch2
        tpipe
        votcopy
        votlint
```

For help on the individual tasks, including their parameter lists, you can supply the word `help` after the task name, so for instance

```
stilts tcopy help
```

results in

```
Usage: tcopy ifmt=<in-format> ofmt=<out-format>
             [in=]<table> [out=]<out-table>
```

Finally, you can get help on any of the parameters of a task by writing `help=<param-name>`, like this:

```
stilts tcopy help=in
```

gives

```
Help for parameter IN in task TCOPY
-----------------------------------

   Name:
      in

   Usage:
      [in=]<table>

   Summary:
      Location of input table

   Description:
      The location of the input table. This is usually a filename or URL,
      and may point to a file compressed in one of the supported compression
      formats (Unix compress, gzip or bzip2). If it is omitted, or equal to
      the special value "-", the input table will be read from standard
      input. In this case the input format must be given explicitly using
      the ifmt parameter.
```

In some cases, as described in Section 2.3, you will be prompted for the value of a parameter with a line something like this:

```
matcher - Name of matching algorithm [sky]:
```

In this case, if you enter "`help`" or a question mark, then the parameter help entry will be printed to the screen, and the prompt will be repeated.

For more detailed descriptions of the tasks, which includes explanatory comments and examples as well as the information above, see the full task descriptions in the Command Reference (Appendix A).

3 Invocation

There are a number of ways of invoking the `stilts` command, depending on how you have installed the package. If you're using a Unix-like operating system, the easiest way is to use the `stilts` script. If you have a full starjava installation it is in the `starjava/bin` directory. Otherwise you can download it separately from wherever you got your STILTS installation in the first place, or find it at the top of the `stilts.jar` or `topcat-*.jar` that contains your STILTS installation, so do something like

```
unzip stilts.jar stilts
chmod +x stilts
```

to extract it (if you don't have `unzip`, try `jar xvf stilts.jar stilts`). `stilts` is a simple shell script which just invokes java with the right classpath and the supplied arguments.

To run using the `stilts` script, first make sure that both the `java` executable and the `stilts` script itself are on your path, and that the `stilts.jar` or `topcat-*.jar` jar file is in the same directory as `stilts`. Then the form of invocation is:

```
stilts <java-flags> <stilts-flags> <task-name> <task-args>
```

A simple example would be:

```
stilts votcopy format=binary t1.xml t2.xml
```

in this case, as often, there are no `<java-flags>` or `<stilts-flags>`. If you use the `-classpath` argument or have a CLASSPATH environment variable set, then classpath elements thus specified will be added to the classpath required to run the command. The examples in the command descriptions below use this form for convenience.

If you don't have a Unix-like shell available however, you will need to invoke Java directly with the appropriate classes on your classpath. If you have the file `stilts.jar`, in most cases you can just write:

```
java <java-flags> -jar stilts.jar <stilts-flags> <task-name> <task-args>
```

which in practice would look something like

```
java -jar /some/where/stilts.jar votcopy format=binary t1.xml t2.xml
```

In the most general case, Java's `-jar` flag might be no good, for one of the following reasons:

1. You have the classes in some form other than the `stilts.jar` file (such as `topcat-full.jar`)
2. You need to specify some extra classes on the classpath, which is required e.g. for use with JDBC (Section 3.4) or if you are extending the commands (Section 7.7.3) using your own classes at runtime

In this case, you will need an invocation of this form:

```
java <java-flags> -classpath <class-path>
     uk.ac.starlink.ttools.Stilts <stilts-flags> <task-name> <task-args>
```

The example above in this case would look something like:

```
java -classpath /some/where/topcat-full.jar uk.ac.starlink.ttools.Stilts
     votcopy format=binary t1.xml t2.xml
```

The `<stilts-flags>`, `<task-name>` and `<task-args>` parts of these invocations are explained in Section 2, and the `<class-path>` and `<java-flags>` parts are explained in the following subsections.

3.1 Class Path

The classpath is the list of places that Java looks to find the bits of compiled code that it uses to run

an application. Depending on how you have done your installation the core STILTS classes could be in various places, but they are probably in a file with one of the names `stilts.jar`, `topcat-lite.jar` or `topcat-full.jar`. The full pathname of one of these files can therefore be used as your classpath. In some cases these files are self-contained and in some cases they reference other jar files in the filesystem - this means that they may or may not continue to work if you move them from their original location.

Under certain circumstances the tools might need additional classes, for instance:

- JDBC drivers (see Section 3.4)
- Providing extended algebraic functions (see Section 7.7.3)
- Installing I/O handlers for new table formats (see SUN/252)

In this case the classpath must contain a list of all the jar files in which the required classes can be found, separated by colons (unix) or semicolons (MS Windows). Note that even if all your jar files are in a single directory you can't use the name of that directory as a class path - you must name each jar file, separated by colons/semicolons.

3.2 Java Flags

In most cases it is not necessary to specify any additional arguments to the Java runtime, but it can be useful in certain circumstances. The two main kinds of options you might want to specify directly to Java are these:

System properties
: System properties are a way of getting information into the Java runtime from the outside, rather like environment variables. There is a list of the ones which have significance to STILTS in Section 3.3. You can set them from the command line using a flag of the form `-Dname=value`. So for instance to ensure that temporary files are written to the `/home/scratch` directory, you could use the flag

```
-Djava.io.tmpdir=/home/scratch
```

Memory size
: Java runs with a fixed amount of 'heap' memory; this is typically 64Mb by default. If one of the tools fails with a message that says it's out of memory then this has proved too small for the job in hand. You can increase the heap memory with the `-Xmx` flag. To set the heap memory size to 256 megabytes, use the flag

```
-Xmx256M
```

(don't forget the 'M' for megabyte). You will probably find performance is dreadful if you specify a heap size larger than the physical memory of the machine you're running on.

Note however that encouraging STILTS to use disk files rather than memory for temporary storage is often a better idea than boosting the heap memory - this is done by specifying the `-disk` flag (`stilts -disk <task-name> ...`), or possibly setting the system property `-Dstartable.storage=disk` (see Section 2.1).

You can specify other options to Java such as tuning and profiling flags etc, but if you want to do that sort of thing you probably don't need me to tell you about it.

If you are using the `stilts` command-line script, any flags to it starting `-D` or `-X` are passed directly to the `java` executable. You can pass other flags to Java with the `stilts` script's `-J` flag; for instance:

```
stilts -Xmx4M -J-verbose:gc calc 'mjdToIso(0)'
```

is equivalent to

```
java -Xmx4M -verbose:gc -jar stilts.jar calc 'mjdToIso(0)'
```

3.3 System Properties

System properties are a way of getting information into the Java runtime - they are a bit like environment variables. There are two ways to set them when using STILTS: either on the command line using arguments of the form `-Dname=value` (see Section 3.2) or in a file in your home directory named `.starjava.properties`, in the form of a `name=value` line. Thus submitting the flag

```
-Dvotable.strict=true
```

on the command line is equivalent to having the following in your `.starjava.properties` file:

```
#  Force strict interpretation of the VOTable standard.
votable.strict=true
```

The following system properties have special significance to STILTS:

`java.io.tmpdir`
: The directory in which STILTS will write any temporary files it needs. This is usually only done if the `-disk` flag has been specified (see Section 2.1).

`jdbc.drivers`
: Can be set to a (colon-separated) list of JDBC driver classes using which SQL databases can be accessed (see Section 3.4).

`jel.classes`
: Can be set to a (colon-separated) list of classes containing static methods which define user-provided functions for synthetic columns or subsets. (see Section 7.7.3).

`mark.workaround`
: If set to "true", this will work around a bug in the `mark()`/`reset()` methods of some java `InputStream` classes. These are rather common, including in Sun's J2SE system libraries. Use this if you are seeing errors that say something like "`Resetting to invalid mark`". Currently defaults to "false".

`startable.readers`
: Can be set to a (colon-separated) list of custom table format input handler classes (see SUN/252).

`startable.storage`
: Can be set to determine the default storage policy. Setting it to "`disk`" has basically the same effect as supplying the "`-disk`" argument on the command line (see Section 2.1). Other possible values are "`memory`", "`sideways`" and "`discard`"; see SUN/252.

`startable.writers`
: Can be set to a (colon-separated) list of custom table format output handler classes (see SUN/252).

`votable.strict`
: Set `true` for strict enforcement of the VOTable standard when parsing VOTables. This prevents the parser from working round certain common errors, such as missing `arraysize` attributes on `FIELD` or `PARAM` elements with `datatype="char"`. False by default.

3.4 JDBC Configuration

This section describes additional configuration which must be done to allow the commands to access SQL-compatible relational databases for reading or writing tables. If you don't need to talk to SQL-type databases, you can ignore the rest of this section. The steps described here are the standard ones for configuring JDBC (which sort-of stands for Java Database Connectivity),

described in more detail on Sun's JDBC web page.

To use STILTS with SQL-compatible databases you must:

- Have access to an SQL-compatible database locally or over the network
- Have a JDBC driver appropriate for that database
- Install that driver for use with STILTS
- Know the format the driver uses for URLs to access database tables
- Have appropriate privileges on the database to perform the desired operations

Installing the driver consists of two steps:

1. Ensure that the classpath you are using includes this driver class as described in Section 3.1
2. Set the `jdbc.drivers` system property to the name of the driver class as described in Section 3.3

These steps are all standard for use of the JDBC system. See SUN/252 for information about JDBC drivers known to work with STIL (the short story is that at least MySQL and PostreSQL will work).

Here is an example of using `tcopy` to write the results of an SQL query on a table in a MySQL database as a VOTable:

```
stilts -classpath /usr/local/jars/mysql-connector-java.jar \
       -Djdbc.drivers=com.mysql.jdbc.Driver \
       tcopy \
       in="jdbc:mysql://localhost/db1#SELECT id, ra, dec FROM gsc WHERE mag < 9" \
       ofmt=votable gsc.vot
```

or invoking Java directly:

```
java -classpath stilts.jar:/usr/local/jars/mysql-connect-java.jar \
     -Djdbc.drivers=com.mysql.jdbc.Driver \
     uk.ac.starlink.ttools.Stilts tcopy \
     in="jdbc:mysql://localhost/db1#SELECT id, ra, dec FROM gsc WHERE mag < 9" \
     ofmt=votable out=gsc.vot
```

You have to exercise some care to get the arguments in the right order here - see Section 3.

Alternatively, you can set some of this up beforehand to make the invocation easier. If you set your CLASSPATH environment variable to include the driver jar file (and the STILTS classes if you're invoking Java directly rather than using the scripts), and if you put the line

```
jdbc.drivers=com.mysql.jdbc.Driver
```

in the `.starjava.properties` file in your home directory, then you could avoid having to give the `-classpath` and `-Djdbc.drivers` flags respectively.

4 Table I/O

Most of the tools in this package either read one or more tables as input, or write one or more tables as output, or both. This section explains what kind of tables the tools can read and write, and how you tell them where to find the tables to operate on.

In most cases input and output table specificcations are given by parameters with the following names (or similar ones):

`in`
Location of the input table

`ifmt`
Format of the input table

`out`
Location of the output table

`ofmt`
Format of the output table

The values of these parameters are discussed in more detail below.

4.1 Table Locations

The location of tables for input and output are usually given using the `in` and `out` parameters respectively. These are often, but not always, filenames. The possibilities are these:

Filename
Very often, you will simply specify a filename as location, and the tool will just read from/write to it in the usual way.

URL
Tables can be read from URLs directly, and in some cases written to them as well. Some non-standard URL protocols are supported as well as the usual ones. The list is:

`http:`
Read from HTTP resources.

`ftp:`
Read from anonymous FTP resources.

`file:`
Read from local files; not particularly useful since you can do much the same using just the filename.

`jar:`
Specialised protocol for looking inside Java Archive files - see JarURLConnection documentation.

`myspace:`
Accesses files in the AstroGrid "MySpace" virtual file store. These URLs look something like "`myspace:/survey/iras_psc.xml`", and can access files in the myspace are that the user is currently logged into. These URLs can be used for both input and output of tables. To use them you must have an AstroGrid account and the AstroGrid WorkBench or similar must be running; if you're not currently logged in a dialogue will pop up to ask you for name and password.

`ivo:`
Understands ivo-type URLs which signify files in the AstroGrid "MySpace" virtual file store. These URLs look something like

". These URLs can be used for both input and output of tables. To use them you must have an AstroGrid account and the AstroGrid WorkBench or similar must be running; if you're not currently logged in a dialogue will pop up to ask you for name and password.

`jdbc:`
Used for communicating with SQL-compliant relational databases. These are a bit different to normal URLs - see section Section 3.4.

Minus sign ("-")
The special location "-" (minus sign) indicates standard input (for reading) or standard output (for writing). This allows you to use STILTS commands in a normal Unix pipeline.

In any of these cases, for input locations compression is taken care of automatically. That means that you can give the filename or URL of a file which is compressed using `gzip`, `bzip2` or Unix `compress` and the program will uncompress it on the fly.

4.2 Table Formats

The generic table commands in STILTS (currently `tpipe`, `tcopy`, `tcat`, `tcatn`, `tcube`, `tjoin`, `tmatch2`, `multicone`, `sqlcone` and `regquery`) have no native format for table storage, they can process data in a number of formats equally well. STIL has its own model of what a table consists of, which is basically:

- Some per-table metadata (parameters)
- A number of columns
- Some per-column metadata
- A number of rows, each containing one entry per column

Some table formats have better facilities for storing this sort of thing than others, and when performing conversions STILTS does its best to translate between them, but it can't perform the impossible: for instance there is nowhere in a Comma-Separated Values file to store descriptions of column units, so these will be lost when converting from VOTable to CSV formats.

The formats the package knows about are dependent on the input and output handlers currently installed. The ones installed by default are listed in the following subsections. More may be added in the future, and it is possible to install new ones at runtime - see the STIL documentation for details.

4.2.1 Input Formats

Some of the tools in this package ask you to specify the format of input tables using the `ifmt` parameter. The following list gives the values usually allowed for this (matching is case-insensitive):

`fits`
FITS format - FITS binary or ASCII tables can be read. By default the first table HDU in the file will used, but this can be altered by supplying the HDU index after a '#' sign, so "table.fits#3" means the third HDU extension.

`colfits`
Column-oriented FITS format. This is where a table is stored as a BINTABLE extension which contains a single row, each cell of the row containing a whole column of the table it represents. This has different performance characteristics from normal FITS tables; in particular it may be considerably efficient for very large, and especially very wide tables where not all of the columns are required at any one time. Only available for uncompressed files on disk.

votable
VOTable format - any legal version 1.0 or 1.1 format VOTable documents, and many illegal ones, can be read. By default the first TABLE element is used, but this can be altered by supplying the 0-based index after a '#' sign, so "table.xml#4" means the fifth TABLE element in the document.

ascii
Plain text file with one row per column in which columns are separated by whitespace.

csv
Comma-Separated Values format, using approximately the conventions used by MS Excel.

tst
Tab-Separated Table format, as used by Starlink's GAIA and ESO's SkyCat amongst other tools.

ipac
IPAC Table Format.

wdc
World Datacentre Format (experimental).

For more details on these formats, see the descriptions in SUN/253.

In some cases (when using VOTable or FITS format tables) the tools can detect the table format automatically, and no explicit specification is necessary. If this isn't the case and you omit the format specification, the tool will fail with a suitable error message. It is always safe to specify the format explicitly; this will be slightly more efficient, and may lead to more helpful error messages in the case that the table can't be read correctly.

4.2.2 Output Formats

Some of the tools ask you to specify the format of output tables using the `ofmt` parameter. The following list gives the values usually allowed for this; in some cases as you can see there are several variants of a given format. You can abbreviate these names, and the first match in the list below will be used, so for instance specifying `votable` is equivalent to specifying `votable-tabledata` and `fits` is equivalent to `fits-plus`. Matching is case-insensitive.

fits-plus
FITS file; primary HDU contains a VOTable representation of the metadata, first extension contains a FITS binary table (behaves the same as `fits-basic` for most purposes)

fits-basic
FITS file; primary HDU is data-less, first extension contains a FITS binary table

colfits-plus
FITS file containing a BINTABLE with a single row; each cell of the row contains a whole column's worth of data. The primary HDU also contains a VOTable representation of the metadata.

colfits-basic
FITS file containing a BINTABLE with a single row; each cell of the row contains a whole column's worth of data. The primary HDU contains nothing.

votable-tabledata
VOTable document with TABLEDATA (pure XML) encoding

votable-binary-inline
VOTable document with BINARY-encoded data inline within a STREAM element

votable-binary-href
VOTable document with BINARY-encoded data in a separate file (only if not writing to a

stream)

votable-fits-href
VOTable document with FITS-encoded data in a separate file (only if not writing to a stream)

votable-fits-inline
VOTable document with FITS-encoded data inline within a `STREAM` element

ascii
Simple space-separated ASCII file format

text
Human-readable plain text (with headers and column boundaries marked out)

csv
Comma-Separated Value format. The first line is a header which contains the column names.

csv-noheader
Comma-Separated Value format with no header line.

tst
Tab-Separated Table format.

html
Standalone HTML document containing a `TABLE` element

html-element
HTML `TABLE` element

latex
LaTeX `tabular` environment

latex-document
LaTeX standalone document containing a `tabular` environment

mirage
Mirage input format

For more details on these formats, see the descriptions in SUN/253.

In some cases the tools may guess what output format you want by looking at the extension of the output filename you have specified.

5 Table Pipelines

Several of the tasks available in STILTS take one or more input tables, do something or other with them, and produce an output table. This is a pretty obvious way to go about things, and in the most straightforward case that's exactly what happens: you name one or more input tables, specify the processing parameters, and name an output table; the task then reads the input tables from disk, does the processing and writes the output table to disk.

However, many of the tasks in STILTS allow you to do pre-processing of the input tables before the main job, post-processing of the output table after the main job, and to decide what happens to the final tabular result, without any intermediate storage of the data. Examples of the kind of pre-processing you might want to do are to rearrange the columns so that they have the right units for the main task, or replace 'magic' values such as -999 with genuine blank values; the kind of post-processing you might want to do is to sort the rows in the output table or delete some of the columns you're not interested in. As for the destination of the final table, you might want to write it to disk, but equally you might not want to store it anywhere, but only be interested in counting the number of rows, or seeing the minima/maxima of a few of the columns, or you might want to send it straight to TOPCAT or some other table viewing application for interactive analysis.

Clearly, you could achieve the same effect by running multiple applications: preprocess your original input tables to write intermediate files on disk, run the main processing application which reads those files from disk and writes a new output file, run another application to postprocess the output file and write a new final output file, and finally do something with this such as counting the rows in it or viewing it in TOPCAT. However, by doing it all within a single task instead, no intermediate results have to be stored, and the whole sequence can be very much more efficient. You can think of this (if it helps) like a Unix pipeline, except what is being streamed from the start to the end of the pipe is not bytes, but table metadata and data. In most cases, the table data is streamed through the pipeline a row at a time, meaning that the amount of memory required is small (though in some cases, for instance row sorting and crossmatching, this is not possible).

Tasks which allow this pre/post-processing, or "filtering", have parameters with names like "`cmd`" which you use to specify processing steps. Tasks with multiple input tables (`tmatch2`, `tcatn`, `tjoin`) may have parameters named `icmd1`, `icmd2`, ... for preprocessing the different input tables and `ocmd` for postprocessing the output table. `tpipe` does nothing except filtering, so there is no distinction between pre- and post-processing, and its filter parameter is just named `cmd`. `tpipe` additionally has a `script` parameter which allows you to use a text file to write the commands in, to prevent the command line getting too long. In both cases there is a parameter named `omode` which defines the "output mode", that is, what happens to the post-processed output table that comes out of the end of the pipeline.

Section 5.1 lists the processing steps available, and explains how to use them, Section 5.2 and Section 5.3 describe the syntax used in some of these filter commands for specifying columns, and Section 5.4 describes the available output modes. See the examples in the command reference, and particularly the `tpipe` examples (Appendix A.12.2), for some examples putting all this together.

5.1 Processing Filters

This section lists the filter commands which can be used for table pipeline processing, in conjunction with `cmd`- or `script`-type parameters.

You can string as many of these together as you like. On the command line, you can repeat the `cmd` (or `icmd1`, or `ocmd`...) parameter multiple times, or use one `cmd` parameter and separate different filter specifiers with semicolons ("`;`"). The effect is the same.

It's important to note that each command in the sequence of processing steps acts on the table at that

point in the sequence. Thus either of the two identical invocations:

```
stilts tpipe cmd='delcols 1; delcols 1; delcols 1'
stilts tpipe cmd='delcols 1' cmd='delcols 1' cmd='delcols 1'
```

has the same effect as

```
stilts tpipe cmd='delcols "1 2 3"'
```

since in the first case the columns are shifted left after each one is deleted, so the table seen by each step has one fewer column than the one before. Note also the use of quotes in the latter of the examples above, which is necessary so that the `<colid-list>` of the `delcols` command is interpreted as one argument not three separate words.

The available filters are described in the following subsections.

5.1.1 `addcol`

Usage:

```
addcol [-after <col-id> | -before <col-id>]
       [-units <units>] [-ucd <ucd>] [-desc <description>]
       <col-name> <expr>
```

Add a new column called `<col-name>` defined by the algebraic expression `<expr>`. By default the new column appears after the last column of the table, but you can position it either before or after a specified column using the `-before` or `-after` flags respectively. The `-units`, `-ucd` and `-desc` flags can be used to define metadata values for the new column.

Syntax for the `<expr>` and `<col-id>` arguments is described in the manual.

5.1.2 `addskycoords`

Usage:

```
addskycoords [-epoch <expr>] [-inunit deg|rad|sex] [-outunit deg|rad|sex]
             <insys> <outsys> <col-id1> <col-id2> <col-name1> <col-name2>
```

Add new columns to the table representing position on the sky. The values are determined by converting a sky position whose coordinates are contained in existing columns. The `<col-id>` arguments give identifiers for the two input coordinate columns in the coordinate system named by `<insys>`, and the `<col-name>` arguments name the two new columns, which will be in the coordinate system named by `<outsys>`. The `<insys>` and `<outsys>` coordinate system specifiers are one of

- `icrs`: ICRS (Hipparcos) (Right Ascension, Declination)
- `fk5`: FK5 J2000.0 (Right Ascension, Declination)
- `fk4`: FK4 B1950.0 (Right Ascension, Declination)
- `galactic`: IAU 1958 Galactic (Longitude, Latitude)
- `supergalactic`: de Vaucouleurs Supergalactic (Longitude, Latitude)
- `ecliptic`: Ecliptic (Longitude, Latitude)

The `-inunit` and `-outunit` flags may be used to indicate the units of the existing coordinates and the units for the new coordinates respectively; use one of `degrees`, `radians` or `sexagesimal` (may be abbreviated), otherwise degrees will be assumed. For sexagesimal, the two corresponding columns must be string-valued in forms like hh:mm:ss.s and dd:mm:ss.s respectively.

For certain conversions, the value specified by the `-epoch` flag is of significance. Where significant its value defaults to 2000.0.

Syntax for the `<expr>` , `<col-id1>` and `<col-id2>` arguments is described in the manual.

5.1.3 `assert`

Usage:

```
assert <expr>
```

Check that a boolean expression is true for each row. If the expression `<expr>` does not evaluate true for any row of the table, execution terminates with an error. As long as no error occurs, the output table is identical to the input one.

The exception generated by an assertion violation is of class `uk.ac.starlink.ttools.filter.AssertException` although that is not usually obvious if you are running from the shell in the usual way.

Syntax for the `<expr>` argument is described in Section 7.

5.1.4 `badval`

Usage:

```
badval <bad-val> <colid-list>
```

For each column specified in `<colid-list>` any occurrence of the value `<bad-val>` is replaced by a blank entry.

Syntax for the `<colid-list>` argument is described in Section 5.3.

5.1.5 `cache`

Usage:

```
cache
```

Stores in memory or on disk a temporary copy of the table at this point in the pipeline. This can provide improvements in efficiency if there is an expensive step upstream and a step which requires more than one read of the data downstream. If you see an error like "Can't re-read data from stream" then adding this step near the start of the filters might help.

5.1.6 `check`

Usage:

```
check
```

Runs checks on the table at the indicated point in the processing pipeline. This is strictly a debugging measure, and may be time-consuming for large tables.

5.1.7 `clearparams`

Usage:

```
clearparams <pname> ...
```

Clears the value of one or more named parameters. Each of the `<pname>` values supplied may be

either a parameter name or a simple wildcard expression matching parameter names. Currently the only wildcarding is a "*" to match any sequence of characters. `clearparams *` will clear all the parameters in the table.

It is not an error to supply <pname>s which do not exist in the table - these have no effect.

5.1.8 `colmeta`

Usage:

```
colmeta [-name <name>] [-units <units>] [-ucd <ucd>] [-desc <descrip>]
        <colid-list>
```

Modifies the metadata of one or more columns. Some or all of the name, units, ucd and description of the column(s), identified by <colid-list> can be set by using some or all of the listed flags. Typically, <colid-list> will simply be the name of a single column.

Syntax for the <colid-list> argument is described in Section 5.3.

5.1.9 `delcols`

Usage:

```
delcols <colid-list>
```

Delete the specified columns. The same column may harmlessly be specified more than once.

Syntax for the <colid-list> argument is described in Section 5.3.

5.1.10 `every`

Usage:

```
every <step>
```

Include only every <step>'th row in the result, starting with the first row.

5.1.11 `explodeall`

Usage:

```
explodeall [-ifndim <ndim>] [-ifshape <dims>]
```

Replaces any columns which is an N-element arrays with N scalar columns. Only columns with fixed array sizes are affected. The action can be restricted to only columns of a certain shape using the flags.

If the `-ifndim` flag is used, then only columns of dimensionality <ndim> will be exploded. <ndim> may be 1, 2, ...

If the `-ifshape` flag is used, then only columns with a specific shape will be exploded; <dims> is a space- or comma-separated list of dimension extents, with the most rapidly-varying first, e.g. '`2 5`' to explode all 2 x 5 element array columns.

5.1.12 `explodecols`

Usage:

```
explodecols <colid-list>
```

Takes a list of specified columns which represent N-element arrays and replaces each one with N scalar columns. Each of the columns specified by `<colid-list>` must have a fixed-length array type, though not all the arrays need to have the same number of elements.

Syntax for the `<colid-list>` argument is described in Section 5.3.

5.1.13 `head`

Usage:

```
head <nrows>
```

Include only the first `<nrows>` rows of the table. If the table has fewer than `<nrows>` rows then it will be unchanged.

5.1.14 `keepcols`

Usage:

```
keepcols <colid-list>
```

Select the columns from the input table which will be included in the output table. The output table will include only those columns listed in `<colid-list>`, in that order. The same column may be listed more than once, in which case it will appear in the output table more than once.

Syntax for the `<colid-list>` argument is described in Section 5.3.

5.1.15 `meta`

Usage:

```
meta [<item> ...]
```

Provides information about the metadata for each column. This filter turns the table sideways, so that each row of the output corresponds to a column of the input. The columns of the output table contain metadata items such as column name, units, UCD etc corresponding to each column of the input table.

By default the output table contains columns for the following items:

- `Index`: Position of column in table
- `Name`: Column name
- `Class`: Data type of objects in column
- `Shape`: Shape of array values
- `Units`: Unit string
- `Description`: Description of data in the column
- `UCD`: Unified Content Descriptor

as well as any table-specific column metadata items that the table contains.

However, the output may be customised by supplying one or more `<item>` headings. These may be selected from the above as well as the following:

- `UCD_desc`: Textual description of UCD

as well as any table-specific metadata. It is not an error to specify an item for which no metadata exists in any of the columns (such entries will result in empty columns).

Any table parameters of the input table are propagated to the output one.

5.1.16 `progress`

Usage:

```
progress
```

Monitors progress by displaying the number of rows processed so far on the terminal (standard error). This number is updated every second or thereabouts; if all the processing is done in under a second you may not see any output. If the total number of rows in the table is known, an ASCII-art progress bar is updated, otherwise just the number of rows seen so far is written.

5.1.17 `random`

Usage:

```
random
```

Ensures that steps downstream see the table as random access. Only useful for debugging.

5.1.18 `replacecol`

Usage:

```
replacecol [-name <name>] [-units <units>] [-ucd <ucd>] [-desc <descrip>]
           <col-id> <expr>
```

Replaces the content of a column with the value of an algebraic expression. The old values are discarded in favour of the result of evaluating `<expr>`. You can specify the metadata for the new column using the `-name`, `-units`, `-ucd` and `-desc` flags; for any of these items which you do not specify, they will take the values from the column being replaced.

It is legal to reference the replaced column in the expression, so for example "`replacecol pixsize pixsize*2`" just multiplies the values in column `pixsize` by 2.

Syntax for the `<col-id>` and `<expr>` arguments is described in the manual.

5.1.19 `replaceval`

Usage:

```
replaceval <old-val> <new-val> <colid-list>
```

For each column specified in `<colid-list>` any instance of `<old-val>` is replaced by `<new-val>`. The value string '`null`' can be used for either `<old-value>` or `<new-value>` to indicate a blank value (but see also the `badval` filter).

Syntax for the `<colid-list>` argument is described in Section 5.3.

5.1.20 `select`

Usage:

```
select <expr>
```

Include in the output table only rows for which the expression `<expr>` evaluates to true. `<expr>` must be an expression which evaluates to a boolean value (true/false).

Syntax for the `<expr>` argument is described in Section 7.

5.1.21 `sequential`

Usage:

```
sequential
```

Ensures that steps downstream see the table as sequential access. Only useful for debugging.

5.1.22 `setparam`

Usage:

```
setparam [-type byte|short|int|long|float|double|boolean|string]
         [-desc <descrip>] [-unit <units>] [-ucd <ucd>]
         <pname> <pval>
```

Sets a named parameter in the table to a given value. The parameter named `<pname>` is set to the value `<pval>`. By default the type of the parameter is determined automatically (if it looks like an integer it's an integer etc) but this can be overridden using the `-type` flag. The parameter description may be set using the `-desc` flag.

5.1.23 `sort`

Usage:

```
sort [-down] [-nullsfirst] <key-list>
```

Sorts the table according to the value of one or more algebraic expressions. The sort key expressions appear, as separate (space-separated) words, in `<key-list>`; sorting is done on the first expression first, but if that results in a tie then the second one is used, and so on.

Each expression must evaluate to a type that it makes sense to sort, for instance numeric. If the `-down` flag is used, the sort order is descending rather than ascending.

Blank entries are by default considered to come at the end of the collation sequence, but if the `-nullsfirst` flag is given then they are considered to come at the start instead.

Syntax for the `<key-list>` argument is described in Section 7.

5.1.24 `sorthead`

Usage:

```
sorthead [-tail] [-down] [-nullsfirst] <nrows> <key-list>
```

Performs a sort on the table according to the value of one or more algebraic expressions, retaining only `<nrows>` rows at the head of the resulting sorted table. The sort key expressions appear, as separate (space-separated) words, in `<key-list>`; sorting is done on the first expression first, but if that results in a tie then the second one is used, and so on. Each expression must evaluate to a type

that it makes sense to sort, for instance numeric.

If the `-tail` flag is used, then the last `<nrows>` rows rather than the first ones are retained.

If the `-down` flag is used the sort order is descending rather than ascending.

Blank entries are by default considered to come at the end of the collation sequence, but if the `-nullsfirst` flag is given then they are considered to come at the start instead.

This filter is functionally equivalent to using `sort` followed by `head`, but it can be done in one pass and is usually cheaper on memory and faster, as long as `<nrows>` is significantly lower than the size of the table.

Syntax for the `<key-list>` argument is described in Section 7.

5.1.25 `stats`

Usage:

```
stats [<item> ...]
```

Calculates statistics on the data in the table. This filter turns the table sideways, so that each row of the output corresponds to a column of the input. The columns of the output table contain statistical items such as mean, standard deviation etc corresponding to each column of the input table.

By default the output table contains columns for the following items:

- `Name`: Column name
- `Mean`: Average
- `StDev`: Population Standard deviation
- `Minimum`: Numeric minimum
- `Maximum`: Numeric maximum
- `NGood`: Number of non-blank cells

However, the output may be customised by supplying one or more `<item>` headings. These may be selected from the above as well as the following:

- `NBad`: Number of blank cells
- `Variance`: Population Variance
- `SampStDev`: Sample Standard Deviation
- `SampVariance`: Sample Variance
- `Skew`: Gamma 1 skewness measure
- `Kurtosis`: Gamma 2 peakedness measure
- `Sum`: Sum of values
- `MinPos`: Row index of numeric minimum
- `MaxPos`: Row index of numeric maximum
- `Cardinality`: Number of distinct values in column; values >100 ignored
- `Median`: Middle value in sequence
- `Quartile1`: First quartile
- `Quartile2`: Second quartile
- `Quartile3`: Third quartile

Additionally, the form "Q.*nn*" may be used to represent the quantile corresponding to the proportion 0.*nn*, e.g.:

- `Q.25`: First quartile
- `Q.625`: Fifth octile

Any parameters of the input table are propagated to the output one.

Note that quantile calculations (including median and quartiles) can be expensive on memory. If you want to calculate quantiles for large tables, it may be wise to reduce the number of columns to only those you need the quantiles for earlier in the pipeline. No interpolation is performed when calculating quantiles.

5.1.26 `tablename`

Usage:

```
tablename <name>
```

Sets the table's name attribute to the given string.

5.1.27 `tail`

Usage:

```
tail <nrows>
```

Include only the last `<nrows>` rows of the table. If the table has fewer than `<nrows>` rows then it will be unchanged.

5.1.28 `transpose`

Usage:

```
transpose [-namecol <col-id>]
```

Transposes the input table so that columns become rows and vice versa. The `-namecol` flag can be used to specify a column in the input table which will provide the column names for the output table. The first column of the output table will contain the column names of the input table.

Syntax for the `<col-id>` argument is described in Section 5.2.

5.1.29 `uniq`

Usage:

```
uniq [-count] [<colid-list>]
```

Eliminates adjacent rows which have the same values. If used with no arguments, then any row which has identical values to its predecessor is removed.

If the `<colid-list>` parameter is given then only the values in the specified columns must be equal in order for the row to be removed.

If the `-count` flag is given, then an additional column with the name DupCount will be prepended to the table giving a count of the number of duplicated input rows represented by each output row. A unique row has a DupCount value of 1.

Syntax for the `<colid-list>` argument is described in Section 5.3.

5.2 Specifying a single column

If an argument is specified in the help text for a command with the symbol `<col-id>` it means you must give a string which identifies one of the existing columns in a table.

There are three ways you can specify a column in this context:

Column Name
The name of the column may be used if it contains no spaces and doesn't start with a minus character ('-'). It is usually matched case insensitively. If multiple columns have the same name, the first one that matches is selected.

Column Index or $ID
The index of the column may always be used; this is a useful fallback if the column name isn't suitable for some reason. The first column is '1', the second is '2' and so on. You may alternatively use the forms '$1', '$2' etc.

Tip: if counting which column has which index is giving you a headache, running `tpipe` with `omode=meta` or `omode=stats` on the table may help.

Column ucd$ specifier
If the column has a Unified Content Descriptor (this will usually only be the case for VOTable or possibly FITS format tables) you can refer to it using an identifier of the form "`ucd$<ucd-spec>`". Depending on the version of UCD scheme used, UCDs can contain various punctuation marks such as underscores, semicolons and dots; for the purpose of this syntax these should all be represented as underscores ("_"). So to identify a column which has the UCD "`phot.mag;em.opt.R`", you should use the identifier "`ucd$phot_mag_em_opt_r`". Matching is not case-sensitive. Futhermore, a trailing underscore acts as a wildcard, so that the above column could also be referenced using the identifier "`ucd$phot_mag_`". If multiple columns have UCDs which match the given identifer, the first one will be used.

5.3 Specifying a list of columns

If an argument is specified in the help text for a command with the symbol `<colid-list>` it means you must give a string which identifies a list of zero, one or more of the existing columns in a table. The string you specify is a separated into separate tokens by whitespace, which means that you will normally have to surround it in single or double quotes to ensure that it is treated as a single argument and not several of them.

Each token in the `<colid-list>` string may be one of the following:

Column Name
The name of a column may be used if it contains no spaces and doesn't start with a minus character ('-'). It is usually matched case insensitively. If multiple columns have the same name, the first one that matches is selected.

Column Index or $ID
The index of the column may always be used; this is a useful fallback if the column name isn't suitable for some reason. The first column is '1', the second is '2' and so on. You may alternatively use the forms '$1', '$2' etc.

Tip: if counting which column has which index is giving you a headache, running `tpipe` with `omode=meta` or `omode=stats` on the table may help.

Wildcard Expression
You can use a simple form of wildcard expression which expands to any columns in the table whose names match the pattern. Currently, the only special character is an asterisk '`*`' which matches any sequence of characters. To match an unknown sequence at the start or end of the string an asterisk must be given explicitly. Other than that, matching is usually case insensitive. The order of the expanded list is the same as the order in which the columns

appear in the table.

Thus "col*" will match columns named col1, Column2 and COL_1024, but not decOld. "*MAG*" will match columns named magnitude, ABS_MAG_U and JMAG. "*" on its own expands to a list of all the columns of the table in order.

Specifying a list which contains a given column more than once is not usually an error, but what effect it has depends on the function you are executing.

5.4 Output Modes

This section lists the output modes which can be used as the value of the omode parameter of tpipe and other commands. Typically, having produced a result table by pipeline processing an input one, you will write it out by specifying omode=out (or not using the omode parameter at all - out is the default). However, you can do other things such as calculate statistics, display metadata, etc. In some of these cases, additional parameters are required. The different output modes, with their associated parameters, are described in the following subsections.

5.4.1 cgi

Usage:

```
omode=cgi ofmt=<out-format>
```

Writes a table to standard output in a way suitable for use as output from a CGI (Common Gateway Interface) program. This is very much like out mode but a short CGI header giving the MIME Content-Type is prepended to the output

Additional parameters for this output mode are:

ofmt = <out-format>
Specifies the format in which the output table will be written (one of the ones in Section 4.2.2 - matching is case-insensitive and you can use just the first few letters).

[Default: votable]

5.4.2 count

Usage:

```
omode=count
```

Counts the number of rows and columns and writes the result to standard output.

5.4.3 discard

Usage:

```
omode=discard
```

Reads all the data in the table in sequential mode and discards it. May be useful in conjunction with the assert filter.

5.4.4 meta

Usage:

```
omode=meta
```

Prints the table metadata to standard output. The name and type etc of each column is tabulated, and table parameters are also shown.

See the `meta` filter for more flexible output of table metadata.

5.4.5 `out`

Usage:

```
omode=out out=<out-table> ofmt=<out-format>
```

Writes a new table.

Additional parameters for this output mode are:

`out = <out-table>`
The location of the output table. This is usually a filename to write to. If it is equal to the special value "-" (the default) the output table will be written to standard output.

[Default: -]

`ofmt = <out-format>`
Specifies the format in which the output table will be written (one of the ones in Section 4.2.2 - matching is case-insensitive and you can use just the first few letters). If it has the special value "`(auto)`" (the default), then the output filename will be examined to try to guess what sort of file is required usually by looking at the extension. If it's not obvious from the filename what output format is intended, an error will result.

[Default: `(auto)`]

5.4.6 `plastic`

Usage:

```
omode=plastic transport=string|file client=<app-name>
```

Broadcasts the table to any registered Plastic-aware applications. PLASTIC, the PLatform for AStronomical Tool InterConnection, is a tool interoperability protocol. A *Plastic hub* must be running in order for this to work.

Additional parameters for this output mode are:

`transport = string|file`
Determines the method (PLASTIC *message*) used to perform the PLASTIC communication. The choices are

- `string`: VOTable serialized as a string and passed as a call parameter (`ivo://votech.org/votable/load`). Not suitable for very large files.
- `file`: VOTable written to a temporary file and the filename passed as a call parameter (`ivo://votech.org/votable/loadFromURL`). The file ought to be deleted once it has been loaded. Not suitable for inter-machine communication.

If no value is set (`null`) then a decision will be taken based on the apparent size of the table.

`client = <app-name>`

Gives the name of a PLASTIC listener application which is to receive the broadcast table. If a non-null value is given, then only the first registered application which reports its application name as that value will receive the message. If no value is supplied, the broadcast will be to all listening applications.

5.4.7 `stats`

Usage:

```
omode=stats
```

Calculates and displays univariate statistics for each of the numeric columns in the table. The following entries are shown for each column as appropriate:

- mean
- population standard deviation
- minimum
- maximum
- number of non-null entries

See the `stats` filter for more flexible statistical calculations.

5.4.8 `topcat`

Usage:

```
omode=topcat
```

Displays the output table directly in TOPCAT. If a TOPCAT instance (version 1.6 or later) is already running on the local host, the table will be opened in that, otherwise a new TOPCAT instance will be launched for display. The latter mode only works if the TOPCAT classes are on the class path.

A variety of mechanisms (e.g. PLASTIC and SOAP) are attempted to transfer the table, depending on what running instances of TOPCAT can be found. Depending on the transport mechanism used, there may be limits to the size of table which can be transmitted to the application in this way.

5.4.9 `tosql`

Usage:

```
omode=tosql protocol=<jdbc-protocol> host=<value> database=<db-name>
            newtable=<table-name> user=<username> password=<passwd>
```

Writes a new table to an SQL database. You need the appropriate JDBC drivers and `-Djdcb.drivers` set as usual (see Section 3.4).

Additional parameters for this output mode are:

`protocol = <jdbc-protocol>`
The driver-specific sub-protocol specifier for the JDBC connection. For MySQL's Connector/J driver, this is `mysql`, and for PostgreSQL's driver it is `postgres`. For other drivers, you may have to consult the driver documentation.

`host = <value>`
The host which is acting as a database server.

[Default: `localhost`]

`database = <db-name>`
The name of the database on the server into which the new table will be written.

`newtable = <table-name>`
The name of the new table which will be written to the database. If a table by this name already exists, it may be overwritten.

`user = <username>`
User name for the SQL connection to the database.

[Default: `mbt`]

`password = <passwd>`
Password for the SQL connection to the database.

6 Crossmatching

STILTS offers flexible and efficient facilities for crossmatching tables. Crossmatching is identifying different rows, which may be in the same or different tables, that refer to the same item. In an astronomical context such an item is usually, though not necessarily, an astronomical source or object. This operation corresponds to what in database terminology is called a *join*.

There are various complexities to specifying such a match. In the first place you have to define what is the condition that must be satisfied for two rows to be considered matching. In the second place you must decide what happens if, for a given row, more than one match can be found. Finally, you have to decide what to do having worked out what the matched rows are; the result will generally be presented as a new output table, but there are various choices about what columns and rows it will consist of. Some of these issues are discussed in this section, and others in the reference sections on the tools themselves in Appendix A.

Matching can in general be a computationally intensive process. The algorithm used by STILTS, except in pathological cases, scales as *O(N log(N))* or thereabouts, where *N* is the total number of rows in all the tables being matched. No preparation (such as sorting) is required on the tables prior to invoking the matching operation. It is reasonably fast; for instance an RA, Dec positional match of two 10^5-row catalogues takes of the order of 60 seconds on current (2005 laptop) hardware. Attempting matches with large tables can lead to running out of memory; the calculation just mentioned required a java heap size of around 200Mb (`-Xmx200M`).

In the current release of STILTS the only crossmatching task is `tmatch2` which finds matches between pairs of tables. In future versions however facilities for finding matches within the same table, and in more than two tables, will be introduced.

6.1 Match Criteria

Determining whether one row represents the same item as another is done by comparing the values in certain of their columns to see if they are the same or similar. The most common astronomical case is to say that two rows match if their celestial coordinates (right ascension and declination) are within a given small radius of each other on the sky. There are other possibilities; for instance the coordinates to compare may be in a Cartesian space, or have a higher (or lower) dimensionality than two, or the match may be exact rather than within an error radius....

To determine the matching criteria, you set the values of the following parameters of `tmatch2`:

`matcher`
: Name of the match criteria type.

`params`
: Fixed value(s) giving the parameters of the match (typically an error radius). If more than one value is required, the values should be separated by spaces.

`values*`
: Expressions to be compared between rows. This will typically contain the names of one or more columns, but each element may be an algebraic expression (see Section 7) rather than just a column name if required. If more than one value is required, the values should be separated by spaces. There is one of these parameters for each table taking part in the match, so for `tmatch2` you must specify both `values1` and `values2`.

For example, suppose we wish to locate objects in two tables which are within 3 arcseconds of each other on the sky. One table has columns RA and DEC which give coordinates in degrees, and the other has columns RArad and DECrad which give coordinates in radians. These are the arguments

which would be used to tell `tmatch2` what the match criteria are:

```
matcher=sky
params=3
values1='RA DEC'
values2='radiansToDegrees(RArad) radiansToDegrees(DECrad)'
```

It is clearly important that corresponding values are comparable (in the same units) between the tables being matched, and in geometrically sensitive cases such as matching on the sky, it's important that they are the units expected by the matcher as well. To determine what those units are, either consult the roster below, or run the following command:

```
stilts tmatch2 help=matcher
```

which will tell you about all the known matchers and their associated `params` and `values*` parameters.

Here is a list of all the basic `matcher` types and the requirements of their associated `params` and `values*` parameters. The units of the required values are given where significant.

`matcher=sky values*='<ra/degrees> <dec/degrees>' params='<max-error/arcsec>'`

Comparison of positions on the celestial sphere with a fixed error radius. Rows are considred to match when the two `ra`, `dec` positions are within `max-error` arcseconds of each other along a great circle.

`matcher=skyerr values*='<ra/degrees> <dec/degrees> <error/arcsec>' params='<max-error/arcsec>'`

Comparison of positions on the celestial sphere with per-row error radii. Rows are considered to match when the separation between the two `ra`, `dec` positions is smaller than *both* the fixed `max-error` value *and* the sum of the two per-row `error` values. If either of the `error` values is blank, then any separation up to `max-error` is considered a match. According to these rules, you might decide to set `max-error` to an arbitarily large number so that only the sum of `errors` will determine the actual match criteria. However please *don't* do this, since `max-error` also functions as a tuning parameter for the matching algorithm, and ought to be reasonably close to the actual maximum acceptable separation.

`matcher=sky3d values*='<ra/degrees> <dec/degrees> <distance>' params='<error/Units of distance>'`

Comparison of positions in the sky taking account of distance from the observer. The position in three-dimensional space is calculated for each row using the `ra`, `dec` and `distance` as spherical polar coordinates, where `distance` is the distance from the observer along the line of sight. Rows are considered to match when their positions in this space are within `error` units of each other. The units of `error` are the same as those of `distance`.

`matcher=exact values*='<matched-value>'`

Comparison of arbitrary key values for exact equality. Rows are considered to match only if the values in their `matched-value` columns are exactly the same. These values can be strings, numbers, or anything else. A blank value never matches, not even with another blank one. Since the `params` parameter holds no values, it does not have to be specified.

`matcher=1d values*='<x>' params='<error>'`

Comparison of positions in 1-dimensional Cartesian space. Rows are considered to match if their `x` column values differ by no more than `error`.

`matcher=2d values*='<x> <y>' params='<error>'`

Comparison of positions in 2-dimensional Cartesian space. Rows are considered to match if the difference in their (`x`,`y`) positions reckoned using Pythagoras is less than `error`.

matcher=Nd values*='<x> <y> ...'
params='<error>'

Comparison of positions in N-dimensional Cartesian space. As for `matcher=2d`, but specify `matcher=3d` or whatever and the corresponding number of entries in the `values*` parameters.

matcher=2d_anisotropic values*='<x> <y>'
params='<error-in-x> <error-in-y>'

Comparison of positions in 2-dimensional Cartesian space using an anisotropic metric. Rows are considered to match if their (`x`,`y`) positions fall within an error ellipse with radii `error-in-x`,`error-in-y` of each other. This kind of match will typically be used for non-'spatial' spaces, for instance (magnitude,redshift) space, in which the metrics along different axes are not related to each other.

matcher=Nd_anisotropic values*='<x> <y> ...'
params='<error-in-x> <error-in-y> ...'

Comparison of positions in N-dimensional Cartesian space using an anisotropic metric. As `matcher=2d_anisotropic`, but specify `matcher=3d_anisotropic` or whatever and the corresponding number of entries in the `values*` and `params` parameters.

In addition to those matching criteria listed above, you can build your own by combining any of these. To do this, take the two (or more) matchers that you want to use, and separate their names with a "+" character. The `values*` parameters of the combined matcher should then hold the concatenation of the `values*` entries of the constituent matchers, and the same for the `params` parameter. So for instance the following can be used:

matcher=sky+1d values*='<ra/degrees> <dec/degrees> <x>'
params='<max-error/arcsec> <error>'

Comparison of positions on the sky with an additional scalar constraint. Rows are considered to match if *both* their `ra`, `dec` positions are within `max-error` arcseconds of each other along a great circle (as for `matcher=sky`) *and* their `x` values differ by no more than `error` (as for `matcher=1d`).

This example might be used for instance to identify objects from two catalogues which are within a couple of arcseconds and also 0.5 blue magnitudes of each other. Rolling your own matchers in this way can give you very flexible match constraints.

7 Algebraic Expression Syntax

The `tpipe` command allows you to use algebraic expressions when making row selections and defining new synthetic columns. They can also be used in defining the quantities to match against in `tmatch2`. In both cases you are defining an expression which has a value in each row as a function of the values in the existing columns in that row. This is a powerful feature which permits you to manipulate and select table data in very flexible ways. The syntax for entering these expressions is explained in this section.

What you write are actually expressions in the Java language, which are compiled into Java bytecode before evaluation. However, this does not mean that you need to be a Java programmer to write them. The syntax is pretty similar to C, but even if you've never programmed in C most simple things, and many complicated ones, are quite intutitive.

The following explanation gives some guidance and examples for writing these expressions. Unfortunately a complete tutorial on writing Java is beyond the scope of this document, but it should provide enough information for even a novice to write useful expressions.

The expressions that you can write are basically any function of all the column values which apply to a given row; the function result can then be used in one of `tpipe`'s commands, e.g. to define the per-row value of a new column (`addcol`, `replacecol`) make a row selection (`select`), and some other places. If the built-in operators and functions are not sufficient, or it's unwieldy to express your function in one line of code, it is possible to add new functions by writing your own classes - see Section 7.7.3.

Note that since these algebraic expressions often contain spaces, you may need to enclose them in single or double quotes so that they don't get confused with other parts of the command string.

Note: if Java is running in an environment with certain security restrictions (a security manager which does not permit creation of custom class loaders) then algebraic expressions won't work at all. It's not particularly likely that security restrictions will be in place if you are running from the command line though.

7.1 Referencing Column Values

To create a useful expression which can be evaluated for each row in a table, you will have to refer to cells in different columns of that row. You can do this in three ways:

By Name
The Name of the column may be used if it is unique (no other column in the table has the same name) and if it has a suitable form. This means that it must have the form of a Java variable - basically starting with a letter and continuing with letters or numbers. In particular it cannot have any spaces in it. The underscore and currency symbols count as letters for this purpose. Column names are treated case-insensitively.

By $ID
The "$ID" identifier of the column may always be used to refer to it; this is a useful fallback if the column name isn't suitable for some reason (for instance it contains spaces or is not unique). This is just a "$" sign followed by the column index - the first column is $1.

By ucd$ specifier
If the column has a Unified Content Descriptor (this will usually only be the case for VOTable or possibly FITS format tables) you can refer to it using an identifier of the form "`ucd$<ucd-spec>`". Depending on the version of UCD scheme used, UCDs can contain various punctuation marks such as underscores, semicolons and dots; for the purpose of this syntax these should all be represented as underscores ("_"). So to identify a column which has the

UCD "phot.mag;em.opt.R", you should use the identifier "ucd$phot_mag_em_opt_r". Matching is not case-sensitive. Futhermore, a trailing underscore acts as a wildcard, so that the above column could also be referenced using the identifier "ucd$phot_mag_". If multiple columns have UCDs which match the given identifer, the first one will be used.

Note that the same syntax can be used for referencing table parameters (see the next section); columns take preference so if a column and a parameter both match the requested UCD, the column value will be used.

There is a special column whose name is "Index" and whose ID is "$0". The value of this is the same as the row number (the first row is 1).

The value of the variables so referenced will be a primitive (boolean, byte, short, char, int, long, float, double) if the column contains one of the corresponding types. Otherwise it will be an Object of the type held by the column, for instance a String. In practice this means: you can write the name of a column, and it will evaluate to the numeric (or string) value that that column contains in each row. You can then use this in normal algebraic expressions such as "B_MAG-U_MAG" as you'd expect.

7.2 Referencing Parameter Values

Some tables have constant values associated with them; these may represent such things as the epoch at which observations were taken, the name of the catalogue, an angular resolution associated with all observations, or any number of other things. Such constants are known as *table parameters* (not to be confused with parameters passed to STILTS commands) and can be thought of as extra columns which have the same value for every row. The values of such parameters can be referenced in STILTS algebraic expressions as follows:

param$*name*
: If the parameter name has a suitable form (starting with a letter and continuing with letters or numbers) it can be referenced by prefixing that name with the string param$.

ucd$*ucd-spec*
: If the column has a Unified Content Descriptor it can be referenced by prefixing the UCD specifier with the string ucd$. Any punctuation marks in the UCD should be replaced by underscores, and a trailing underscore is interpreted as a wildcard. See Section 7.1 for more discussion.

Note that if a parameter has a name in an unsuitable form (e.g. containing spaces) and has no UCD then it cannot be referenced in an expression.

7.3 Null Values

When no special steps are taken, if a null value (blank cell) is encountered in evaluating an expression (usually because one of the columns it relies on has a null value in the row in question) then the result of the expression is also null.

It is possible to exercise more control than this, but it requires a little bit of care, because the expressions work in terms of primitive values (numeric or boolean ones) which don't in general have a defined null value. The name "null" in expressions gives you the java null reference, but this cannot be matched against a primitive value or used as the return value of a primitive expression.

For most purposes, the following two tips should enable you to work with null values:

Testing for null
: To test whether a column contains a null value, prepend the string "NULL_" (use upper case) to

the column name or $ID. This will yield a boolean value which is true if the column contains a blank, and false otherwise.

Returning null

To return a null value from a numeric expression, use the name "`NULL`" (upper case). To return a null value from a non-numeric expression (e.g. a String column) use the name "`null`" (lower case).

Null values are often used in conjunction with the conditional operator, "`? :`"; the expression

```
test ? tval : fval
```

returns the value `tval` if the boolean expression `test` evaluates true, or `fval` if `test` evaluates false. So for instance the following expression:

```
Vmag == -99 ? NULL : Vmag
```

can be used to define a new column which has the same value as the `Vmag` column for most values, but if `Vmag` has the "magic" value -99 the new column will contain a blank. The opposite trick (substituting a blank value with a magic one) can be done like this:

```
NULL_Vmag ? -99 : Vmag
```

Some more examples are given in Section 7.6.

7.4 Operators

The operators are pretty much the same as in the C language. The common ones are:

Arithmetic

`+` (add)
`-` (subtract)
`*` (multiply)
`/` (divide)
`%` (modulus)

Boolean

`!` (not)
`&&` (and)
`||` (or)
`^` (exclusive-or)
`==` (numeric identity)
`!=` (numeric non-identity)
`<` (less than)
`>` (greater than)
`<=` (less than or equal)
`>=` (greater than or equal)

Numeric Typecasts

`(byte)` (numeric -> signed byte)
`(short)` (numeric -> 2-byte integer)
`(int)` (numeric -> 4-byte integer)
`(long)` (numeric -> 8-byte integer)
`(float)` (numeric -> 4-type floating point)
`(double)` (numeric -> 8-byte floating point)

Note you may find the Maths (Section 7.5.6) conversion functions more convenient for numeric conversions than these.

Other

`+` (string concatenation)
`[]` (array dereferencing)
`?:` (conditional switch)
`instanceof` (class membership)

7.5 Functions

Many functions are available for use within your expressions, covering standard mathematical and trigonometric functions, arithmetic utility functions, type conversions, and some more specialised astronomical ones. You can use them in just the way you'd expect, by using the function name (unlike column names, this is case-sensitive) followed by comma-separated arguments in brackets, so

```
max(IMAG,JMAG)
```

will give you the larger of the values in the columns IMAG and JMAG, and so on.

The functions available for use by default are listed by class in the following subsections with their arguments and short descriptions. The `funcs` command provides another way to browse these function descriptions online.

7.5.1 Coords

Functions for angle transformations and manipulations. In particular, methods for translating between radians and HH:MM:SS.S or DDD:MM:SS.S type sexagesimal representations are provided.

`DEGREE`
The size of one degree in radians.

`HOUR`
The size of one hour of right ascension in radians.

`ARC_MINUTE`
The size of one arcminute in radians.

`ARC_SECOND`
The size of one arcsecond in radians.

`radiansToDms( rad )`
Converts an angle in radians to a formatted degrees:minutes:seconds string. No fractional part of the seconds field is given.

- `rad` *(floating point)*: angle in radians
- return value *(String)*: DMS-format string representing `rad`

`radiansToDms( rad, secFig )`
Converts an angle in radians to a formatted degrees:minutes:seconds string with a given number of decimal places in the seconds field.

- `rad` *(floating point)*: angle in radians
- `secFig` *(integer)*: number of decimal places in the seconds field
- return value *(String)*: HMS-format string representing `rad`

radiansToHms(rad)
Converts an angle in radians to a formatted hours:minutes:seconds string. No fractional part of the seconds field is given.

- `rad` *(floating point)*: angle in radians
- return value *(String)*: HMS-format string representing `rad`

radiansToHms(rad, secFig)
Converts an angle in radians to a formatted hours:minutes:seconds string with a given number of decimal places in the seconds field.

- `rad` *(floating point)*: angle in radians
- `secFig` *(integer)*: number of decimal places in the seconds field
- return value *(String)*: HMS-format string representing `rad`

dmsToRadians(dms)
Converts a formatted degrees:minutes:seconds string to an angle in radians. Delimiters may be colon, space, characters `dm[s]`, or some others. Additional spaces and leading +/- are permitted.

- `dms` *(String)*: formatted DMS string
- return value *(floating point)*: angle in radians specified by `dms`

hmsToRadians(hms)
Converts a formatted hours:minutes:seconds string to an angle in radians. Delimiters may be colon, space, characters `hm[s]`, or some others. Additional spaces and leading +/- are permitted.

- `hms` *(String)*: formatted HMS string
- return value *(floating point)*: angle in radians specified by `hms`

dmsToRadians(deg, min, sec)
Converts degrees, minutes, seconds to an angle in radians.

In conversions of this type, one has to be careful to get the sign right in converting angles which are between 0 and -1 degrees. This routine uses the sign bit of the `deg` argument, taking care to distinguish between +0 and -0 (their internal representations are different for floating point values). It is illegal for the `min` or `sec` arguments to be negative.

- `deg` *(floating point)*: degrees part of angle
- `min` *(floating point)*: minutes part of angle
- `sec` *(floating point)*: seconds part of angle
- return value *(floating point)*: specified angle in radians

hmsToRadians(hour, min, sec)
Converts hours, minutes, seconds to an angle in radians.

In conversions of this type, one has to be careful to get the sign right in converting angles which are between 0 and -1 hours. This routine uses the sign bit of the `hour` argument, taking care to distinguish between +0 and -0 (their internal representations are different for floating point values).

- `hour` *(floating point)*: degrees part of angle
- `min` *(floating point)*: minutes part of angle
- `sec` *(floating point)*: seconds part of angle
- return value *(floating point)*: specified angle in radians

skyDistance(ra1, dec1, ra2, dec2)
Calculates the separation (distance around a great circle) of two points on the sky.

- `ra1` *(floating point)*: right ascension of point 1 in radians
- `dec1` *(floating point)*: declination of point 1 in radians
- `ra2` *(floating point)*: right ascension of point 2 in radians
- `dec2` *(floating point)*: declination of point 2 in radians
- return value *(floating point)*: angular distance between point 1 and point 2 in radians

`skyDistanceDegrees( ra1, dec1, ra2, dec2 )`
Calculates the separation (distance around a great circle) of two points on the sky in degrees.

- `ra1` *(floating point)*: right ascension of point 1 in degrees
- `dec1` *(floating point)*: declination of point 1 in degrees
- `ra2` *(floating point)*: right ascension of point 2 in degrees
- `dec2` *(floating point)*: declination of point 2 in degrees
- return value *(floating point)*: angular distance between point 1 and point 2 in degrees

`hoursToRadians( hours )`
Converts hours to radians.

- `hours` *(floating point)*: angle in hours
- return value *(floating point)*: angle in radians

`degreesToRadians( deg )`
Converts degrees to radians.

- `deg` *(floating point)*: angle in degrees
- return value *(floating point)*: angle in radians

`radiansToDegrees( rad )`
Converts radians to degrees.

- `rad` *(floating point)*: angle in radians
- return value *(floating point)*: angle in degrees

`raFK4toFK5( raFK4, decFK4 )`
Converts a B1950.0 FK4 position to J2000.0 FK5 at an epoch of B1950.0 yielding Right Ascension. This assumes zero proper motion in the FK5 frame.

- `raFK4` *(floating point)*: right ascension in B1950.0 FK4 system (radians)
- `decFK4` *(floating point)*: declination in B1950.0 FK4 system (radians)
- return value *(floating point)*: right ascension in J2000.0 FK5 system (radians)

`decFK4toFK5( raFK4, decFK4 )`
Converts a B1950.0 FK4 position to J2000.0 FK5 at an epoch of B1950.0 yielding Declination This assumes zero proper motion in the FK5 frame.

- `raFK4` *(floating point)*: right ascension in B1950.0 FK4 system (radians)
- `decFK4` *(floating point)*: declination in B1950.0 FK4 system (radians)
- return value *(floating point)*: declination in J2000.0 FK5 system (radians)

`raFK5toFK4( raFK5, decFK5 )`
Converts a J2000.0 FK5 position to B1950.0 FK4 at an epoch of B1950.0 yielding Declination. This assumes zero proper motion, parallax and radial velocity in the FK5 frame.

- `raFK5` *(floating point)*: right ascension in J2000.0 FK5 system (radians)
- `decFK5` *(floating point)*: declination in J2000.0 FK5 system (radians)
- return value *(floating point)*: right ascension in the FK4 system (radians)

`decFK5toFK4( raFK5, decFK5 )`
Converts a J2000.0 FK5 position to B1950.0 FK4 at an epoch of B1950.0 yielding Declination. This assumes zero proper motion, parallax and radial velocity in the FK5 frame.

- `raFK5` *(floating point)*: right ascension in J2000.0 FK5 system (radians)
- `decFK5` *(floating point)*: declination in J2000.0 FK5 system (radians)
- return value *(floating point)*: right ascension in the FK4 system (radians)

`raFK4toFK5( raFK4, decFK4, bepoch )`
Converts a B1950.0 FK4 position to J2000.0 FK5 yielding Right Ascension. This assumes zero proper motion in the FK5 frame. The `bepoch` parameter is the epoch at which the position in the FK4 frame was determined.

- `raFK4` *(floating point)*: right ascension in B1950.0 FK4 system (radians)
- `decFK4` *(floating point)*: declination in B1950.0 FK4 system (radians)
- `bepoch` *(floating point)*: Besselian epoch
- return value *(floating point)*: right ascension in J2000.0 FK5 system (radians)

`decFK4toFK5( raFK4, decFK4, bepoch )`
Converts a B1950.0 FK4 position to J2000.0 FK5 yielding Declination. This assumes zero proper motion in the FK5 frame. The `bepoch` parameter is the epoch at which the position in the FK4 frame was determined.

- `raFK4` *(floating point)*: right ascension in B1950.0 FK4 system (radians)
- `decFK4` *(floating point)*: declination in B1950.0 FK4 system (radians)
- `bepoch` *(floating point)*: Besselian epoch
- return value *(floating point)*: declination in J2000.0 FK5 system (radians)

`raFK5toFK4( raFK5, decFK5, bepoch )`
Converts a J2000.0 FK5 position to B1950.0 FK4 yielding Declination. This assumes zero proper motion, parallax and radial velocity in the FK5 frame.

- `raFK5` *(floating point)*: right ascension in J2000.0 FK5 system (radians)
- `decFK5` *(floating point)*: declination in J2000.0 FK5 system (radians)
- `bepoch` *(floating point)*: Besselian epoch
- return value *(floating point)*: right ascension in the FK4 system (radians)

`decFK5toFK4( raFK5, decFK5, bepoch )`
Converts a J2000.0 FK5 position to B1950.0 FK4 yielding Declination. This assumes zero proper motion, parallax and radial velocity in the FK5 frame.

- `raFK5` *(floating point)*: right ascension in J2000.0 FK5 system (radians)
- `decFK5` *(floating point)*: declination in J2000.0 FK5 system (radians)
- `bepoch` *(floating point)*: Besselian epoch
- return value *(floating point)*: right ascension in the FK4 system (radians)

7.5.2 Arithmetic

Standard arithmetic functions including things like rounding, sign manipulation, and maximum/minimum functions.

`roundUp( x )`
Rounds a value up to an integer value. Formally, returns the smallest (closest to negative infinity) integer value that is not less than the argument.

- `x` *(floating point)*: a value.
- return value *(integer)*: `x` rounded up

`roundDown( x )`
Rounds a value down to an integer value. Formally, returns the largest (closest to positive

infinity) integer value that is not greater than the argument.

- `x` *(floating point)*: a value
- return value *(integer)*: `x` rounded down

`round( x )`

Rounds a value to the nearest integer. Formally, returns the integer that is closest in value to the argument. If two integers are equally close, the result is the even one.

- `x` *(floating point)*: a floating point value.
- return value *(integer)*: `x` rounded to the nearest integer

`roundDecimal( x, dp )`

Rounds a value to a given number of decimal places. The result is a `float` (32-bit floating point value), so this is only suitable for relatively low-precision values. It's intended for truncating the number of apparent significant figures represented by a value which you know has been obtained by combining other values of limited precision. For more control, see the functions in the `Formats` class.

- `x` *(floating point)*: a floating point value
- `dp` *(integer)*: number of decimal places (digits after the decimal point) to retain
- return value *(floating point)*: floating point value close to `x` but with a limited apparent precision

`abs( x )`

Returns the absolute value of an integer value. If the argument is not negative, the argument is returned. If the argument is negative, the negation of the argument is returned.

- `x` *(integer)*: the argument whose absolute value is to be determined
- return value *(integer)*: the absolute value of the argument.

`abs( x )`

Returns the absolute value of a floating point value. If the argument is not negative, the argument is returned. If the argument is negative, the negation of the argument is returned.

- `x` *(floating point)*: the argument whose absolute value is to be determined
- return value *(floating point)*: the absolute value of the argument.

`max( a, b )`

Returns the greater of two integer values. If the arguments have the same value, the result is that same value.

- `a` *(integer)*: an argument.
- `b` *(integer)*: another argument.
- return value *(integer)*: the larger of `a` and `b`.

`max( a, b )`

Returns the greater of two floating point values. If the arguments have the same value, the result is that same value. If either value is blank, then the result is blank.

- `a` *(floating point)*: an argument.
- `b` *(floating point)*: another argument.
- return value *(floating point)*: the larger of `a` and `b`.

`min( a, b )`

Returns the smaller of two integer values. If the arguments have the same value, the result is that same value.

- `a` *(integer)*: an argument.
- `b` *(integer)*: another argument.

- return value *(integer)*: the smaller of `a` and `b`.

`min( a, b )`
Returns the smaller of two floating point values. If the arguments have the same value, the result is that same value. If either value is blank, then the result is blank.

- `a` *(floating point)*: an argument.
- `b` *(floating point)*: another argument.
- return value *(floating point)*: the smaller of `a` and `b`.

7.5.3 Fluxes

Functions for conversion between flux and magnitude values. Functions are provided for conversion between flux in Janskys and AB magnitudes.

Some constants for approximate conversions between different magnitude scales are also provided:

- Constants `JOHNSON_AB_*`, for Johnson <-> AB magnitude conversions (http://www.astro.utoronto.ca/~patton/astro/mags.html (http://www.astro.utoronto.ca/~patton/astro/mags.html), citing Frei and Gunn 1995).
- Constants `VEGA_AB_*`, for Vega <-> AB magnitude conversions (Blanton et al., Astronomical Journal *127*, 2562-2578 (2005), eqs.(5)).

`JOHNSON_AB_V`
Approximate offset between Johnson and AB magnitudes in V band. $V_J \sim = V_{AB} + $`JOHNSON_AB_V`.

`JOHNSON_AB_B`
Approximate offset between Johnson and AB magnitudes in B band. $B_J \sim = B_{AB} + $`JOHNSON_AB_B`.

`JOHNSON_AB_Bj`
Approximate offset between Johnson and AB magnitudes in Bj band. $Bj_J \sim = Bj_{AB} + $`JOHNSON_AB_Bj`.

`JOHNSON_AB_R`
Approximate offset between Johnson and AB magnitudes in R band. $R_J \sim = R_{AB} + $`JOHNSON_AB_R`.

`JOHNSON_AB_I`
Approximate offset between Johnson and AB magnitudes in I band. $I_J \sim = I_{AB} + $`JOHNSON_AB_I`.

`JOHNSON_AB_g`
Approximate offset between Johnson and AB magnitudes in g band. $g_J \sim = g_{AB} + $`JOHNSON_AB_g`.

`JOHNSON_AB_r`
Approximate offset between Johnson and AB magnitudes in r band. $r_J \sim = r_{AB} + $`JOHNSON_AB_r`.

`JOHNSON_AB_i`
Approximate offset between Johnson and AB magnitudes in i band. $i_J \sim = i_{AB} + $`JOHNSON_AB_i`.

`JOHNSON_AB_Rc`
Approximate offset between Johnson and AB magnitudes in Rc band. $Rc_J \sim = Rc_{AB} + $`JOHNSON_AB_Rc`.

`JOHNSON_AB_Ic`
Approximate offset between Johnson and AB magnitudes in Ic band. $Ic_J \sim = Ic_{AB} + $`JOHNSON_AB_Ic`.

`JOHNSON_AB_uPrime`
Offset between Johnson and AB magnitudes in u' band (zero). $u'_J = u'_{AB} + $`JOHNSON_AB_uPrime` $= u'_{AB}$.

`JOHNSON_AB_gPrime`
Offset between Johnson and AB magnitudes in g' band (zero). $g'_J = g'_{AB} + $`JOHNSON_AB_gPrime` $= g'_{AB}$.

`JOHNSON_AB_rPrime`
Offset between Johnson and AB magnitudes in r' band (zero). $r'_J = r'_{AB} + $`JOHNSON_AB_rPrime` $= r'_{AB}$.

`JOHNSON_AB_iPrime`
Offset between Johnson and AB magnitudes in i' band (zero). $i'_J = i'_{AB} + $`JOHNSON_AB_iPrime` $= i'_{AB}$.

`JOHNSON_AB_zPrime`
Offset between Johnson and AB magnitudes in z' band (zero). $z'_J = z'_{AB} + $`JOHNSON_AB_zPrime` $= z'_{AB}$.

`VEGA_AB_J`
Approximate offset between Vega (as in 2MASS) and AB magnitudes in J band. $J_{Vega} \sim = J_{AB} + $`VEGA_AB_J`.

`VEGA_AB_H`
Approximate offset between Vega (as in 2MASS) and AB magnitudes in H band. $H_{Vega} \sim = H_{AB} + $`VEGA_AB_H`.

`VEGA_AB_K`
Approximate offset between Vega (as in 2MASS) and AB magnitudes in K band. $K_{Vega} \sim = K_{AB} + $`VEGA_AB_K`.

`abToJansky( magAB )`
Converts AB magnitude to flux in Jansky.

$F/Jy = 10^{(23-(AB+48.6)/2.5)}$

- `magAB` *(floating point)*: AB magnitude value
- return value *(floating point)*: equivalent flux in Jansky

`janskyToAb( fluxJansky )`
Converts flux in Jansky to AB magnitude.

$AB = 2.5*(23-\log_{10}(F/Jy))-48.6$

- `fluxJansky` *(floating point)*: flux in Jansky

- return value *(floating point)*: equivalent AB magnitude

`luminosityToFlux( lumin, dist )`
Converts luminosity to flux given a luminosity distance.

F=lumin/(4 x Pi x dist^2)

- `lumin` *(floating point)*: luminosity
- `dist` *(floating point)*: luminosity distance
- return value *(floating point)*: equivalent flux

`fluxToLuminosity( flux, dist )`
Converts flux to luminosity given a luminosity distance.

lumin=(4 x Pi x dist^2) F

- `flux` *(floating point)*: flux
- `dist` *(floating point)*: luminosity distance
- return value *(floating point)*: equivalent luminosity

7.5.4 Strings

String manipulation and query functions.

`concat( s1, s2 )`
Concatenates two strings. In most cases the same effect can be achieved by writing `s1+s2`, but blank values can sometimes appear as the string "`null`" if you do it like that.

- `s1` *(String)*: first string
- `s2` *(String)*: second string
- return value *(String)*: `s1` followed by `s2`

`concat( s1, s2, s3 )`
Concatenates three strings. In most cases the same effect can be achieved by writing `s1+s2+s3`, but blank values can sometimes appear as the string "`null`" if you do it like that.

- `s1` *(String)*: first string
- `s2` *(String)*: second string
- `s3` *(String)*: third string
- return value *(String)*: `s1` followed by `s2` followed by `s3`

`concat( s1, s2, s3, s4 )`
Concatenates four strings. In most cases the same effect can be achieved by writing `s1+s2+s3+s4`, but blank values can sometimes appear as the string "`null`" if you do it like that.

- `s1` *(String)*: first string
- `s2` *(String)*: second string
- `s3` *(String)*: third string
- `s4` *(String)*: fourth string
- return value *(String)*: `s1` followed by `s2` followed by `s3` followed by `s4`

`equals( s1, s2 )`
Determines whether two strings are equal. Note you should use this function instead of `s1==s2`, which can (for technical reasons) return false even if the strings are the same.

- `s1` *(String)*: first string
- `s2` *(String)*: second string
- return value *(boolean)*: true if s1 and s2 are both blank, or have the same content

`equalsIgnoreCase( s1, s2 )`
Determines whether two strings are equal apart from possible upper/lower case distinctions.

- `s1` *(String)*: first string
- `s2` *(String)*: second string
- return value *(boolean)*: true if s1 and s2 are both blank, or have the same content apart from case folding

`startsWith( whole, start )`
Determines whether a string starts with a certain substring.

- `whole` *(String)*: the string to test
- `start` *(String)*: the sequence that may appear at the start of `whole`
- return value *(boolean)*: true if the first few characters of `whole` are the same as `start`

`endsWith( whole, end )`
Determines whether a string ends with a certain substring.

- `whole` *(String)*: the string to test
- `end` *(String)*: the sequence that may appear at the end of `whole`
- return value *(boolean)*: true if the last few characters of `whole` are the same as `end`

`contains( whole, sub )`
Determines whether a string contains a given substring.

- `whole` *(String)*: the string to test
- `sub` *(String)*: the sequence that may appear within `whole`
- return value *(boolean)*: true if the sequence `sub` appears within `whole`

`length( str )`
Returns the length of a string in characters.

- `str` *(String)*: string
- return value *(integer)*: number of characters in `str`

`matches( str, regex )`
Tests whether a string matches a given regular expression.

- `str` *(String)*: string to test
- `regex` *(String)*: regular expression string
- return value *(boolean)*: true if `regex` matches `str` anywhere

`matchGroup( str, regex )`
Returns the first grouped expression matched in a string defined by a regular expression. A grouped expression is one enclosed in parentheses.

- `str` *(String)*: string to match against
- `regex` *(String)*: regular expression containing a grouped section
- return value *(String)*: contents of the matched group (or null, if `regex` didn't match `str`)

`replaceFirst( str, regex, replacement )`
Replaces the first occurrence of a regular expression in a string with a different substring value.

- `str` *(String)*: string to manipulate
- `regex` *(String)*: regular expression to match in `str`
- `replacement` *(String)*: replacement string
- return value *(String)*: same as `str`, but with the first match (if any) of `regex` replaced by `replacement`

`replaceAll( str, regex, replacement )`
Replaces all occurrences of a regular expression in a string with a different substring value.

- `str` *(String)*: string to manipulate
- `regex` *(String)*: regular expression to match in `str`
- `replacement` *(String)*: replacement string
- return value *(String)*: same as `str`, but with all matches of `regex` replaced by `replacement`

`substring( str, startIndex )`
Returns the last part of a given string. The substring begins with the character at the specified index and extends to the end of this string.

- `str` *(String)*: the input string
- `startIndex` *(integer)*: the beginning index, inclusive
- return value *(String)*: last part of `str`, omitting the first `startIndex` characters

`substring( str, startIndex, endIndex )`
Returns a substring of a given string. The substring begins with the character at `startIndex` and continues to the character at index `endIndex-1` Thus the length of the substring is `endIndex-startIndex`.

- `str` *(String)*: the input string
- `startIndex` *(integer)*: the beginning index, inclusive
- `endIndex` *(integer)*: the end index, inclusive
- return value *(String)*: substring of `str`

`toUpperCase( str )`
Returns an uppercased version of a string.

- `str` *(String)*: input string
- return value *(String)*: uppercased version of `str`

`toLowerCase( str )`
Returns an uppercased version of a string.

- `str` *(String)*: input string
- return value *(String)*: uppercased version of `str`

`trim( str )`
Trims whitespace from both ends of a string.

- `str` *(String)*: input string
- return value *(String)*: str with any spaces trimmed from start and finish

`padWithZeros( value, ndigit )`
Takes an integer argument and returns a string representing the same numeric value but padded with leading zeros to a specified length.

- `value` *(long integer)*: numeric value to pad
- `ndigit` *(integer)*: the number of digits in the resulting string
- return value *(String)*: a string evaluating to the same as `value` with at least `ndigit` characters

7.5.5 Formats

Functions for formatting numeric values.

formatDecimal(value, dp)
Turns a floating point value into a string with a given number of decimal places using standard settings.

- `value` *(floating point)*: value to format
- `dp` *(integer)*: number of decimal places (digits after the decmal point)
- return value *(String)*: formatted string

formatDecimalLocal(value, dp)
Turns a floating point value into a string using current locale settings. For instance if language is set to French, decimal points will be represented as a comma "," instead of a full stop ".". Otherwise behaves the same as the corresponding `formatDecimal` function.

- `value` *(floating point)*: value to format
- `dp` *(integer)*: number of decimal places (digits after the decmal point)
- return value *(String)*: formatted string

formatDecimal(value, format)
Turns a floating point value into a formatted string using standard settings. The `format` string is as defined by Java's `java.text.DecimalFormat` (http://java.sun.com/j2se/1.4.2/docs/api/java/text/DecimalFormat.html) class.

- `value` *(floating point)*: value to format
- `format` *(String)*: format specifier
- return value *(String)*: formatted string

formatDecimalLocal(value, format)
Turns a floating point value into a formatted string using current locale settings. For instance if language is set to French, decimal points will be represented as a comma "," instead of a full stop ".". Otherwise behaves the same as the corresponding `formatDecimal` function.

- `value` *(floating point)*: value to format
- `format` *(String)*: format specifier
- return value *(String)*: formatted string

7.5.6 Maths

Standard mathematical and trigonometric functions.

E
Euler's number *e*, the base of natural logarithms.

PI
Pi, the ratio of the circumference of a circle to its diameter.

RANDOM
Evaluates to a random number in the range 0<=x<1. This is different for each cell of the table. The quality of the randomness may not be particularly good.

sin(theta)
Sine of an angle.

- `theta` *(floating point)*: an angle, in radians.
- return value *(floating point)*: the sine of the argument.

cos(theta)
Cosine of an angle.

- `theta` *(floating point)*: an angle, in radians.
- return value *(floating point)*: the cosine of the argument.

tan(theta)
Tangent of an angle.

- `theta` *(floating point)*: an angle, in radians.
- return value *(floating point)*: the tangent of the argument.

asin(x)
Arc sine of an angle. The result is in the range of -*pi*/2 through *pi*/2.

- `x` *(floating point)*: the value whose arc sine is to be returned.
- return value *(floating point)*: the arc sine of the argument (radians)

acos(x)
Arc cosine of an angle. The result is in the range of 0.0 through *pi*.

- `x` *(floating point)*: the value whose arc cosine is to be returned.
- return value *(floating point)*: the arc cosine of the argument (radians)

atan(x)
Arc tangent of an angle. The result is in the range of -*pi*/2 through *pi*/2.

- `x` *(floating point)*: the value whose arc tangent is to be returned.
- return value *(floating point)*: the arc tangent of the argument (radians)

exp(x)
Euler's number *e* raised to a power.

- `x` *(floating point)*: the exponent to raise *e* to.
- return value *(floating point)*: the value e^{x}, where *e* is the base of the natural logarithms.

log10(x)
Logarithm to base 10.

- `x` *(floating point)*: argument
- return value *(floating point)*: $\log_{10}(x)$

ln(x)
Natural logarithm.

- `x` *(floating point)*: argument
- return value *(floating point)*: $\log_{e}(x)$

sqrt(x)
Square root. The result is correctly rounded and positive.

- `x` *(floating point)*: a value.
- return value *(floating point)*: the positive square root of `x`. If the argument is NaN or less than zero, the result is NaN.

atan2(y, x)
Converts rectangular coordinates (`x`,`y`) to polar (`r`,`theta`). This method computes the phase `theta` by computing an arc tangent of `y/x` in the range of -*pi* to *pi*.

- `y` *(floating point)*: the ordinate coordinate
- `x` *(floating point)*: the abscissa coordinate

- return value *(floating point)*: the `theta` component (radians) of the point (`r`,`theta`) in polar coordinates that corresponds to the point (`x`,`y`) in Cartesian coordinates.

`pow( a, b )`
Exponentiation. The result is the value of the first argument raised to the power of the second argument.

- `a` *(floating point)*: the base.
- `b` *(floating point)*: the exponent.
- return value *(floating point)*: the value a^b .

`sinh( x )`
Hyperbolic sine.

- `x` *(floating point)*: parameter
- return value *(floating point)*: result

`cosh( x )`
Hyperbolic cosine.

- `x` *(floating point)*: parameter
- return value *(floating point)*: result

`tanh( x )`
Hyperbolic tangent.

- `x` *(floating point)*: parameter
- return value *(floating point)*: result

`asinh( x )`
Inverse hyperbolic sine.

- `x` *(floating point)*: parameter
- return value *(floating point)*: result

`acosh( x )`
Inverse hyperbolic cosine.

- `x` *(floating point)*: parameter
- return value *(floating point)*: result

`atanh( x )`
Inverse hyperbolic tangent.

- `x` *(floating point)*: parameter
- return value *(floating point)*: result

7.5.7 Times

Functions for conversion of time values between various forms. The forms used are

Modified Julian Date (MJD)
A continuous measure in days since midnight at the start of 17 November 1858. Based on UTC.

ISO 8601
A string representation of the form `yyyy-mm-ddThh:mm:ss.s`, where the `T` is a literal character (a space character may be used instead). Based on UTC.

Julian Epoch

A continuous measure based on a Julian year of exactly 365.25 days. For approximate purposes this resembles the fractional number of years AD represented by the date. Sometimes (but not here) represented by prefixing a 'J'; J2000.0 is defined as 2000 January 1.5 in the TT timescale.

Besselian Epoch
A continuous measure based on a tropical year of about 365.2422 days. For approximate purposes this resembles the fractional number of years AD represented by the date. Sometimes (but not here) represented by prefixing a 'B'.

Decimal Year
Fractional number of years AD represented by the date. 2000.0, or equivalently 1999.99recurring, is midnight at the start of the first of January 2000. Because of leap years, the size of a unit depends on what year it is in.

Therefore midday on the 25th of October 2004 is `2004-10-25T12:00:00` in ISO 8601 format, 53303.5 as an MJD value, 2004.81588 as a Julian Epoch and 2004.81726 as a Besselian Epoch.

Currently this implementation cannot be relied upon to better than a millisecond.

`isoToMjd( isoDate )`
Converts an ISO8601 date string to Modified Julian Date. The basic format of the `isoDate` argument is `yyyy-mm-ddThh:mm:ss.s`, though some deviations from this form are permitted:

- The '`T`' which separates date from time can be replaced by a space
- The seconds, minutes and/or hours can be omitted
- The decimal part of the seconds can be any length, and is optional
- A '`Z`' (which indicates UTC) may be appended to the time

Some legal examples are therefore: "`1994-12-21T14:18:23.2`", "`1968-01-14`", and "`2112-05-25 16:45Z`".

- `isoDate` *(String)*: date in ISO 8601 format
- return value *(floating point)*: modified Julian date corresponding to `isoDate`

`dateToMjd( year, month, day, hour, min, sec )`
Converts a calendar date and time to Modified Julian Date.

- `year` *(integer)*: year AD
- `month` *(integer)*: index of month; January is 1, December is 12
- `day` *(integer)*: day of month (the first day is 1)
- `hour` *(integer)*: hour (0-23)
- `min` *(integer)*: minute (0-59)
- `sec` *(floating point)*: second (0<=sec<60)
- return value *(floating point)*: modified Julian date corresponding to arguments

`dateToMjd( year, month, day )`
Converts a calendar date to Modified Julian Date.

- `year` *(integer)*: year AD
- `month` *(integer)*: index of month; January is 1, December is 12
- `day` *(integer)*: day of month (the first day is 1)
- return value *(floating point)*: modified Julian date corresponding to 00:00:00 of the date specified by the arguments

`decYearToMjd( decYear )`
Converts a Decimal Year to a Modified Julian Date.

- `decYear` *(floating point)*: decimal year

- return value *(floating point)*: modified Julian Date

`mjdToIso( mjd )`
Converts a Modified Julian Date value to an ISO 8601-format date-time string. The output format is `yyyy-mm-ddThh:mm:ss`.

- `mjd` *(floating point)*: modified Julian date
- return value *(String)*: ISO 8601 format date corresponding to `mjd`

`mjdToDate( mjd )`
Converts a Modified Julian Date value to an ISO 8601-format date string. The output format is `yyyy-mm-dd`.

- `mjd` *(floating point)*: modified Julian date
- return value *(String)*: ISO 8601 format date corresponding to `mjd`

`mjdToTime( mjd )`
Converts a Modified Julian Date value to an ISO 8601-format time-only string. The output format is `hh:mm:ss`.

- `mjd` *(floating point)*: modified Julian date
- return value *(String)*: ISO 8601 format time corresponding to `mjd`

`mjdToDecYear( mjd )`
Converts a Modified Julian Date to Decimal Year.

- `mjd` *(floating point)*: modified Julian Date
- return value *(floating point)*: decimal year

`formatMjd( mjd, format )`
Converts a Modified Julian Date value to a date using a customisable date format. The format is as defined by the `java.text.SimpleDateFormat` (http://java.sun.com/j2se/1.4.2/docs/api/java/text/SimpleDateFormat.html) class. The default output corresponds to the string "`yyyy-MM-dd'T'HH:mm:ss`"

- `mjd` *(floating point)*: modified Julian date
- `format` *(String)*: formatting patttern
- return value *(String)*: custom formatted time corresponding to `mjd`

`mjdToJulian( mjd )`
Converts a Modified Julian Date to Julian Epoch. For approximate purposes, the result of this routine consists of an integral part which gives the year AD and a fractional part which represents the distance through that year, so that for instance 2000.5 is approximately 1 July 2000.

- `mjd` *(floating point)*: modified Julian date
- return value *(floating point)*: Julian epoch

`julianToMjd( julianEpoch )`
Converts a Julian Epoch to Modified Julian Date. For approximate purposes, the argument of this routine consists of an integral part which gives the year AD and a fractional part which represents the distance through that year, so that for instance 2000.5 is approximately 1 July 2000.

- `julianEpoch` *(floating point)*: Julian epoch
- return value *(floating point)*: modified Julian date

`mjdToBesselian( mjd )`
Converts Modified Julian Date to Besselian Epoch. For approximate purposes, the result of this routine consists of an integral part which gives the year AD and a fractional part which

represents the distance through that year, so that for instance 1950.5 is approximately 1 July 1950.

- `mjd` *(floating point)*: modified Julian date
- return value *(floating point)*: Besselian epoch

`besselianToMjd( besselianEpoch )`
Converts Besselian Epoch to Modified Julian Date. For approximate purposes, the argument of this routine consists of an integral part which gives the year AD and a fractional part which represents the distance through that year, so that for instance 1950.5 is approximately 1 July 1950.

- `besselianEpoch` *(floating point)*: Besselian epoch
- return value *(floating point)*: modified Julian date

`unixMillisToMjd( unixMillis )`
Converts from milliseconds since the Unix epoch (1970-01-01T00:00:00) to a modified Julian date value

- `unixMillis` *(long integer)*: milliseconds since the Unix epoch
- return value *(floating point)*: modified Julian date

`mjdToUnixMillis( mjd )`
Converts from modified Julian date to milliseconds since the Unix epoch (1970-01-01T00:00:00).

- `mjd` *(floating point)*: modified Julian date
- return value *(long integer)*: milliseconds since the Unix epoch

7.5.8 Distances

Functions for converting between different measures of cosmological distance.

The following parameters are used:

- **z**: redshift
- **H0**: Hubble constant in km/sec/Mpc (example value ~70)
- **omegaM**: Density ratio of the universe (example value 0.3)
- **omegaLambda**: Normalised cosmological constant (example value 0.7)

For a flat universe, `omegaM+omegaLambda=1`

The terms and formulae used here are taken from the paper by D.W.Hogg, *Distance measures in cosmology*, astro-ph/9905116 (http://arxiv.org/abs/astro-ph/9905116) v4 (2000).

`SPEED_OF_LIGHT`
Speed of light in m/s.

`METRE_PER_PARSEC`
Number of metres in a parsec.

`SEC_PER_YEAR`
Number of seconds in a year.

`MpcToM( distMpc )`

Converts from MegaParsecs to metres.

- `distMpc` *(floating point)*: distance in Mpc
- return value *(floating point)*: distance in m

`mToMpc( distM )`

Converts from metres to MegaParsecs.

- `distM` *(floating point)*: distance in m
- return value *(floating point)*: distance in Mpc

`zToDist( z )`

Quick and dirty function for converting from redshift to distance.

Warning: this makes some reasonable assumptions about the cosmology and returns the luminosity distance. It is only intended for approximate use. If you care about the details, use one of the more specific functions here.

- `z` *(floating point)*: redshift
- return value *(floating point)*: some distance measure in Mpc

`zToAge( z )`

Quick and dirty function for converting from redshift to time.

Warning: this makes some reasonable assumptions about the cosmology. It is only intended for approximate use. If you care about the details use one of the more specific functions here.

- `z` *(floating point)*: redshift
- return value *(floating point)*: 'age' of photons from redshift `z` in Gyr

`comovingDistanceL( z, H0, omegaM, omegaLambda )`

Line-of-sight comoving distance.

- `z` *(floating point)*: redshift
- `H0` *(floating point)*: Hubble constant in km/sec/Mpc
- `omegaM` *(floating point)*: density ratio of the universe
- `omegaLambda` *(floating point)*: normalised cosmological constant
- return value *(floating point)*: line-of-sight comoving distance in Mpc

`comovingDistanceT( z, H0, omegaM, omegaLambda )`

Transverse comoving distance.

- `z` *(floating point)*: redshift
- `H0` *(floating point)*: Hubble constant in km/sec/Mpc
- `omegaM` *(floating point)*: density ratio of the universe
- `omegaLambda` *(floating point)*: normalised cosmological constant
- return value *(floating point)*: transverse comoving distance in Mpc

`angularDiameterDistance( z, H0, omegaM, omegaLambda )`

Angular diameter distance.

- `z` *(floating point)*: redshift
- `H0` *(floating point)*: Hubble constant in km/sec/Mpc
- `omegaM` *(floating point)*: density ratio of the universe
- `omegaLambda` *(floating point)*: normalised cosmological constant
- return value *(floating point)*: angular diameter distance in Mpc

`luminosityDistance( z, H0, omegaM, omegaLambda )`

Luminosity distance.

- `z` *(floating point)*: redshift

- `H0` *(floating point)*: Hubble constant in km/sec/Mpc
- `omegaM` *(floating point)*: density ratio of the universe
- `omegaLambda` *(floating point)*: normalised cosmological constant
- return value *(floating point)*: luminosity distance in Mpc

`lookbackTime( z, H0, omegaM, omegaLambda )`
Lookback time. This returns the difference between the age of the universe at time of observation (now) and the age of the universe at the time when photons of redshift `z` were emitted.

- `z` *(floating point)*: redshift
- `H0` *(floating point)*: Hubble constant in km/sec/Mpc
- `omegaM` *(floating point)*: density ratio of the universe
- `omegaLambda` *(floating point)*: normalised cosmological constant
- return value *(floating point)*: lookback time in Gyr

`comovingVolume( z, H0, omegaM, omegaLambda )`
Comoving volume. This returns the all-sky total comoving volume out to a given redshift `z`.

- `z` *(floating point)*: redshift
- `H0` *(floating point)*: Hubble constant in km/sec/Mpc
- `omegaM` *(floating point)*: density ratio of the universe
- `omegaLambda` *(floating point)*: normalised cosmological constant
- return value *(floating point)*: comoving volume in Gpc^3

7.5.9 Conversions

Functions for converting between strings and numeric values.

`toString( value )`
Turns a numeric value into a string.

- `value` *(floating point)*: numeric value
- return value *(String)*: a string representation of `value`

`parseByte( str )`
Attempts to interpret a string as a byte (8-bit signed integer) value. If the input string can't be interpreted in this way, a blank value will result.

- `str` *(String)*: string containing numeric representation
- return value *(byte)*: byte value of `str`

`parseShort( str )`
Attempts to interpret a string as a short (16-bit signed integer) value. If the input string can't be interpreted in this way, a blank value will result.

- `str` *(String)*: string containing numeric representation
- return value *(short integer)*: byte value of `str`

`parseInt( str )`
Attempts to interpret a string as an int (32-bit signed integer) value. If the input string can't be interpreted in this way, a blank value will result.

- `str` *(String)*: string containing numeric representation
- return value *(integer)*: byte value of `str`

`parseLong( str )`

Attempts to interpret a string as a long (64-bit signed integer) value. If the input string can't be interpreted in this way, a blank value will result.

- `str` *(String)*: string containing numeric representation
- return value *(long integer)*: byte value of `str`

`parseFloat( str )`
Attempts to interpret a string as a float (32-bit floating point) value. If the input string can't be interpreted in this way, a blank value will result.

- `str` *(String)*: string containing numeric representation
- return value *(floating point)*: byte value of `str`

`parseDouble( str )`
Attempts to interpret a string as a double (64-bit signed integer) value. If the input string can't be interpreted in this way, a blank value will result.

- `str` *(String)*: string containing numeric representation
- return value *(floating point)*: byte value of `str`

`toByte( value )`
Attempts to convert the numeric argument to a byte (8-bit signed integer) result. If it is out of range, a blank value will result.

- `value` *(floating point)*: numeric value for conversion
- return value *(byte)*: `value` converted to type byte

`toShort( value )`
Attempts to convert the numeric argument to a short (16-bit signed integer) result. If it is out of range, a blank value will result.

- `value` *(floating point)*: numeric value for conversion
- return value *(short integer)*: `value` converted to type short

`toInteger( value )`
Attempts to convert the numeric argument to an int (32-bit signed integer) result. If it is out of range, a blank value will result.

- `value` *(floating point)*: numeric value for conversion
- return value *(integer)*: `value` converted to type int

`toLong( value )`
Attempts to convert the numeric argument to a long (64-bit signed integer) result. If it is out of range, a blank value will result.

- `value` *(floating point)*: numeric value for conversion
- return value *(long integer)*: `value` converted to type long

`toFloat( value )`
Attempts to convert the numeric argument to a float (32-bit floating point) result. If it is out of range, a blank value will result.

- `value` *(floating point)*: numeric value for conversion
- return value *(floating point)*: `value` converted to type float

`toDouble( value )`
Converts the numeric argument to a double (64-bit signed integer) result.

- `value` *(floating point)*: numeric value for conversion
- return value *(floating point)*: `value` converted to type double

`toHex( value )`
Converts the integer argument to hexadecimal form.

- `value` *(long integer)*: integer value
- return value *(String)*: hexadecimal representation of `value`

`fromHex( hexVal )`
Converts a string representing a hexadecimal number to its integer value.

- `hexVal` *(String)*: hexadecimal representation of value
- return value *(integer)*: integer value represented by `hexVal`

7.6 Examples

Here are some examples for defining new columns; the expressions below could appear as the `<expr>` in a `tpipe addcol` or `sortexpr` command).

Average

```
(first + second) * 0.5
```

Square root

```
sqrt(variance)
```

Angle conversion

```
radiansToDegrees(DEC_radians)
degreesToRadians(RA_degrees)
```

Conversion from string to number

```
parseInt($12)
parseDouble(ident)
```

Conversion from number to string

```
toString(index)
```

Conversion between numeric types

```
toShort(obs_type)
toDouble(range)
```

or

```
(short) obs_type
(double) range
```

Conversion from sexagesimal to radians

```
hmsToRadians(RA1950)
dmsToRadians(decDeg,decMin,decSec)
```

Conversion from radians to sexagesimal

```
radiansToDms($3)
radiansToHms(RA,2)
```

Outlier clipping

```
min(1000, max(value, 0))
```

Converting a magic value to null

```
jmag == 9999 ? NULL : jmag
```

Converting a null value to a magic one

```
NULL_jmag ? 9999 : jmag
```

Taking the third scalar element from an array-valued column

```
psfCounts[2]
```

and here are some examples of boolean expressions that could be used for row selection (appearing in a `tpipe select` command)

Within a numeric range

```
RA > 100 && RA < 120 && Dec > 75 && Dec < 85
```

Within a circle

```
$2*$2 + $3*$3 < 1
skyDistance(ra0,dec0,degreesToRadians(RA),degreesToRadians(DEC))<15*ARC_MINUTE
```

First 100 rows

```
index <= 100
```

(though you could use `tpipe cmd='head 100'` instead)

Every tenth row

```
index % 10 == 0
```

(though you could use `tpipe cmd='every 10'` instead)

String equality/matching

```
equals(SECTOR, "ZZ9 Plural Z Alpha")
equalsIgnoreCase(SECTOR, "zz9 plural z alpha")
startsWith(SECTOR, "ZZ")
contains(ph_qual, "U")
```

String regular expression matching

```
matches(SECTOR, "[XYZ] Alpha")
```

Test for non-blank value

```
! NULL_ellipticity
```

7.7 Advanced Topics

This section contains some notes on getting the most out of the algebraic expressions facility. If you're not a Java programmer, some of the following may be a bit daunting - read on at your own risk!

7.7.1 Expression evaluation

This note provides a bit more detail for Java programmers on what is going on here; it describes how the use of functions in STILTS algebraic expressions relates to normal Java code.

The expressions which you write are compiled to Java bytecode when you enter them (if there is a 'compilation error' it will be reported straight away). The functions listed in the previous subsections are all the `public static` methods of the classes which are made available by default. The classes listed are all in the package `uk.ac.starlink.ttools.func`. However, the public static methods are all imported into an anonymous namespace for bytecode compilation, so that you write (`sqrt(x,y)` and not `Maths.sqrt(x,y)`. The same happens to other classes that are imported (which can be in any package or none) - their public static methods all go into the anonymous namespace. Thus, method name clashes are a possibility.

This cleverness is all made possible by the rather wonderful JEL (http://galaxy.fzu.cz/JEL/).

7.7.2 Instance Methods

There is another category of functions which can be used apart from those listed in Section 7.5. These are called, in Java/object-oriented parlance, "instance methods" and represent functions that can be executed on an object.

It is possible to invoke any of its public instance methods on any object (though not on primitive values - numeric and boolean ones). The syntax is that you place a "." followed by the method invocation after the object you want to invoke the method on, hence `NAME.substring(3)` instead of `substring(NAME,3)`. If you know what you're doing, feel free to go ahead and do this. However, most of the instance methods you're likely to want to use have equivalents in the normal functions listed in the previous section, so unless you're a Java programmer or feeling adventurous, you may be best off ignoring this feature.

7.7.3 Adding User-Defined Functions

The functions provided by default for use with algebraic expressions, while powerful, may not provide all the operations you need. For this reason, it is possible to write your own extensions to the expression language. In this way you can specify abritrarily complicated functions. Note however that this will only allow you to define new columns or subsets where each cell is a function only of the other cells in the same row - it will not allow values in one row to be functions of values in another.

In order to do this, you have to write and compile a (probably short) program in the Java language. A full discussion of how to go about this is beyond the scope of this document, so if you are new to Java and/or programming you may need to find a friendly local programmer to assist (or mail the author). The following explanation is aimed at Java programmers, but may not be incomprehensible to non-specialists.

The steps you need to follow are:

1. Write and compile a class containing one or more static public methods representing the function(s) required
2. Make this class available on the application's classpath at runtime as described in Section 3.1
3. Specify the class's name to the application, as the value of the `jel.classes` system property (colon-separated if there are several) as described in Section 3.3

Any public static methods defined in the classes thus specified will then be available for use. They should be defined to take and return the relevant primitive or Object types for the function required. For instance a class written as follows would define a three-value average:

```
public class AuxFuncs {
    public static double average3( double x, double y, double z ) {
        return ( x + y + z ) / 3.0;
    }
}
```

and the command

```
stilts tpipe cmd='addcol AVERAGE "average3($1,$2,$3)"'
```

would add a new column named AVERAGE giving the average of the first three existing columns. Exactly how you would build this is dependent on your system, but it might involve doing something like the following:

1. Writing a file named `AuxFuncs.java` containing the above code
2. Compiling it using a command like "`javac AuxFuncs.java`"

3. Running `tpipe` using the flags "`stilts -classpath . -Djel.classes=AuxFuncs tpipe`"

A Command Reference

This appendix provides the reference documentation for the commands in the package. For each one a description of its purpose, a list of its command-line arguments, and some examples are given.

A.1 `calc`: Evaluates expressions

`calc` is a very simple utility for evaluating expressions. It uses the same expression evaluator as is used in `tpipe` and the other generic table tasks for things like creating new columns, so it can be used as a quick test to see what expressions work, or in order to evaluate expressions using the various algebraic functions documented in Section 7.5. Since usually no table is involved, you can't refer to column names in the expressions. It has one mandatory parameter, the expression to evaluate, and writes the result to the screen.

A.1.1 Usage

The usage of `calc` is

```
stilts <stilts-flags> calc table=<table>
                           [expression=]<expr>
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`expression = <expr>`
An expression to evaluate. The functions in Section 7.5 can be used.

`table = <table>`
A table which provides the context within which `expression` is evaluated. This parameter is optional, and will usually not be required; its only purpose is to allow use of constant expressions (table parameters) associated with the table. These can be referenced using identifiers of the form `param$*` or `ucd$*` - see Section 7.2 for more detail.

A.1.2 Examples

Here are some examples of using `calc`:

`stilts calc 1+2`
Calculates one plus two. Writes "3" to standard output.

`stilts calc 'isoToMjd("2005-12-25T00:00:00")'`
Works out the Modified Julian Day corresponding to Christmas 2005. The output is "53729.0".

`stilts calc 'param$author' table=catalogue.xml`
In this case the expression is evaluated in the context of the supplied table, which means that the table's parameters can be referenced in the expression. This example just outputs the value of the table parameter named "author".

A.2 `funcs`: Browse functions used by algebraic expression langauage

`funcs` is a utility which allows you to browse the functions you can use in STILTS's algebraic expression language. Invoking the command causes a window to pop up on the display with two parts. The left hand panel contains a tree-like representation of the functions available - the top level shows the classes (categories) into which the functions are divided, and if you open these up (by double clicking on them) each contains a list of functions and constants in that class. If you click on any of these classes or their constituent functions or constants, a full descritption of what they are and how to use them will appear in the right hand panel.

The information available from this command is the same as that given in Section 7.5, but the graphical browser may be a more convenient way to view the documentation. There are no parameters.

A.2.1 Usage

The usage of `funcs` is

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

A.3 `multicone`: Makes multiple cone search queries to the same service

`multicone` is a utility which performs a cone search query for each row of an input table and concatenates the results of all these queries together into one big output table. You give the **service URL** for the cone search server you wish to use, and expressions (usually column names) defining how to get the search parameters (sky position and search radius) for each row of the input table. The program then goes through the input table and dispatches a cone search query to the server for each row. For each of these queries the service should respond with a VOTable containing the objects it knows about in the specified region; hopefully the columns will be the same or very similar for all the different queries since they are using the same service. The response tables are stitched together top-to-bottom (in the same way as `tcat`) and the result is output.

This is in some ways like doing a positional crossmatch where one of the catalogues is local and the other is remote. Because of both the network communication and the naive algorithm however, it is only suitable if the local catalogue has a rather small number of rows.

The **cone search** protocol is not currently a formal IVOA standard, but it is a simple service widely implemented by catalogue servers. A description of the protocol can be found at http://us-vo.org/pubs/files/conesearch.html.

You can locate available cone search services and their service URLs by interrogating the **VO Registry**. One way to do this is using the `regquery` command. For instance, to identify registered cone search services that have something to do with Sloan data, you could execute the folowing:

```
stilts regquery query="serviceType = 'CONE' and title like '%Sloan%'" \
       ocmd="keepcols 'shortName serviceUrl'" \
       ofmt=ascii
```

Writing just `query="serviceType = 'CONE'"` with no further qualification will give you all registered cone search services. See the section on `regquery` (Appendix A.4) for more explanation.

Note that when running, `multicone` often generates a lot of WARNING messages. Most of these are complaining about badly formed VOTables being returned from the cone search services.

STILTS does its best to work out what the service responses mean in this case, and usually makes a good enough job of it.

This command is experimental. It may be modified or renamed in a future release of STILTS.

A.3.1 Usage

The usage of `multicone` is

```
stilts <stilts-flags> multicone ifmt=<in-format> istream=true|false
                                icmd=<cmds> ocmd=<cmds>
                                omode=<out-mode> <mode-args>
                                out=<out-table> ofmt=<out-format> ra=<expr>
                                dec=<expr> sr=<expr> copycols=<colid-list>
                                find=best|all ostream=true|false
                                serviceurl=<value> verb=1|2|3
                                [in=]<table>
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`copycols = <colid-list>`
List of columns from the input table which are to be copied to the output table. Each column identified here will be prepended to the columns of the combined output table, and its value for each row taken from the input table row which provided the parameters of the query which produced it. See Section 5.3 for list syntax.

`dec = <expr>`
Expression which evaluates to the declination in degrees in the ICRS coordinate system for the request at each row of the input table. This will usually be the name or ID of a column in the input table, or a function involving one.

`find = best|all`
Determines which matches are retained. If `best` is selected, then only the query table row which best matches the row from the input table will be output. If `all` is selected, then any rows in the query table which match the input table are output.

[Default: `all`]

`icmd = <cmds>`
Commands to operate on the input table, before any other processing takes place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`icmd=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ifmt = <in-format>`
Specifies the format of the input table (one of the known formats listed in Section 4.2.1). This flag can be used if you know what format your input table is in. If it has the special value `(auto)` (the default), then an attempt will be made to detect the format of the table automatically. This cannot always be done correctly however, in which case the program will exit with an error explaining which formats were attempted.

[Default: `(auto)`]

`in = <table>`
The location of the input table. This is usually a filename or URL, and may point to a file compressed in one of the supported compression formats (Unix compress, gzip or bzip2). If it is omitted, or equal to the special value "-", the input table will be read from standard input. In this case the input format must be given explicitly using the `ifmt` parameter.

`istream = true|false`
If set true, the `in` table will be read as a stream. It is necessary to give the `ifmt` parameter in this case. Depending on the required operations and processing mode, this may cause the read to fail (sometimes it is necessary to read the input table more than once). It is not normally necessary to set this flag; in most cases the data will be streamed automatically if that is the best thing to do. However it can sometimes result in less resource usage when processing large files in certain formats (such as VOTable).

[Default: `false`]

`ocmd = <cmds>`
Commands to operate on the output table, after all other processing has taken place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`ocmd=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ofmt = <out-format>`
Specifies the format in which the output table will be written (one of the ones in Section 4.2.2 - matching is case-insensitive and you can use just the first few letters). If it has the special value "`(auto)`" (the default), then the output filename will be examined to try to guess what sort of file is required usually by looking at the extension. If it's not obvious from the filename what output format is intended, an error will result.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: `(auto)`]

`omode = <out-mode> <mode-args>`
The mode in which the result table will be output. The default mode is `out`, which means that the result will be written as a new table to disk or elsewhere, as determined by the `out` and `ofmt` parameters. However, there are other possibilities, which correspond to uses to which a table can be put other than outputting it, such as displaying metadata, calculating statistics, or populating a table in an SQL database. For some values of this parameter, additional parameters (`<mode-args>`) are required to determine the exact behaviour.

Possible values are

- `out`
- `meta`
- `stats`
- `count`
- `cgi`
- `discard`
- `topcat`
- `plastic`
- `tosql`

Use the `help=omode` flag or see Section 5.4 for more information.

[Default: `out`]

`ostream = true|false`
If set true, this will cause the operation to stream on output, so that the output table is built up as the results are obtained from the cone search service. The disadvantage of this is that some output modes and formats need multiple passes through the data to work, so depending on the output destination, the operation may fail if this is set. Use with care (or be prepared for the operation to fail).

[Default: `false`]

`out = <out-table>`
The location of the output table. This is usually a filename to write to. If it is equal to the special value "-" (the default) the output table will be written to standard output.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: -]

`ra = <expr>`
Expression which evaluates to the right ascension in degrees in the ICRS coordinate system for the request at each row of the input table. This will usually be the name or ID of a column in the input table, or a function involving one.

`serviceurl = <value>`
The base part of a URL which defines the queries to be made. Additional parameters will be appended to this using CGI syntax ("`name=value`", separated by '&' characters). If this value does not end in either a '?' or a '&', one will be added as appropriate.

Note that the `regquery` command can be used to locate the service URL for cone search services.

`sr = <expr>`
Expression which evaluates to the search radius in degrees for the request at each row of the input table. This will often be a constant numerical value, but may be the name or ID of a column in the input table, or a function involving one.

`verb = 1|2|3`
Verbosity level of the tables returned by the query service. A value of 1 indicates the bare minimum and 3 indicates all available information.

A.3.2 Examples

Here are some examples of `multicone`:

```
stilts multicone serviceurl=http://archive.stsci.edu/hst/search.php \
                 in=messier.xml ra=RA dec=DEC sr=0.05 \
                 out=matches.xml
```

This queries the HST cone search service from Space Telescope for records within .05 degrees of each Messier object contained in a local VOTable `messier.xml`. The result is written to a new VOTable, `matches.xml`. The J2000 positions of each record in the input file are held in columns named RA and DEC respectively.

```
stilts multicone \
       serviceurl='http://www.nofs.navy.mil/cgi-bin/vo_cone.cgi?CAT=NOMAD' \
       in=vizier.xml#7 \
       icmd='addskycoords -inunit sex fk4 fk5 RAB1950 DEB1950 RAJ2000 DEJ2000' \
       icmd='progress'
       ra=RAJ2000 dec=DEJ2000 sr=0.01 \
       ocmd='replacecol -units rad RA hmsToRadians(RA[0],RA[1],RA[2])' \
       ocmd='replacecol -units rad DEC dmsToRadians(DEC[0],DEC[1],DEC[2])' \
```

omode=topcat

In this example some pre-processing of the input catalogue and post-processing of the output catalogue is performed as well as the multiple cone search itself.

The input catalogue, which is the 8th TABLE element in a VOTable file, contains sky positions in sexagesimal FK4 (B1950) coordinates. The `icmd=addskycoords...` parameter specifies a filter which will add new columns in FK5 (J2000) degrees, which are what the multicone command requires. The `icmd=progress` parameter specifies a filter which will write progress information to the terminal so you can see how the queries are progressing.

The NOMAD service specified by the `serviceurl` parameter used here happens to return results with the RA/DEC columns represented in a rather eccentric format, namely 3-element floating point arrays representing (hours,minutes,seconds)/(degrees,minutes,seconds). The two `ocmd=replacecol...` filters replace the values of these columns with the scalar equivalents in radians. Finally, the `omode=topcat` parameter causes the result table to be loaded directly into TOPCAT (if it is available).

```
stilts multicone serviceurl='http://archive.stsci.edu/iue/search.php?' \
                 in=queries.txt ifmt=ascii \
                 ra='$1' dec='$2' sr='$3' copycols='$4' \
                 out=found.fits
```

Here the input is a plain text table with four unnamed columns, giving in order the right ascension, declination, positional error and name of target objects. The command carries out a cone search to the named service for each one. Note in this case the search radius (`sr` parameter) is taken from the table and so varies for each query. The `copycols` parameter has the value '`$4`', which means that the value of the fourth column of the input table will be prepended to each row of the output table for which it is responsible. Output is to a FITS table.

A.4 `regquery`: Queries the VO registry

`regquery` submits a query to the Virtual Observatory **registry** and returns the result as a table containing all the records which match the condition specified. The resulting table can be written out in any of the supported formats or otherwise processed in the usual ways. Currently the registry used by default is the SOAP service offered by the US NVO registry at http://voservices.net/registry/registry.asmx. Because VO registries generally harvest from each other, the content of this one can be expected to be similar to that stored in registries maintained by other organisations.

A.4.1 Usage

The usage of `regquery` is

```
stilts <stilts-flags> regquery query=<value> regurl=<value> ocmd=<cmds>
                              omode=<out-mode> <mode-args> out=<out-table>
                              ofmt=<out-format>
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

ocmd = <cmds>

Commands to operate on the output table, after all other processing has taken place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter

can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`ocmd=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ofmt = <out-format>`
Specifies the format in which the output table will be written (one of the ones in Section 4.2.2 - matching is case-insensitive and you can use just the first few letters). If it has the special value "`(auto)`" (the default), then the output filename will be examined to try to guess what sort of file is required usually by looking at the extension. If it's not obvious from the filename what output format is intended, an error will result.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: `(auto)`]

`omode = <out-mode> <mode-args>`
The mode in which the result table will be output. The default mode is `out`, which means that the result will be written as a new table to disk or elsewhere, as determined by the `out` and `ofmt` parameters. However, there are other possibilities, which correspond to uses to which a table can be put other than outputting it, such as displaying metadata, calculating statistics, or populating a table in an SQL database. For some values of this parameter, additional parameters (`<mode-args>`) are required to determine the exact behaviour.

Possible values are

- `out`
- `meta`
- `stats`
- `count`
- `cgi`
- `discard`
- `topcat`
- `plastic`
- `tosql`

Use the `help=omode` flag or see Section 5.4 for more information.

[Default: `out`]

`out = <out-table>`
The location of the output table. This is usually a filename to write to. If it is equal to the special value "-" (the default) the output table will be written to standard output.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: -]

`query = <value>`
Text of an SQL WHERE clause defining which resource records you wish to retrieve from the registry. Some examples are:

- `serviceType='CONE'`
- `title like '%2MASS%'`
- `publisher like 'CDS%' and title like '%galax%'`

The special value "ALL" will attempt to retrieve all the records in the registry (though this is not necessarily a sensible thing to do).

A full description of SQL syntax is beyond the scope of this documentation, but in general you

want to use `<field-name> like '<value>` where '%' is a wildcard character. Logical operators `and` and `or` and parentheses can be used to group and combine expressions. You can find the various `<field-name>`s by executing one of the queries above and looking at the column names in the returned table.

`regurl = <value>`
The URL of a SOAP endpoint which provides suitable registry query services.

[Default: `http://voservices.net/registry/registry.asmx`]

A.4.2 Examples

Here are some examples of `regquery`:

`stilts regquery query="identifier like '%astrogrid%'" out=ag.xml`

Retrieves all the records in the registry whose `identifier` field contain the string "`astrogrid`". The '%' characters function as wildcards for the `like` operator. The output is written to a local VOTable file which can be examined or further processed later.

`stilts regquery query="serviceType = 'SSAP'" omode=count`

Queries the registry for all the records whose `serviceType` fields equal the string `SSAP` (this identifies services which support the Simple Spectral Access Protocol). These records are not stored, but the `omode=count` output mode counts the rows. This therefore tells you how many SSAP servers are registered.

```
stilts regquery query="serviceType = 'CONE' and title like '%Sloan%'" \
                ocmd="keepcols 'shortName serviceUrl'" \
                ofmt=ascii out=-
```

Queries the registry for all cone search services (http://us-vo.org/pubs/files/conesearch.html) whose title contains the term "Sloan". The `keepcols` filter takes the result and throws away all the columns except for `shortName` and `serviceUrl`, and these are written to the terminal in ASCII format. This may be useful to find the service URL for a cone search service with particular data for use with the `multicone` command.

A.5 `sqlcone`: Crossmatch between local table and table in SQL database

`sqlcone` resembles `multicone` (Appendix A.3), but instead of sending an HTTP query to a remote cone search service for each match (i.e. each row of the input table), it executes an SQL query directly. The query is a SELECT statement with a WHERE clause which makes restrictions on Right Ascension and Declination columns; the names of these columns must be given as parameters. The effect is that of a spatial join between a client-side table and a table stored in the database.

This command can only be used if you have access to an SQL database via JDBC. The details of how to configure a JDBC connection to a database are discussed in Section 3.4 - obviously you will need a database to connect to and appropriate read permissions on it as well as the relevant drivers.

A.5.1 Usage

The usage of `sqlcone` is

```
stilts <stilts-flags> sqlcone ifmt=<in-format> istream=true|false
                              icmd=<cmds> ocmd=<cmds>
                              omode=<out-mode> <mode-args> out=<out-table>
                              ofmt=<out-format> ra=<expr> dec=<expr>
                              sr=<expr> copycols=<colid-list> find=best|all
```

```
ostream=true|false db=<jdbc-url> user=<value>
password=<value> dbtable=<table-name>
dbra=<sql-col> dbdec=<sql-col>
selectcols=<sql-cols> where=<sql-condition>
[in=]<table>
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`copycols = <colid-list>`
List of columns from the input table which are to be copied to the output table. Each column identified here will be prepended to the columns of the combined output table, and its value for each row taken from the input table row which provided the parameters of the query which produced it. See Section 5.3 for list syntax.

`db = <jdbc-url>`
URL which defines a connection to a database. This has the form `jdbc:<subprotocol>:<subname>` - the details are database- and driver-dependent. Consult Sun's JDBC documentation and that for the particular JDBC driver you are using for details. Note that the relevant driver class will need to be on your classpath and referenced in the `jdbc.drivers` system property as well for the connection to be made.

`dbdec = <sql-col>`
The name of a column in the SQL database table `dbtable` which gives the declination in degrees.

`dbra = <sql-col>`
The name of a column in the SQL database table `dbtable` which gives the right ascension in degrees.

`dbtable = <table-name>`
The name of the table in the SQL database which provides the remote data.

`dec = <expr>`
Expression which evaluates to the declination in degrees for the request at each row of the input table. This will usually be the name or ID of a column in the input table, or a function involving one.

`find = best|all`
Determines which matches are retained. If `best` is selected, then only the query table row which best matches the row from the input table will be output. If `all` is selected, then any rows in the query table which match the input table are output.

[Default: `all`]

`icmd = <cmds>`
Commands to operate on the input table, before any other processing takes place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`icmd=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ifmt = <in-format>`
Specifies the format of the input table (one of the known formats listed in Section 4.2.1). This flag can be used if you know what format your input table is in. If it has the special value `(auto)` (the default), then an attempt will be made to detect the format of the table automatically. This cannot always be done correctly however, in which case the program will exit with an error explaining which formats were attempted.

[Default: `(auto)`]

`in = <table>`
The location of the input table. This is usually a filename or URL, and may point to a file compressed in one of the supported compression formats (Unix compress, gzip or bzip2). If it is omitted, or equal to the special value "-", the input table will be read from standard input. In this case the input format must be given explicitly using the `ifmt` parameter.

`istream = true|false`
If set true, the `in` table will be read as a stream. It is necessary to give the `ifmt` parameter in this case. Depending on the required operations and processing mode, this may cause the read to fail (sometimes it is necessary to read the input table more than once). It is not normally necessary to set this flag; in most cases the data will be streamed automatically if that is the best thing to do. However it can sometimes result in less resource usage when processing large files in certain formats (such as VOTable).

[Default: `false`]

`ocmd = <cmds>`
Commands to operate on the output table, after all other processing has taken place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`ocmd=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ofmt = <out-format>`
Specifies the format in which the output table will be written (one of the ones in Section 4.2.2 - matching is case-insensitive and you can use just the first few letters). If it has the special value "`(auto)`" (the default), then the output filename will be examined to try to guess what sort of file is required usually by looking at the extension. If it's not obvious from the filename what output format is intended, an error will result.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: `(auto)`]

`omode = <out-mode> <mode-args>`
The mode in which the result table will be output. The default mode is `out`, which means that the result will be written as a new table to disk or elsewhere, as determined by the `out` and `ofmt` parameters. However, there are other possibilities, which correspond to uses to which a table can be put other than outputting it, such as displaying metadata, calculating statistics, or populating a table in an SQL database. For some values of this parameter, additional parameters (`<mode-args>`) are required to determine the exact behaviour.

Possible values are

- `out`
- `meta`

- stats
- count
- cgi
- discard
- topcat
- plastic
- tosql

Use the help=omode flag or see Section 5.4 for more information.

[Default: out]

ostream = true|false
If set true, this will cause the operation to stream on output, so that the output table is built up as the results are obtained from the cone search service. The disadvantage of this is that some output modes and formats need multiple passes through the data to work, so depending on the output destination, the operation may fail if this is set. Use with care (or be prepared for the operation to fail).

[Default: false]

out = <out-table>
The location of the output table. This is usually a filename to write to. If it is equal to the special value "-" (the default) the output table will be written to standard output.

This parameter must only be given if omode has its default value of "out".

[Default: -]

password = <value>
Password for logging in to SQL database.

ra = <expr>
Expression which evaluates to the right ascension in degrees for the request at each row of the input table. This will usually be the name or ID of a column in the input table, or a function involving one.

selectcols = <sql-cols>
An SQL expression for the list of columns to be selected from the table in the database. A value of "*" retrieves all columns.

[Default: *]

sr = <expr>
Expression which evaluates to the search radius in degrees for the request at each row of the input table. This will often be a constant numerical value, but may be the name or ID of a column in the input table, or a function involving one.

user = <value>
User name for logging in to SQL database. Defaults to the current username.

[Default: mbt]

where = <sql-condition>
An SQL expression further limiting the rows to be selected from the database. This will be combined with the constraints on position implied by the cone search centres and radii. The value of this parameter should just be a condition, it should not contain the WHERE keyword. A null value indicates no additional criteria.

A.5.2 Examples

Here are some examples of sqlcone:

```
stilts -classpath lib/drivers/mysql-connector-java.jar \
       -Djdbc.drivers=com.mysql.jdbc.Driver
       sqlcone in=messier.xml ra=RA dec=DEC sr=0.05 \
               db='jdbc:mysql://localhost/ASTRO1' user=mbt \
               dbtable=FIRST dbra=_RA2000 dbdec=_DE2000 \
               out=matches.xml
```

This performs a series of SELECT statements on the table FIRST in the local MySQL database ASTRO1 to identify database objects in the region of each object represented in the VOTable `messier.xml`. The result, a join between the Messier and FIRST tables, is output as a VOTable called `matches.xml`. In this case a password has not been supplied on the command line, so if one is required it will be prompted for on the console.

A.6 `tcat`: Concatenates multiple similar tables

`tcat` is a tool for concatenating any number of similar tables one after the other. The tables must be of similar form to each other (same number and types of columns). Preprocessing of the tables may be done using the `icmd` parameter, which will operate in the same way on all the input tables. Table parameters of the output table will be taken from the first of the input tables.

Subject to some constraints on the details of the input and output formats and processing, `tcat` is capable of joining an unlimited number of tables together to produce an output table of unlimited length, without large memory requirements.

If you have heterogeneous tables, in different formats of requiring different preprocessing steps from each other before they can be concatenated, use `tcatn`.

A.6.1 Usage

The usage of `tcat` is

```
stilts <stilts-flags> tcat in=<table> [<table> ...] ifmt=<in-format>
                           istream=true|false icmd=<cmds> ocmd=<cmds>
                           omode=<out-mode> <mode-args> out=<out-table>
                           ofmt=<out-format> seqcol=<colname>
                           loccol=<colname> uloccol=<colname>
                           lazy=true|false countrows=true|false
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`countrows = true|false`
Whether to count the rows in the table before starting the output. This is essentially a tuning parameter - if writing to an output format which requires the number of rows up front (such as normal FITS) it may result in skipping the number of passes through the input files required for processing. Unless you have a good understanding of the internals of the software, your best bet for working out whether to set this true or false is to try it both ways

[Default: `false`]

`icmd = <cmds>`
Commands which will operate on each of the input tables, before any other processing takes place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps.

The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`icmd=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ifmt = <in-format>`
Specifies the format of the input table (one of the known formats listed in Section 4.2.1). This flag can be used if you know what format your input table is in. If it has the special value `(auto)` (the default), then an attempt will be made to detect the format of the table automatically. This cannot always be done correctly however, in which case the program will exit with an error explaining which formats were attempted.

The same format parameter applies to all the tables specified by `in`.

[Default: `(auto)`]

`in = <table> [<table> ...]`
Locations of the input tables. Either specify the parameter multiple times, or supply the input tables as a space-separated list within a single use. Each table location may be a filename or URL, and may point to data compressed in one of the supported compression formats (Unix compress, gzip or bzip2).

A list of input table locations may be given in an external file by using the indirction character '@'. Thus "`in=@filename`" causes the file `filename` to be read for a list of input table locations. The locations in the file should each be on a separate line.

`istream = true|false`
If set true, the `in` table will be read as a stream. It is necessary to give the `ifmt` parameter in this case. Depending on the required operations and processing mode, this may cause the read to fail (sometimes it is necessary to read the input table more than once). It is not normally necessary to set this flag; in most cases the data will be streamed automatically if that is the best thing to do. However it can sometimes result in less resource usage when processing large files in certain formats (such as VOTable).

The same streaming flag applies to all the tables specified by `in`.

[Default: `false`]

`lazy = true|false`
Whether to perform table resolution lazily. If true, each table is only accessed when the time comes to add its rows to the output; if false, then all the tables are accessed up front. This is mostly a tuning parameter, and on the whole it doesn't matter much how it is set, but for joining an enormous number of tables setting it true may avoid running out of resources.

[Default: `false`]

`loccol = <colname>`
Name of a column to be added to the output table which will contain the location (as specified in the input parameter(s)) of the input table from which each row originated.

`ocmd = <cmds>`
Commands to operate on the output table, after all other processing has taken place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character

'@'. Thus "ocmd=@filename" causes the file filename to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

ofmt = <out-format>
Specifies the format in which the output table will be written (one of the ones in Section 4.2.2 - matching is case-insensitive and you can use just the first few letters). If it has the special value "(auto)" (the default), then the output filename will be examined to try to guess what sort of file is required usually by looking at the extension. If it's not obvious from the filename what output format is intended, an error will result.

This parameter must only be given if omode has its default value of "out".

[Default: (auto)]

omode = <out-mode> <mode-args>
The mode in which the result table will be output. The default mode is out, which means that the result will be written as a new table to disk or elsewhere, as determined by the out and ofmt parameters. However, there are other possibilities, which correspond to uses to which a table can be put other than outputting it, such as displaying metadata, calculating statistics, or populating a table in an SQL database. For some values of this parameter, additional parameters (<mode-args>) are required to determine the exact behaviour.

Possible values are

- out
- meta
- stats
- count
- cgi
- discard
- topcat
- plastic
- tosql

Use the help=omode flag or see Section 5.4 for more information.

[Default: out]

out = <out-table>
The location of the output table. This is usually a filename to write to. If it is equal to the special value "-" (the default) the output table will be written to standard output.

This parameter must only be given if omode has its default value of "out".

[Default: -]

seqcol = <colname>
Name of a column to be added to the output table which will contain the sequence number of the input table from which each row originated. This column will contain 1 for the rows from the first concatenated table, 2 for the second, and so on.

uloccol = <colname>
Name of a column to be added to the output table which will contain the unique part of the location (as specified in the input parameter(s)) of the input table from which each row originated. If not null, parameters will also be added to the output table giving the pre- and post-fix string common to all the locations. For example, if the input tables are "/data/cat_a1.fits" and "/data/cat_b2.fits" then the output table will contain a new column <colname> which takes the value "a1" for rows from the first table and "b2" for rows from the second, and new parameters "<colname>_prefix" and "<colname>_postfix" with the values "/data/cat_" and ".fits" respectively.

A.6.2 Examples

Here are some examples of `tcat`:

`stilts tcat ifmt=ascii in=t1.txt in=t2.txt in=t3.txt out=table.txt`

Concatenates the three named ASCII format tables to produce an output table. All three must have compatible numbers and types of columns.

`stilts tcat ifmt=ascii in="t1.txt t2.txt t3.txt" out=table.txt`

Has exactly the same effect as the previous example.

`stilts tcat ifmt=ascii in=@inlist out=table.txt`

This will have the same effect as the previous two examples if a file name "inlist" in the current directory contains three lines, "t1.txt", "t2.txt" and "t3.txt".

```
stilts tcat in=r368776.fits#1 in=r368776#2 in=r368776.fits#3 in=r368776.fits#4
           out=r368776_all.fits icmd=progress seqcol=ID
```

Concatenates the contents of four tables (the first four extension HDUs) from a multi-extension FITS file to produce a single FITS table. Progress through each of the input files is reported to the console. An additional column "ID" will be appended to the output which contains 1 for all the rows from the first input table, 2 for the rows from the second one and so on. Many Unix shells (csh, bash) will allow you to list the input files using the following shorthand: "`in=r368776.fits#{1,2,3,4}`".

```
stilts tcat in='rA.csv rB.csv rC.csv' ifmt=csv \
           icmd='keepcols "RA DEC FLUX"' icmd='sorthead 10 FLUX' \
           ocmd='sort FLUX'
```

Takes the 10 rows with highest FLUX values from each of three input tables (in comma-separated value format) and joins them together to produce a 30-row output table. This is then sorted in FLUX order, and the resulting table is output to the console in text format. Only the columns RA, DEC and FLUX are output; any other columns are discarded. The input tables don't need to have identical forms to each other, but each must have at least an RA, DEC and FLUX column.

A.7 `tcatn`: Concatenates multiple tables

`tcatn` is a tool for concatenating a number of tables one after the other. Each table can be manipulated separately prior to the concatenatation. If you have two tables T1 and T2 which contain similar columns, and you want to treat them as a single table, you can use `tcatn` to produce a new table whose metadata (row headings etc) comes from T1 and whose data consists of all the rows of T1 followed by all the rows of T2.

For this concatenation to make sense, each column of T1 must be compatible with the corresponding column of T2 - they must have compatible types and, presumably, meanings. If this is not the case for the tables that you wish to concatenate, for instance the columns are in different orders, or the units differ between a column in T1 and its opposite number in T2, you can use the `icmd1` and/or `icmd2` parameters to manipulate the input tables so that the column sequences are compatible. See Appendix A.7.2 for some examples.

If the tables are similar to each other (same format, same columns, same preprocessing stages required if any), you may find it easier to use `tcat` instead.

A.7.1 Usage

The usage of `tcatn` is

```
stilts <stilts-flags> tcatn nin=<count> ifmtN=<in-format> inN=<tableN>
                           icmdN=<cmds> ocmd=<cmds>
                           omode=<out-mode> <mode-args> out=<out-table>
                           ofmt=<out-format> seqcol=<colname>
                           loccol=<colname> uloccol=<colname>
                           countrows=true|false
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`countrows = true|false`
Whether to count the rows in the table before starting the output. This is essentially a tuning parameter - if writing to an output format which requires the number of rows up front (such as normal FITS) it may result in skipping the number of passes through the input files required for processing. Unless you have a good understanding of the internals of the software, your best bet for working out whether to set this true or false is to try it both ways

[Default: `false`]

`icmdN = <cmds>`
Commands to operate on input table #N, before any other processing takes place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`icmdN=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ifmtN = <in-format>`
Specifies the format of input table #N (one of the known formats listed in Section 4.2.1). This flag can be used if you know what format your input table is in. If it has the special value `(auto)` (the default), then an attempt will be made to detect the format of the table automatically. This cannot always be done correctly however, in which case the program will exit with an error explaining which formats were attempted.

[Default: `(auto)`]

`inN = <tableN>`
The location of input table #N. This is usually a filename or URL, and may point to a file compressed in one of the supported compression formats (Unix compress, gzip or bzip2). If it is omitted, or equal to the special value "-", the input table will be read from standard input. In this case the input format must be given explicitly using the `ifmtN` parameter.

`loccol = <colname>`
Name of a column to be added to the output table which will contain the location (as specified in the input parameter(s)) of the input table from which each row originated.

`nin = <count>`
The number of input tables for this task. For each of the input tables N there will be associated parameters `ifmtN`, `inN` and `icmdN`.

`ocmd = <cmds>`
Commands to operate on the output table, after all other processing has taken place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`ocmd=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ofmt = <out-format>`

Specifies the format in which the output table will be written (one of the ones in Section 4.2.2 - matching is case-insensitive and you can use just the first few letters). If it has the special value "`(auto)`" (the default), then the output filename will be examined to try to guess what sort of file is required usually by looking at the extension. If it's not obvious from the filename what output format is intended, an error will result.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: `(auto)`]

`omode = <out-mode> <mode-args>`

The mode in which the result table will be output. The default mode is `out`, which means that the result will be written as a new table to disk or elsewhere, as determined by the `out` and `ofmt` parameters. However, there are other possibilities, which correspond to uses to which a table can be put other than outputting it, such as displaying metadata, calculating statistics, or populating a table in an SQL database. For some values of this parameter, additional parameters (`<mode-args>`) are required to determine the exact behaviour.

Possible values are

- `out`
- `meta`
- `stats`
- `count`
- `cgi`
- `discard`
- `topcat`
- `plastic`
- `tosql`

Use the `help=omode` flag or see Section 5.4 for more information.

[Default: `out`]

`out = <out-table>`

The location of the output table. This is usually a filename to write to. If it is equal to the special value "-" (the default) the output table will be written to standard output.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: `-`]

`seqcol = <colname>`

Name of a column to be added to the output table which will contain the sequence number of the input table from which each row originated. This column will contain 1 for the rows from the first concatenated table, 2 for the second, and so on.

`uloccol = <colname>`

Name of a column to be added to the output table which will contain the unique part of the location (as specified in the input parameter(s)) of the input table from which each row originated. If not null, parameters will also be added to the output table giving the pre- and

post-fix string common to all the locations. For example, if the input tables are "/data/cat_a1.fits" and "/data/cat_b2.fits" then the output table will contain a new column <colname> which takes the value "a1" for rows from the first table and "b2" for rows from the second, and new parameters "<colname>_prefix" and "<colname>_postfix" with the values "/data/cat_" and ".fits" respectively.

A.7.2 Examples

Here are some examples of `tcatn`:

```
stilts tcatn nin=2 in1=obs1.fits in2=obs2.fits out=combined.fits
```

Concatenates two similar observation catalogues to form a combined one. In this case, both input and output tables are FITS files.

```
stilts tcatn nin=3 omode=stats in1=obs1.txt ifmt1=ascii
                               in2=obs2.xml ifmt2=votable
                               in3=obs3.fit ifmt3=fits
```

Three catalogues with similar forms but in different data formats are joined. Instead of writing the result to an output file, the resulting joined catalogue is examined to calculate its statistics, which are written to standard output.

```
stilts tcatn nin=2 in1=survey.vot.gz ifmt2=csv in2=more_data.csv
             icmd1='addskycoords fk5 galactic RA2000 DEC2000 GLON GLAT' \
             icmd1='keepcols "OBJ_ID GLON GLAT"' \
             icmd2='keepcols "ident gal_long gal_lat"' \
             loccol=FILENAME
             omode=topcat
```

In this case we are trying to concatenate results from two tables which are quite dissimilar to each other. In the first place, one is a VOTable (no `ifmt1` parameter is required since VOTables can be detected automatically), and the other is a comma-separated-values file (for which the `ifmt2=csv` parameter must be given). In the second place, the column structure of the two tables may be quite different. By pre-processing the two tables using the `icmd1` & `icmd2` parameters, we produce in each case an input table which consists of three columns of compatible types and meanings: an integer identifier and floating point galactic longitude and latitude coordinates. The second table contains such columns to start with, but the first table requires an initial step to convert FK5 J2000.0 coordinates to galactic ones. `tcatn` joins the two doctored tables together, to produce a table which contains only these three columns, with all the rows from both input tables, and sends the result directly to a new or running instance of TOPCAT. An additional column named FILENAME is appended to the table before sending it; this contains "survey.vot.gz" for all the columns from the first table and "more_data.csv" for all the columns from the second one.

A.8 `tcopy`: Converts between table formats

`tcopy` is a table copying tool. It simply copies a table from one place to another, but since you can specify the input and output formats as desired, it works as a converter from any of the supported input formats (Section 4.2.1) to any of the supported output formats (Section 4.2.2).

`tcopy` is just a stripped-down version of `tpipe` - it doesn't do anything that `tpipe` can't, but the usage is slightly simplified. It is provided as a drop-in replacement for the old `tablecopy` (`uk.ac.starlink.table.TableCopy`) tool which was supplied with earlier versions of STIL and TOPCAT - it has the same arguments and behaviour as `tablecopy`, but is implemented somewhat differently and will in some cases be more efficient.

A.8.1 Usage

The usage of `tcopy` is

```
stilts <stilts-flags> tcopy ifmt=<in-format> ofmt=<out-format>
                            [in=]<table> [out=]<out-table>
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`ifmt = <in-format>`
Specifies the format of the input table (one of the known formats listed in Section 4.2.1). This flag can be used if you know what format your input table is in. If it has the special value `(auto)` (the default), then an attempt will be made to detect the format of the table automatically. This cannot always be done correctly however, in which case the program will exit with an error explaining which formats were attempted.

[Default: `(auto)`]

`in = <table>`
The location of the input table. This is usually a filename or URL, and may point to a file compressed in one of the supported compression formats (Unix compress, gzip or bzip2). If it is omitted, or equal to the special value "-", the input table will be read from standard input. In this case the input format must be given explicitly using the `ifmt` parameter.

`ofmt = <out-format>`
Specifies the format in which the output table will be written (one of the ones in Section 4.2.2 - matching is case-insensitive and you can use just the first few letters). If it has the special value "`(auto)`" (the default), then the output filename will be examined to try to guess what sort of file is required usually by looking at the extension. If it's not obvious from the filename what output format is intended, an error will result.

[Default: `(auto)`]

`out = <out-table>`
The location of the output table. This is usually a filename to write to. If it is equal to the special value "-" (the default) the output table will be written to standard output.

[Default: `-`]

A.8.2 Examples

Here are some examples of `tcopy` in use:

`stilts tcopy stars.fits stars.xml`

Copies a FITS table to a VOTable. Since no input format is specified, the format is automatically detected (FITS is one of the formats for which this is possible). Since no output format is specified, the `stars.xml` filename is examined to make a guess at the kind of output to write: the `.xml` ending is taken to mean a TABLEDATA-encoded VOTable.

`stilts tcopy stars.fits stars.xml ifmt=fits ofmt=votable`

Does the same as the previous example, but the input and output formats have been specified explicitly.

`stilts tcopy ofmt=text http://remote.host/data/vizer.xml.gz#4 -`

Prints the contents of a remote, compressed VOTable to the terminal in a human-readable form. The `#4` at the end of the URL indicates that the data from the fifth `TABLE` element in the remote document are to be used. The gzip compression of the table is taken care of automatically.

```
stilts tcopy ifmt=csv ofmt=latex spec.csv
```

Converts a comma-separated values file to a LaTeX table environment, writing the result to standard output.

```
stilts -classpath /usr/local/jars/pg73jdbc3.jar \
       -Djdbc.drivers=org.postgresql.Driver \
       tcopy in="jdbc:postgresql://localhost/imsim#SELECT ra, dec, Imag FROM dqc" \
             ofmt=fits wfslist.cat
```

Makes an SQL query on a PostgreSQL database and writes the results to a FITS file. The whole command is shown here, to show that the classpath is augmented to include the PostgreSQL driver class, and the driver class is named using the `jdbc.drivers` system property. As you can see, using SQL from Java is a bit fiddly, and there are other ways to perform this setup than on the command line - see Section 3.4 and `tpipe`'s `omode=tosql` output mode.

A.9 `tcube`: Calculates N-dimensional histograms

`tcube` constructs an N-dimensional histogram, or density map, from N columns of an input table, and writes it out as an N-dimensional data cube. The parameters you supply define which N numeric columns of the input table you want to use and the dimensions (bounds and pixel sizes) of the output grid. Each table row then defines a point in N-dimensional space. The program goes through each row, and if the point that row defines falls within the bounds of the output grid you have defined, increments the value associated with the corresponding pixel. The resulting N-dimensional array, whose pixel values represent a count of the rows associated with that region of the N-dimensional space, is then written out as a FITS file. In one dimension, this gives you a normal histogram of a given variable. In two dimensions it might typically be used to plot the density on the sky of objects from a catalogue.

As with some of the other generic table commands, you can perform extensive pre-processing on the input table by use of the `icmd` parameter before the actual cube counts are calculated.

A.9.1 Usage

The usage of `tcube` is

```
stilts <stilts-flags> tcube cols=<col-id> ... ifmt=<in-format>
                            istream=true|false icmd=<cmds>
                            bounds=[<lo>]:[<hi>] ... binsizes=<size> ...
                            nbins=<num> ... out=<out-file>
                            otype=byte|short|int|long|float|double
                            scale=<col-id>
                            [in=]<table>
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`binsizes = <size> ...`

Gives the extent of of the data bins (cube pixels) in each dimension in data coordinates. The form of the value is a space-separated list of values, giving a list of extents for the first, second,

... dimension. Either this parameter or the `nbins` parameter must be supplied.

`bounds = [<lo>]:[<hi>] ...`
Gives the bounds for each dimension of the cube in data coordinates. The form of the value is a space-separated list of words, each giving an optional lower bound, then a colon, then an optional upper bound, for instance "1:100 0:20" to represent a range for two-dimensional output between 1 and 100 of the first coordinate (table column) and between 0 and 20 for the second. Either or both numbers may be omitted to indicate that the bounds should be determined automatically by assessing the range of the data in the table. A null value for the parameter indicates that all bounds should be determined automatically for all the dimensions.

If any of the bounds need to be determined automatically in this way, two passes through the data will be required, the first to determine bounds and the second to populate the cube.

`cols = <col-id> ...`
Columns to use for this task. One or more `<col-id>` elements, separated by spaces, should be given. Each one represents a column in the table, using either its name or index.

The number of columns listed in the value of this parameter defines the dimensionality of the output data cube.

`icmd = <cmds>`
Commands to operate on the input table, before any other processing takes place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`icmd=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ifmt = <in-format>`
Specifies the format of the input table (one of the known formats listed in Section 4.2.1). This flag can be used if you know what format your input table is in. If it has the special value `(auto)` (the default), then an attempt will be made to detect the format of the table automatically. This cannot always be done correctly however, in which case the program will exit with an error explaining which formats were attempted.

[Default: `(auto)`]

`in = <table>`
The location of the input table. This is usually a filename or URL, and may point to a file compressed in one of the supported compression formats (Unix compress, gzip or bzip2). If it is omitted, or equal to the special value "-", the input table will be read from standard input. In this case the input format must be given explicitly using the `ifmt` parameter.

`istream = true|false`
If set true, the `in` table will be read as a stream. It is necessary to give the `ifmt` parameter in this case. Depending on the required operations and processing mode, this may cause the read to fail (sometimes it is necessary to read the input table more than once). It is not normally necessary to set this flag; in most cases the data will be streamed automatically if that is the best thing to do. However it can sometimes result in less resource usage when processing large files in certain formats (such as VOTable).

[Default: `false`]

`nbins = <num> ...`
Gives the number of bins (cube pixels) in each dimension. The form of the value is a

space-separated list of integers, giving the number of pixels for the output cube in the first, second, ... dimension. Either this parameter or the `binsizes` parameter must be supplied.

`otype = byte|short|int|long|float|double`
The type of numeric value which will fill the output array. If no selection is made, the output type will be determined automatically as the shortest type required to hold all the values in the array. Currently, integers are always signed (no BSCALE/BZERO), so for instance the largest value that can be recorded in 8 bits is 127.

`out = <out-file>`
The location of the output file. This is usually a filename to write to. If it is equal to the special value "-" the output will be written to standard output.

The output cube is currently written as a single-HDU FITS file.

[Default: -]

`scale = <col-id>`
Optionally gives a value by which the count in each bin is scaled. If this value is `null` (the default) then for each row that falls within the bounds of a pixel, the pixel value will be incremented by 1. If a column ID is given, then instead of 1 being added, the value of that column for the row in question is added. The effect of this is that the output image contains the mean of the given column for the rows corresponding to each pixel rather than just a count of them.

A.9.2 Examples

```
stilts tcube in=2QZ_6QZ_pubcat.fits out=ccm.fits \
             cols='Bj_R U_Bj Bj' binsizes='0.05 0.05 0.5' bounds='-2:1 -3:2 :'
```

Calculates a 3-dimensional colour-colour-magnitude grid from three existing columns in a table. The bin (pixel) sizes are specified. The data bounds are specified explicitly for the (first two) colour dimensions, but for the (third) magnitude dimension it is determined from the minimum and maximum values the data in that column of the table. The output is a three-dimensional FITS cube.

```
stilts tcube in=iras_psc.vot out=iras_psc_map.fits \
             icmd='addskycoords fk5 galactic ra dec glat glon' \
             cols='glat glon' nbins='400 200'
```

Calculates a map of object densities in galactic coordinates from a catalogue of IRAS point sources. The output is a two-dimensional FITS image representing the sky in galactic coordinates. Bounds are determined automatically from the data, and the number of pixels in each dimension (400 in latitude and 200 in longitude) are specified, which means that the pixel sizes don't have to be. Since the input table contains sky positions in equatorial coordinates rather than galactic ones, the `addskycoords` filter is used to preprocess the data before the cube generation step (see Section 5.1).

A.10 `tjoin`: Joins multiple tables side-to-side

`tjoin` performs a trivial side-by-side join of multiple tables. The N'th row of the output table consists of the N'th row of the first input table, followed by the N'th row of the second input table, ... and so on. It is suitable if you want to amalgamate two or more tables whose row orderings correspond exactly to each other.

For the (more usual) case in which the rows of the tables to be joined are not already in the right order, use the `tmatch` command.

A.10.1 Usage

The usage of `tjoin` is

```
stilts <stilts-flags> tjoin nin=<count> ifmtN=<in-format> inN=<tableN>
                            icmdN=<cmds> ocmd=<cmds>
                            omode=<out-mode> <mode-args> out=<out-table>
                            ofmt=<out-format> fixcols=none|dups|all
                            suffixN=<value>
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`fixcols = none|dups|all`
Determines how input columns are renamed before insertion into the output table. The choices are:

- `none`: columns are not renamed
- `dups`: columns which would otherwise have duplicate names in the output will be renamed to indicate which table they came from
- `all`: all columns will be renamed to indicate which table they came from

[Default: `dups`]

`icmdN = <cmds>`
Commands to operate on input table #N, before any other processing takes place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`icmdN=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ifmtN = <in-format>`
Specifies the format of input table #N (one of the known formats listed in Section 4.2.1). This flag can be used if you know what format your input table is in. If it has the special value `(auto)` (the default), then an attempt will be made to detect the format of the table automatically. This cannot always be done correctly however, in which case the program will exit with an error explaining which formats were attempted.

[Default: `(auto)`]

`inN = <tableN>`
The location of input table #N. This is usually a filename or URL, and may point to a file compressed in one of the supported compression formats (Unix compress, gzip or bzip2). If it is omitted, or equal to the special value "-", the input table will be read from standard input. In this case the input format must be given explicitly using the `ifmtN` parameter.

`nin = <count>`
The number of input tables for this task. For each of the input tables N there will be associated parameters `ifmtN`, `inN` and `icmdN`.

`ocmd = <cmds>`
Commands to operate on the output table, after all other processing has taken place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`ocmd=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ofmt = <out-format>`

Specifies the format in which the output table will be written (one of the ones in Section 4.2.2 - matching is case-insensitive and you can use just the first few letters). If it has the special value "`(auto)`" (the default), then the output filename will be examined to try to guess what sort of file is required usually by looking at the extension. If it's not obvious from the filename what output format is intended, an error will result.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: `(auto)`]

`omode = <out-mode> <mode-args>`

The mode in which the result table will be output. The default mode is `out`, which means that the result will be written as a new table to disk or elsewhere, as determined by the `out` and `ofmt` parameters. However, there are other possibilities, which correspond to uses to which a table can be put other than outputting it, such as displaying metadata, calculating statistics, or populating a table in an SQL database. For some values of this parameter, additional parameters (`<mode-args>`) are required to determine the exact behaviour.

Possible values are

- `out`
- `meta`
- `stats`
- `count`
- `cgi`
- `discard`
- `topcat`
- `plastic`
- `tosql`

Use the `help=omode` flag or see Section 5.4 for more information.

[Default: `out`]

`out = <out-table>`

The location of the output table. This is usually a filename to write to. If it is equal to the special value "-" (the default) the output table will be written to standard output.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: `-`]

`suffixN = <value>`

If the `fixcols` parameter is set so that input columns are renamed for insertion into the output table, this parameter determines how they are renamed. It specifies a suffix which is appended to all renamed columns from table N.

[Default: `_N`]

A.10.2 Examples

Here are some examples of using `tjoin`

`stilts tjoin nin=2 in1=positions.fit in2=fluxes.fits out=combined.fits`

Takes two input FITS files and sticks them together side by side, writing the result as a third FITS file. The output will have the same number of rows as each of the input catalogues, and a number of columns equal to the sum of those in the two input catalogues.

```
stilts tjoin nin=3 fixcols=all \
             ifmt1=ascii in1=t1.txt suffix1=_T1 \
             ifmt2=ascii in2=t2.txt suffix2=_T2 \
             ifmt3=ascii in3=t3.txt suffix3=_T3 \
             ocmd='select FLAG_T1==0' \
             omode=stats
```

This joins three ascii tables together. Each column of the output table is renamed by appending a string to it ("_T1" for the first table, "_T2" for the second...). Only those rows of the output for which the FLAG column in the first input table, and hence the FLAG_T1 column in the output table, have the value zero are selected. Statistics are calculated for all the columns of these selected rows, and written to the output.

A.11 `tmatch2`: Crossmatches 2 tables

`tmatch2` is an efficient and highly configurable tool for crossmatching pairs of tables. It can match rows between tables on the basis of their relative position in the sky, or alternatively using many other criteria such as separation in some isotropic or anisotropic Cartesian space, identity of a key value, or some combination of these; the full range of match criteria is discussed in Section 6.1. You can choose whether you want to identify all the matches or only the closest, and what form the output table takes, for instance matched rows only, or all rows from one or both tables, or only the unmatched rows.

A.11.1 Usage

The usage of `tmatch2` is

```
   stilts <stilts-flags> tmatch2 ifmt1=<in-format> ifmt2=<in-format>
                                 icmd1=<cmds> icmd2=<cmds> ocmd=<cmds>
                                 omode=<out-mode> <mode-args> out=<out-table>
                                 ofmt=<out-format> matcher=<matcher-name>
                                 values1=<expr-list> values2=<expr-list>
                                 params=<match-params>
                                 join=1and2|1or2|all1|all2|1not2|2not1|1xor2
                                 find=best|all duptag1=<trail-string>
                                 duptag2=<trail-string>
                                 [in1=]<table1> [in2=]<table2>
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`duptag1 = <trail-string>`

If the same column name appears in both of the input tables, those columns are renamed in the output table to avoid ambiguity. The output column name of such a duplicated column is formed by appending the value of this parameter to its name in the input table.

[Default: `_1`]

duptag2 = <trail-string>
If the same column name appears in both of the input tables, those columns are renamed in the output table to avoid ambiguity. The output column name of such a duplicated column is formed by appending the value of this parameter to its name in the input table.

[Default: _2]

find = best|all
Determines which matches are retained. If `best` is selected, then only the best match between the two tables will be retained; in this case the data from a row of either input table will appear in at most one row of the output table. If `all` is selected, then all pairs of rows from the two input tables which match the input criteria will be represented in the output table.

[Default: `best`]

icmd1 = <cmds>
Commands to operate on the first input table, before any other processing takes place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`icmd1=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

icmd2 = <cmds>
Commands to operate on the second input table, before any other processing takes place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`icmd2=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

ifmt1 = <in-format>
Specifies the format of the first input table (one of the known formats listed in Section 4.2.1). This flag can be used if you know what format your input table is in. If it has the special value `(auto)` (the default), then an attempt will be made to detect the format of the table automatically. This cannot always be done correctly however, in which case the program will exit with an error explaining which formats were attempted.

[Default: `(auto)`]

ifmt2 = <in-format>
Specifies the format of the second input table (one of the known formats listed in Section 4.2.1). This flag can be used if you know what format your input table is in. If it has the special value `(auto)` (the default), then an attempt will be made to detect the format of the table automatically. This cannot always be done correctly however, in which case the program will exit with an error explaining which formats were attempted.

[Default: `(auto)`]

in1 = <table1>
The location of the first input table. This is usually a filename or URL, and may point to a file

compressed in one of the supported compression formats (Unix compress, gzip or bzip2). If it is omitted, or equal to the special value "-", the input table will be read from standard input. In this case the input format must be given explicitly using the `ifmt1` parameter.

`in2 = <table2>`
The location of the second input table. This is usually a filename or URL, and may point to a file compressed in one of the supported compression formats (Unix compress, gzip or bzip2). If it is omitted, or equal to the special value "-", the input table will be read from standard input. In this case the input format must be given explicitly using the `ifmt2` parameter.

`join = 1and2|1or2|all1|all2|1not2|2not1|1xor2`
Determines which rows are included in the output table. The matching algorithm determines which of the rows from the first table correspond to which rows from the second. This parameter determines what to do with that information. Perhaps the most obvious thing is to write out a table containing only rows which correspond to a row in both of the two input tables. However, you may also want to see the unmatched rows from one or both input tables, or rows present in one table but unmatched in the other, or other possibilities. The options are:

- `1and2`: An output row for each row represented in both input tables
- `1or2`: An output row for each row represented in either or both of the input tables
- `all1`: An output row for each matched or unmatched row in table 1
- `all2`: An output row for each matched or unmatched row in table 2
- `1not2`: An output row only for rows which appear in the first table but are not matched in the second table
- `2not1`: An output row only for rows which appear in the second table but are not matched in the first table
- `1xor2`: An output row only for rows represented in one of the input tables but not the other one

[Default: `1and2`]

`matcher = <matcher-name>`
Defines the nature of the matching that will be performed. Depending on the name supplied, this may be positional matching using celestial or Cartesian coordinates, exact matching on the value of a string column, or other things. A list and explanation of the available matching algorithms is given in Section 6.1. The value supplied for this parameter determines the meanings of the values required by the `params`, `values1` and `values2` parameters.

[Default: `sky`]

`ocmd = <cmds>`
Commands to operate on the output table, after all other processing has taken place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps. The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`ocmd=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ofmt = <out-format>`
Specifies the format in which the output table will be written (one of the ones in Section 4.2.2 - matching is case-insensitive and you can use just the first few letters). If it has the special value "`(auto)`" (the default), then the output filename will be examined to try to guess what sort of file is required usually by looking at the extension. If it's not obvious from the filename what output format is intended, an error will result.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: `(auto)`]

`omode = <out-mode> <mode-args>`

The mode in which the result table will be output. The default mode is `out`, which means that the result will be written as a new table to disk or elsewhere, as determined by the `out` and `ofmt` parameters. However, there are other possibilities, which correspond to uses to which a table can be put other than outputting it, such as displaying metadata, calculating statistics, or populating a table in an SQL database. For some values of this parameter, additional parameters (`<mode-args>`) are required to determine the exact behaviour.

Possible values are

- `out`
- `meta`
- `stats`
- `count`
- `cgi`
- `discard`
- `topcat`
- `plastic`
- `tosql`

Use the `help=omode` flag or see Section 5.4 for more information.

[Default: `out`]

`out = <out-table>`

The location of the output table. This is usually a filename to write to. If it is equal to the special value "-" (the default) the output table will be written to standard output.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: `-`]

`params = <match-params>`

Determines the parameters of this match. This is typically one or more tolerances such as error radii. It may contain zero or more values; the values that are required depend on the match type selected by the `matcher` parameter. If it contains multiple values, they must be separated by spaces; values which contain a space can be 'quoted' or "quoted".

`values1 = <expr-list>`

Defines the values from table 1 which are used to determine whether a match has occurred. These will typically be coordinate values such as RA and Dec and perhaps some per-row error values as well, though exactly what values are required is determined by the kind of match as determined by `matcher`. Depending on the kind of match, the number and type of the values required will be different. Multiple values should be separated by whitespace; if whitespace occurs within a single value it must be 'quoted' or "quoted". Elements of the expression list are commonly just column names, but may be algebraic expressions calculated from zero or more columns as explained in Section 7.

`values2 = <expr-list>`

Defines the values from table 2 which are used to determine whether a match has occurred. These will typically be coordinate values such as RA and Dec and perhaps some per-row error values as well, though exactly what values are required is determined by the kind of match as determined by `matcher`. Depending on the kind of match, the number and type of the values required will be different. Multiple values should be separated by whitespace; if whitespace occurs within a single value it must be 'quoted' or "quoted". Elements of the expression list are commonly just column names, but may be algebraic expressions calculated from zero or more columns as explained in Section 7.

A.11.2 Examples

Here are some examples of using `tmatch2`

```
stilts tmatch2 in1=obs_v.xml in2=obs_i.xml out=obs_iv.xml \
               matcher=sky values1="ra dec" values2="ra dec" params="2"
```

Takes two input catalogues (VOTables), one with observations in the V band and the other in the I band, and performs a match to find objects within 2 arcseconds of each other. The result is a new table containing only rows where a match was found.

```
stilts tmatch2 survey.fits ifmt2=csv mycat.csv \
               icmd1='addskycoords fk4 fk5 RA1950 DEC1950 RA2000 DEC2000' \
               matcher=skyerr \
               params=10 values1="RA2000 DEC2000 POS_ERR"  values2="RA DEC 0" \
               join=2not1 omode=count
```

Here a comma-separated-values file is being compared with a FITS catalogue representing some survey results. Positions in the survey catalogue use the FK4 B1950.0 system, and so a preprocessing step is inserted to create new position columns in the first input table using the FK5 J2000.0 system, which is what the other input table uses. The survey catalogue contains a POS_ERR column which gives the positional uncertainty of its entries, so the `skyerr` matcher is used, which takes account of this; the third entry in the `values1` parameter is the POS_ERR column (in arcsec). Since the second input table has no positional uncertainty information, 0 is used as the third entry in `values2`. The `params` still has to contain a value which gives the maximum error for matching (i.e. >= the largest value in the POS_ERR column). The join type is `2not1`, which means the output table will only contain those entries which are in the second input table but not in the first one. The output table is not stored, but the number of rows it contains (the number of objects represented in the CSV file but not the survey) is written to the screen.

```
stilts tmatch2 ifmt1=ascii ifmt2=ascii int1=cat-a.txt in2=cat-b.txt \
               matcher=2d values1='X Y' values2='X Y' params=5 join=1and2 \
               duptag1=_a duptag2=_b \
               ocmd='addcol XDIFF X_a-X_b; addcol YDIFF Y_a-Y_b' \
               ocmd'keepcols "XDIFF YDIFF"' omode=stats
```

Two ASCII-format catalogues are matched, where rows are considered to match if their X,Y positions are within 5 units of each other in some Cartesian space. The result of the matching operation is a table of all the matched rows, containing columns named X_a, Y_a, X_b and Y_b (along with any others in the input tables) - the `duptag*` parameters describe how the input X and Y columns are to be renamed to avoid duplicate column names in the output table. To this result are added two new columns, representing the X and Y positional difference between the rows from one input table and those from the other. The `keepcols` filter then throws all the other columns away, retaining only these difference columns. The final two-column table is not stored anywhere, but (`omode=stats`) statistics including mean and standard deviation are calculated on its columns and displayed to the screen. Having done all this, you can examine the average X and Y differences between the two input tables for matched rows, and if they differ significantly from zero, you can conclude that there is a systematic error between the positions in the two input files.

```
stilts tmatch2 in1=mgc.fits in2=6dfgs.xml join=1and2 find=all \
               matcher=sky+1d params='3 0.5' \
               values1='ra dec bmag' values2='RA2000 DEC2000 B_MAG" \
               out=pairs.fits
```

This performs a match with a matcher that combines `sky` and `1d` match criteria. This means that the only rows which match are those which are *both* within 3 arcsec of each other on the sky *and* and within 0.5 blue magnitudes. Note that for both the `params` and the `values1` and `values2` parameters, the items for the `sky` matcher (RA and DEC) are listed first, followed by those for the `1d` matcher (in this case, blue magnitude).

A.12 `tpipe`: Performs pipeline processing on a table

`tpipe` performs all kinds of general purpose manipulations which take one table as input. It is extremely flexible, and can do the following things amongst others:

- calculate statistics
- display metadata
- select rows in various ways, including algebraically
- define new columns as algebraic functions of old ones
- delete or rearrange columns
- sort rows
- convert between table formats

and combine these operations. You can think of it as a supercharged table copying tool.

The basic operation of `tpipe` is that it reads an input table, performs zero or more processing steps on it, and then does something with the output. There are therefore three classes of things you need to tell it when it runs:

Input table location
Specified by the `in`, `ifmt` and `istream` parameters.

Processing steps
Either provide a string giving steps as the value of one or more `cmd` parameters, or the name of a file containing the steps using the `script` parameter. The steps that you can perform are described in Section 5.1.

Output table destination
What happens to the output table is determined by the value of the `omode` parameter. By default, `omode=out`, in which case the table is written to a new table file in a format determined by `ofmt`. However, you can do other things with the result such as calculate the per-column statistics (`omode=stats`), view only the table and column metadata (`omode=meta`), display it directly in TOPCAT (`omode=topcat`) etc.

See Section 5 for a more detailed explanation of these ideas.

The parameters mentioned above are listed in detail in the next section.

A.12.1 Usage

The usage of `tpipe` is

```
stilts <stilts-flags> tpipe ifmt=<in-format> istream=true|false cmd=<cmds>
                            omode=<out-mode> <mode-args> out=<out-table>
                            ofmt=<out-format>
                            [in=]<table>
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`cmd = <cmds>`
Commands to operate on the input table, before any other processing takes place.

The value of this parameter is one or more of the filter commands described in Section 5.1. If more than one is given, they must be separated by semicolon characters (";"). This parameter can be repeated multiple times on the same command line to build up a list of processing steps.

The sequence of commands given in this way defines the processing pipeline which is performed on the table.

Commands may alteratively be supplied in an external file, by using the indirection character '@'. Thus "`icmd=@filename`" causes the file `filename` to be read for a list of filter commands to execute. The commands in the file may be separated by newline characters and/or semicolons.

`ifmt = <in-format>`
Specifies the format of the input table (one of the known formats listed in Section 4.2.1). This flag can be used if you know what format your input table is in. If it has the special value `(auto)` (the default), then an attempt will be made to detect the format of the table automatically. This cannot always be done correctly however, in which case the program will exit with an error explaining which formats were attempted.

[Default: `(auto)`]

`in = <table>`
The location of the input table. This is usually a filename or URL, and may point to a file compressed in one of the supported compression formats (Unix compress, gzip or bzip2). If it is omitted, or equal to the special value "-", the input table will be read from standard input. In this case the input format must be given explicitly using the `ifmt` parameter.

`istream = true|false`
If set true, the `in` table will be read as a stream. It is necessary to give the `ifmt` parameter in this case. Depending on the required operations and processing mode, this may cause the read to fail (sometimes it is necessary to read the input table more than once). It is not normally necessary to set this flag; in most cases the data will be streamed automatically if that is the best thing to do. However it can sometimes result in less resource usage when processing large files in certain formats (such as VOTable).

[Default: `false`]

`ofmt = <out-format>`
Specifies the format in which the output table will be written (one of the ones in Section 4.2.2 - matching is case-insensitive and you can use just the first few letters). If it has the special value "`(auto)`" (the default), then the output filename will be examined to try to guess what sort of file is required usually by looking at the extension. If it's not obvious from the filename what output format is intended, an error will result.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: `(auto)`]

`omode = <out-mode> <mode-args>`
The mode in which the result table will be output. The default mode is `out`, which means that the result will be written as a new table to disk or elsewhere, as determined by the `out` and `ofmt` parameters. However, there are other possibilities, which correspond to uses to which a table can be put other than outputting it, such as displaying metadata, calculating statistics, or populating a table in an SQL database. For some values of this parameter, additional parameters (`<mode-args>`) are required to determine the exact behaviour.

Possible values are

- `out`
- `meta`
- `stats`
- `count`
- `cgi`
- `discard`
- `topcat`
- `plastic`

- `tosql`

Use the `help=omode` flag or see Section 5.4 for more information.

[Default: `out`]

`out = <out-table>`

The location of the output table. This is usually a filename to write to. If it is equal to the special value "-" (the default) the output table will be written to standard output.

This parameter must only be given if `omode` has its default value of "`out`".

[Default: `-`]

A.12.2 Examples

Here are some examples of `tpipe` in use with explanations of what's going on. For simplicity these examples assume that you have the `stilts` script installed and are using a Unix-like shell; see Section 3 for an explanation of how to invoke the command if you just have the Java classes.

```
stilts tpipe cat.fits
```

Writes a FITS table to standard output in human-readable form. Since no mode specifier is given, `omode=out` is assumed, and output is to standard output in `text` format.

```
stilts tpipe cmd='head 5' cat.fits.gz
```

Does the same as the last example, but with one processing step: only the first five rows of the table are output. In this case, the input file is compressed using gzip - this is automatically detected.

```
stilts tpipe ifmt=csv xxx.csv \
             cmd='keepcols "index ra dec"' \
             omode=out ofmt=fits xxx.fits
```

Reads from a comma-separated values file, writes to a FITS file, and discards all columns in the input table apart from INDEX, RA and DEC. Note the quoting in the `cmd` argument: the outer quotes are so that the argument of the `cmd` parameter itself (`keepcols "index ra dec"`) is not split up by spaces (to protect it from the shell), and the inner quotes are to keep the `colid-list` argument of the `keepcols` command together.

```
stilts tpipe ifmt=votable \
             cmd='addcol IV_SUM "(IMAG+VMAG)"' \
             cmd='addcol IV_DIFF "(IMAG-VMAG)"' \
             cmd='delcols "IMAG VMAG"' \
             omode=out ofmt=votable \
      < tab1.vot \
      > tab2.vot
```

Replaces two columns by their sum and difference in a VOTable. Since neither the `in` nor `out` parameters have been specified, the input and output are actually byte streams on standard input and standard output of the `tpipe` command in this case. The processing steps first add a column representing the sum, then add a column representing the difference, then delete the original columns.

```
stilts tpipe cmd='addskycoords -inunit sex fk5 gal \
                               RA2000 DEC2000 GAL_LONG GAL_LAT' \
             6dfgs.fits 6dfgs+gal.fits
```

Adds columns giving galactic coordinates to a table. Both input and output tables are FITS files. The galactic coordinates, stored in new columns named GAL_LONG and GAL_LAT, are calculated from FK5 J2000.0 coordinates given in the existing columns named RA2000 and DEC2000. The input (FK5) coordinates are represented as sexagesimal strings (hh:mm:ss, dd:mm:ss), and the output ones are numeric degrees.

```
stilts -disk tpipe 2dfgrs_ngp.fits \
                   cmd='keepcols "SEQNUM AREA ECCENT"' \
                   cmd='sort -down AREA' \
                   cmd='head 20'
```

Displays selected columns for the 20 rows with largest values in the AREA column of a FITS table. First the columns of interest are selected, then the rows are sorted into descending order by the value of the AREA column, then the first 20 rows of the resulting table are selected, and the result is written to standard output. Since a sort is being performed here, it's not possible to do all the processing a row at a time, since all the AREA values must be available for comparison during the sort. Two things are done here to accommodate this fact: first the column selection is done before the sort, so that it's only a 3-column table which needs to be available for random access, reducing the temporary storage required. Secondly the `-disk` flag is supplied, which means that temporary disk files rather than memory will be used for caching table data.

```
stilts tpipe 2dfgrs_ngp.fits \
             cmd='keepcols "SEQNUM AREA ECCENT"' \
             cmd='sorthead -down 20 AREA'
```

Has exactly the same effect as the previous example. However, the algorithm used by the `sorthead` filter is in most cases faster and cheaper on memory (only 20 rows ever have to be stored in this case), so this is generally a better approach than combining the `sort` and `head` filters.

```
stilts tpipe omode=meta cmd=@commands.lis http://archive.org/data/survey.vot.Z
```

Outputs column and table metadata about a table. In this case the table is a compressed VOTable at the end of a URL. Processing is performed according to the commands contained in a file named "commands.lis" in the current directory.

```
stilts tpipe in=survey.fits
             cmd='select "skyDistance(hmsToRadians(RA),dmsToRadians(DEC), \
                                      hmsToRadians(2,28,11),dmsToRadians(-6,49,45) \
                         < 5 * ARC_MINUTE"' \
             omode=count
```

Counts the number of rows within a given 5 arcmin cone of sky in a FITS table. The `skyDistance` function is an expression which calculates the distance between the position specified in a row (as given by its RA and DEC columns) and a given point on the sky (here, 02:28:11,-06:49:45). Since `skyDistance`'s arguments and return value are in radians, some conversions are required: the RA and DEC columns are sexagesimal strings which are converted using the `hmsToRadians` and `dmsToRadians` functions respectively. Different versions of these functions (ones which take numeric arguments) are used to convert the coordinates of the fixed point to radians. The result is compared to a multiple of the `ARC_MINUTE` constant, which is the size of an arcminute in radians. Any rows of the input table for which this comparison is true are included in the output. An alternative function, `skyDistanceDegrees` which works in degrees, is also available. The functions and constants used here are described in detail in Section 7.5.1.

```
stilts tpipe ifmt=ascii survey.txt \
             cmd='select "OBJTYPE == 3 && Z > 0.15"' \
             cmd='keepcols "IMAG JMAG KMAG"' \
             omode=stats
```

Calculate statistics on the I, J and K magnitudes of selected objects from a catalogue. Only those rows with the given OBJTYPE and in the given Z range are included. The minimum, maximum, mean, standard deviation etc of the IMAG, JMAG and KMAG columns will be written to standard output.

```
stilts -classpath lib/drivers/mysql-connector-java.jar \
       -Djdbc.drivers=com.mysql.jdbc.Driver \
       tpipe in=x.fits cmd="explodeall" omode=tosql \
             protocol=mysql host=localhost database=ASTRO1 newtable=TABLEX \
```

```
            user=mbt
```

Writes a FITS table to an SQL table, converting array-valued columns to scalar ones. To make the SQL connection work properly, the classpath is augmented to include the path of the MySQL JDBC driver and the `jdbc.drivers` system property is set to the JDBC driver class name. The output will be written as a new table named TABLEX in the MySQL database named ASTRO1 on a MySQL server on the local host. The password, if required, will be prompted for, as would any of the other required parameters if they had not been given on the command line. Any existing table in ASTRO1 with the name TABLEX is overwritten. The only processing done here is by the `explodeall` command, which takes any columns which have fixed-size array values and replaces them in the output with multiple scalar columns.

```
java -classpath stilts.jar:lib/drivers/mysql-connector-java.jar
     -Djdbc.drivers=com.mysql.jdbc.Driver \
     uk.ac.starlink.ttools.Stilts \
     tpipe in=x.fits \
           cmd=explodeall \
           omode=out \
           out="jdbc:mysql://localhost/ASTRO1?user=mbt#TABLEX"
```

This does exactly the same as the previous example, but achieves it in a slightly different way. In the first place, java is invoked directly with the necessary flags rather than getting the `stilts` script to do it. Note that you cannot use java's `-jar` flag in this case, because doing it like that would not permit access to the additional classes that contain the JDBC driver. In the second place we use `omode=out` rather than `omode=tosql`. For this we need to supply an `out` value which encodes the information about the SQL connection and table in a special URL-like format. As you can see, this is a bit arcane, which is why the `omode=tosql` mode can be a help.

```
stilts tpipe USNOB.FITS cmd='every 1000000' omode=stats
```

Calculates statistics on a selection of the rows in a catalogue, and writes the result to the terminal. In this example, every millionth row is sampled.

A.13 `votcopy`: Transforms between VOTable encodings

The VOTable standard provides for three basic encodings of the actual data within each table: TABLEDATA, BINARY and FITS. TABLEDATA is a pure-XML encoding, which is relatively easy for humans to read and write. However, it is verbose and not very efficient for transmission and processing, for which reason the more compact BINARY format has been defined. FITS format shares the advantages of BINARY, but is more likely to be used where a VOTable is providing metadata 'decoration' for an existing FITS table. In addition, the BINARY and FITS encodings may carry their data either inline (as the base64-encoded text content of a `STREAM` element) or externally (referenced by a `STREAM` element's `href` attribute).

These different formats have their different advantages and disadvantages. Since, to some extent, programmers are humans too, much existing VOTable software deals in TABLEDATA format even though it may not be the most efficient way to proceed. Conversely, you might wish to examine the contents of a BINARY-encoded table without use of any software more specialised than a text editor. So there are times when it is desirable to convert from one of these encodings to another.

`votcopy` is a tool which translates between these encodings while making a minimum of other changes to the VOTable document. The processing may result in some changes to lexical details such as whitespace in start tags, but the element structure is not modified. Unlike `tpipe` it does not impose STIL's model of what constitutes a table on the data between reading it in and writing it out, so subtleties dependent on the exact structure of the VOTable document will not be mangled. The only important changes should be the contents of `DATA` elements in the document.

A.13.1 Usage

The usage of `votcopy` is

```
stilts <stilts-flags> votcopy charset=<xml-encoding> cache=true|false
                              href=true|false base=<location>
                              [in=]<location> [out=]<location>
                              [format=]TABLEDATA|BINARY|FITS
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`base = <location>`
Determines the name of external output files written when the `href` flag is true. Normally these are given names based on the name of the output file. But if this flag is given, the names will be based on the `<location>` string. This flag is compulsory if `href` is true and `out=-` (output is to standard out), since in this case there is no default base name to use.

`cache = true|false`
Determines whether the input tables are read into a cache prior to being written out. The default is selected automatically depending on the input table; so you should normally leave this flag alone.

`charset = <xml-encoding>`
Selects the Unicode encoding used for the output XML. The available options and default are dependent on your JVM, but the default probably corresponds to UTF-8. Use `help=charset` for a full listing.

`format = TABLEDATA|BINARY|FITS`
Determines the encoding format of the table data in the output document. If `null` is selected, then the tables will be data-less (will contain no DATA element), leaving only the document structure. Data-less tables are legal VOTable elements.

[Default: `tabledata`]

`href = true|false`
In the case of BINARY or FITS encoding, this determines whether the STREAM elements output will contain their data inline or externally. If set false, the output document will be self-contained, with STREAM data inline as base64-encoded characters. If true, then for each TABLE in the document the binary data will be written to a separate file and referenced by an href attribute on the corresponding STREAM element. The name of these files is usually determined by the name of the main output file; but see also the `base` flag.

`in = <location>`
Location of the input VOTable. May be a URL, filename, or "-" to indicate standard input. The input table may be compressed using one of the known compression formats (Unix compress, gzip or bzip2).

[Default: -]

`out = <location>`
Location of the output VOTable. May be a filename or "-" to indicate standard output.

[Default: -]

A.13.2 Examples

Normal use of votcopy is pretty straightforward. We give here a couple of examples of its input and output.

Here is an example VOTable document, cat.vot:

```
<VOTABLE>
<RESOURCE>

<TABLE name="Authors">
<FIELD name="AuthorName" datatype="char" arraysize="*"/>
<DATA>
<TABLEDATA>
<TR><TD>Charles Messier</TD></TR>
<TR><TD>Mark Taylor</TD></TR>
</TABLEDATA>
</DATA>
</TABLE>

<RESOURCE>
<COOSYS equinox="J2000.0" epoch="J2000.0" system="eq_FK4"/>
<TABLE name="Messier Objects">
<FIELD name="Identifier" datatype="char" arraysize="10"/>
<FIELD name="RA" datatype="double" units="degrees"/>
<FIELD name="Dec" datatype="double" units="degrees"/>
<DATA>
<TABLEDATA>
<TR> <TD>M51</TD> <TD>202.43</TD> <TD>47.22</TD> </TR>
<TR> <TD>M97</TD> <TD>168.63</TD> <TD>55.03</TD> </TR>
</TABLEDATA>
</DATA>
</TABLE>
</RESOURCE>

</RESOURCE>
</VOTABLE>
```

Note that it contains more structure than just a flat table: there are two TABLE elements, the RESOURCE element of the second one being nested in the RESOURCE of the first. Processing this document using a generic table tool such as tpipe or tcopy would lose this structure.

To convert the data encoding to BINARY format, we simply execute

```
stilts votcopy format=binary cat.vot
```

and the output is

```
<?xml version="1.0"?>
<VOTABLE>
<RESOURCE>

<TABLE name="Authors">
<FIELD name="AuthorName" datatype="char" arraysize="*"/>
<DATA>
<BINARY>
<STREAM encoding='base64'>
AAAAD0NoYXJsZXMgTWVzc2llcgAAAAtNYXJrIFRheWxvcg==
</STREAM>
</BINARY>
</DATA>
</TABLE>

<RESOURCE>
<COOSYS equinox="J2000.0" epoch="J2000.0" system="eq_FK4"/>
<TABLE name="Messier Objects">
<FIELD name="Identifier" datatype="char" arraysize="10"/>
<FIELD name="RA" datatype="double" units="degrees"/>
<FIELD name="Dec" datatype="double" units="degrees"/>
<DATA>
<BINARY>
<STREAM encoding='base64'>
TTUxAAAAAAAAAEBpTcKPXCj2QEecKPXCj1xNOTcAAAAAAAAAQGUUKPXCj1xAS4PX
Cj1wpA==
</STREAM>
</BINARY>
```

```
</DATA>
</TABLE>
</RESOURCE>

</RESOURCE>
</VOTABLE>
```

Note that both tables in the document have been translated to BINARY format. The basic structure of the document is unchanged: the only differences are within the `DATA` elements. If we ran

```
stilts votcopy format=tabledata
```

on either this output or the original input then the output would be identical (apart perhaps from whitespace) to the input table, since the data are originally in TABLEDATA format.

To generate a VOTable document with the data in external files, the `href` parameter is used. We will output in FITS format this time. Executing:

```
stilts votcopy format=fits href=true cat.vot fcat.vot
```

writes the following to the file `fcat.vot`:

```
...
<DATA>
<FITS>
<STREAM href="fcat-1.fits"/>
</FITS>
</DATA>
...
<DATA>
<FITS>
<STREAM href="fcat-2.fits"/>
</FITS>
</DATA>
...
```

(the unchanged parts of the document have been skipped here for brevity). The actual data are written in two additional files in the same directory as the output file, `fcat-1.fits` and `fcat-2.fits`. These filenames are based on the main output filename, but can be altered using the `base` flag if required. Note this has also given you FITS binary table versions of all the tables in the input VOTable document, which can be operated on by normal FITS-aware software quite separately from the VOTable if required.

A.14 `votlint`: Validates VOTable documents

The VOTable standard, while not hugely complicated, has a number of subtleties and it's not difficult to produce VOTable documents which violate it in various ways. In fact it's probably true to say that most VOTable documents out there are not strictly legal. In some cases the errors are small and a parser is likely to process the document without noticing the trouble. In other cases, the errors are so serious that it's hard for any software to make sense of it. In many cases in between, different software will react in different ways, in the worst case appearing to parse a VOTable but in fact understanding the wrong data.

`votlint` is a program which can check a VOTable document and spot places where it does not conform to the VOTable standard, or places which look like they may not mean what the author intended. It is meant for use in two main scenarios:

1. For authors of VOTables and VOTable-producing software, to check that the documents they produce are legal and problem-free.
2. For users of VOTables (including authors of VOTable-processing software) who are having problems with one and want to know whether it is the data or the software at fault.

Validating a VOTable document against the VOTable schema or DTD of course goes a long way towards checking a VOTable document for errors (though it's clear that many VOTable authors don't even go this far), but it by no means does the whole job, simply because the schema/DTD

specification languages don't have the facilities to understand the data structure of a VOTable document. For instance the VOTable schema will allow any plain text content in a `TD` element, but whether this makes sense in a VOTable depends on the `datatype` attribute of the corresponding `FIELD` element. There are many other examples. `votlint` tackles this by parsing the VOTable document in a way which understands its structure and assessing the content as critically as it can. For any incorrect or questionable content it finds, it will output a short message describing the problem and giving its location in the document. What you do with this information is then up to you.

Using `votlint` is very straightforward. The `votable` argument gives the location (filename or URL) of a VOTable document. Otherwise, the document will be read from standard input. Error and warning messages will be written on standard error. Each message is prefixed with the location at which the error was found (if possible the line and column are shown, though this is dependent on your JVM's default XML parser). The processing is SAX-based, so arbitrarily long tables can be processed without heavy memory use.

`votlint` can't guarantee to pick up every possible error in a VOTable document, but it ought to pick up many of the most serious errors that are commonly made in authoring VOTables.

A.14.1 Usage

The usage of `votlint` is

```
stilts <stilts-flags> votlint validate=true|false version=1.0|1.1
                             out=<location>
                             [votable=]<location>
```

If you don't have the `stilts` script installed, write "`java -jar stilts.jar`" instead of "`stilts`" - see Section 3. The available `<stilts-flags>` are listed in Section 2.1.

Parameter values are assigned on the command line as explained in Section 2.3. They are as follows:

`out = <location>`
Destination file for output messages. May be a filename or "-" to indicate standard output.

[Default: -]

`validate = true|false`
Whether to validate the input document aganist the VOTable DTD. If true (the default), then as well as `votlint`'s own checks, it is validated against an appropriate version of the VOTable DTD which picks up such things as the presence of unknown elements and attributes, elements in the wrong place, and so on. Sometimes however, particularly when XML namespaces are involved, the validator can get confused and may produce a lot of spurious errors. Setting this flag false prevents this validation step so that only `votlint`'s own checks are performed. In this case many violations of the VOTable standard concerning document structure will go unnoticed.

[Default: `true`]

`version = 1.0|1.1`
Selects the version of the VOTable standard which the input table is supposed to exemplify. Currently the version can be 1.0 or 1.1. The version may also be specified within the document using the "version" attribute of the document's VOTABLE element; if it is and it conflicts with the value specified by this flag, a warning is issued.

`votable = <location>`
Location of the VOTable to be checked. This may be a filename, URL or "-" (the default), to indicate standard input. The input may be compressed using one of the known compression

formats (Unix compress, gzip or bzip2).

[Default: -]

A.14.2 Items Checked

Votlint checks that the XML input is well-formed, and, unless the `valid=false` parameter is supplied, that it validates against the 1.0 or 1.1 (as appropriate) DTD. Although VOTable 1.1 is properly defined against an XML Schema rather than a DTD, in conjunction with the other checks done, the DTD validation turns out to be pretty comprehensive. Some of the DTD validity checks are also done by `votlint` internally, so that some validity-type errors may give rise to more than one warning. In general, the program errs on the side of verbosity.

In addition to these checks, the following checks are carried out, and lead to ERROR reports if violations are found:

- `TD` contents incompatible `datatype`/`arraysize` attributes declared in `FIELD`
- BINARY data streams which don't match metadata declared in `FIELD`
- `PARAM` values incompatible with declared `datatype`/`arraysize`
- Meaningless `arraysize` declarations
- Array-valued `TD` elements with the wrong number of elements
- Array-valued `PARAM` values with the wrong number of elements
- `nrows` attribute on `TABLE` element different from the number of rows actually in the table
- `VOTABLE` `version` attribute is unknown
- `ref` attributes without matching `ID` elements elsewhere in the document
- Same `ID` attribute value on multiple elements.

Additionally, the following conditions, which are not actually forbidden by the VOTable standard, will generate WARNING reports. Some of these may result from harmless constructions, but it is wise at least to take a look at the input which caused them:

- Wrong number of `TD` elements in row of `TABLEDATA` table
- Mismatch between VOTable and FITS column metadata for FITS data encoding
- `TABLE` with no `FIELD` elements
- Use of deprecated attributes
- `FIELD` or `PARAM` elements with `datatype` of either `char` or `unicodeChar` and undeclared `arraysize` - this is a common error which can result in ignoring all but the first character in `TD` elements from a column
- `ref` attributes which reference other elements by `ID` where the reference makes no, or questionable sense (e.g. `FIELDref` references `FIELD` in a different table)
- Multiple sibling elements (such as `FIELD`s) with the same `name` attributes

A.14.3 Examples

Here is a brief example of running `votlint` against a (very short) imperfect VOTable document. If the document looks like this:

```
<VOTABLE version="1.1">
 <RESOURCE>
  <TABLE nrows="2">
   <FIELD name="Identifier" datatype="char"/>
   <FIELD name="RA" datatype="double"/>
   <FIELD name="Dec" datatype="double"/>
   <DESCRIPTION>A very small table</DESCRIPTION>
   <DATA>
    <TABLEDATA>
     <TR>
      <TD>Fomalhaut</TD>
```

```
       <TD>344.48</TD>
       <TD>-29.618</TD>
       <TD>HD 216956</TD>
      </TR>
     </TABLEDATA>
    </DATA>
   </TABLE>
  </RESOURCE>
</VOTABLE>
```

then the output of a `votlint` run looks like this:

```
INFO (l.4): No arraysize for character, FIELD implies single character
ERROR (l.7): Element "TABLE" does not allow "DESCRIPTION" here.
WARNING (l.11): Characters after first in char scalar ignored (missing arraysize?)
WARNING (l.15): Wrong number of TDs in row (expecting 3 found 4)
ERROR (l.18): Row count (1) not equal to nrows attribute (2)
```

Note the warning at line 11 has resulted from the same error as the one at line 4 - because the `FIELD` element has no `arraysize` attribute, `arraysize="1"` (single character) is assumed, while the author almost certainly intended `arraysize="*"` (unknown length string).

By examining these warnings you can see what needs to be done to fix this table up. Here is what it should look like:

```
<VOTABLE version="1.1">
 <RESOURCE>
  <TABLE nrows="1">                                    <!-- change row count -->
   <DESCRIPTION>A very small table</DESCRIPTION>   <!-- move DESCRIPTION -->
   <FIELD name="Identifier" datatype="char"
                            arraysize="*"/>        <!-- add arraysize -->
   <FIELD name="RA" datatype="double"/>
   <FIELD name="Dec" datatype="double"/>
   <DATA>
    <TABLEDATA>
     <TR>
      <TD>Fomalhaut</TD>
      <TD>344.48</TD>
      <TD>-29.618</TD>
     </TR>                                             <!-- remove extra TD -->
    </TABLEDATA>
   </DATA>
  </TABLE>
 </RESOURCE>
</VOTABLE>
```

When fed this version, `votlint` gives no warnings.

B Release Notes

This is STILTS, Starlink Tables Infrastructure Library Tool Set. It is a collection of non-graphical utilites for general purpose table and VOTable manipulation developed by Starlink.

Author
Mark Taylor (Starlink, Bristol University)

Email
m.b.taylor@bristol.ac.uk

WWW
http://www.starlink.ac.uk/stilts/

User comments, suggestions, requests and bug reports to the above address are welcomed.

B.1 Acknowledgements

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Apart from the excellent Java 2 Standard Edition itself, the following external libraries provide important parts of STILTS's functionality:

- JEL (GNU) for algebraic expression evaluation
- PixTools (Fermilab EAG) for HEALPix-based celestial sphere row matching
- HTM (Sloan Digital Sky Survey) for HTM-based celestial sphere row matching (now deprecated within STILTS)

Thanks in particular to Nickolai Kouropatkine and Chris Stoughton of Fermilab for writing the PixTools specially for use in STIL.

Many people have contributed ideas and advice to the development of STILTS and its related products. I can't list all of them here, but my thanks are especially due to the following:

- Malcolm Currie (Starlink, RAL)
- Clive Davenhall (Royal Observatory Edinburgh)
- Peter Draper (Starlink, Durham)
- David Giaretta (Starlink, RAL)
- Clive Page (AstroGrid, Leicester)

B.2 Version History

Releases to date have been as follows:

Version 0.1b (29 April 2005)
First public release

Version 0.2b (30 June 2005)

- Added Times func class for MJD-ISO8601 time conversions.
- Fixed bug when doing NULL_ test expressions on first column in table.

Version 1.0b (30 September 2005)
This is the first non-experimental release of STILTS, and it incorporates major changes and

backward incompatibilities since version 0.2b.

Parameter system
The parameter system has undergone a complete rewrite; there is now only a single command "`stilts`", invoked using the `stilts` script or the `stilts.jar` jar file, and the various tasks are named as subsequent arguments on the command line. Command arguments are supplied after that. The new invocation syntax is described in detail elsewhere in this document. As well as invocation features such as improved on-line help, optional prompting, parameter defaulting, and more uniform access to common features, this will make it more straightforward to wrap these tasks for use in non-command-line environments, such as behind a SOAP or CORBA interface, or in a CEA-like execution environment.

Crossmatching
A new command `tmatch2` has been introduced. This provides flexible and efficient crossmatching between two input tables. Future releases will provide commands for intra-table and multi-table matching.

Concatentation
A new command `tcat` has been introduced, which allows two tables to be glued together top-to-bottom. This is currently working but very rudimentary - improvements will be forthcoming in future releases.

Calculator
A new utility command `calc` has been introduced, which performs one-line expression evaluations from the command line.

Pipeline filters
The following new filter commands for use in `tpipe` and other commands have been introduced:

- `addskycoords`: calculates new celestial coordinate pair from existing ones (FK4, FK5, ecliptic, galactic, supergalactic)
- `replacecol`: replaces column data, using existing metadata
- `badval`: replaces given 'magic' value with null
- `replaceval`: replaces given 'magic' value with any specified value
- `tablename`: edits table name
- `explodecols` and `explodecols` commands replace `explode`

The new `stream` parameter of `tpipe` now allows you to write filter commands in an external file, to facilitate more manageable command lines.

Wildarding for column specification is now allowed for some filter commands.

Algebraic functions

- New functions for converting time values between different coordinate systems (Modified Julian Date, ISO-8601, Julian Epoch and Besselian Epoch).
- New RANDOM special function.

Documentation
SUN/256 has undergone many changes. Much of the tool documentation is now automatically generated from the code itself, which goes a long way to ensuring that the documentation is correct with respect to the current state of the code.

Version 1.0-1b (7 October 2005)
Fixed jar file manifest bug which prevented working on Java 1.5

Version 1.1 (10 May 2006)
A number of new features and capabilities have been introduced:

`tcube` Command

The new tcube (Appendix A.9) command calculates N-dimensional histograms (density maps) from N columns of an input table and writes the result to a FITS file.

Processing Filters

The following new filters have been added:

- `stats` filter provides the same information as the old `stats` output mode, but allows much more flexible use of the results. It can also calculate many new quantities, including quantiles, skew and kurtosis.
- `meta` filter provides the same information as the old `meta` output mode, but allows much more flexible use of the results.
- `assert` filter provides in-pipeline logical assertions.
- `uniq` filter collapses multiple adjacent identical or similar rows.
- `sorthead` filter provides a (usually) more efficient method of doing what you could previously do by combining `sort` and `head` filters.
- `colmeta` filter adds/modifies metadata for selected columns.
- `check` filter checks table in stream - for debugging purposes only.

Additionally usage of the `sort` filter has been changed so that it can now do everything that `sortexpr` used to be able to do; `sortexpr` is now withdrawn.

Output Modes

The following new output modes have been introduced:

- `plastic` mode broadcasts the table to one or all registered PLASTIC listeners.
- `cgi` mode writes the table to standard output in a form suitable for output from a CGI script.
- `discard` mode throws away the table.

and usage of the following has been modified:

- `topcat` mode now attempts to use PLASTIC (amongst other methods) to contact TOPCAT.
- `stats` and `meta` modes are mildly deprecated in favour of the corresponding new filters (see above).

Other new features

- New IPAC table format input handler added.
- New `csv-noheader` format variant output handler added.
- `roundDecimal` and `formatDecimal` functions introduced for more control over visual appearance of numeric values.
- Experimental facilities for automatically generating a CEA application description file.

Bug fixes and minor improvements

- Now copes with 'K'-format FITS binary table columns (64-bit integers).
- Improved, though still imperfect, retention of table-wide metadata in VOTables.
- Distinctions between null and false values in boolean columns are handled more carefully for FITS and VOTable files.
- Efficiency improvement when writing FITS-plus format (now only requires a maximum of two passes rather than three of the input rows).
- Added the `mark.workaround` system property which can optionally work around a bug in some input streams ("Resetting to invalid mark" errors).
- Fixed a bug in Cartesian matching which failed to match if the required error in any dimension was zero.
- Fixed erroneous reports about unknown `ucd` and `utype` attributes of TABLE element in `votlint`.

- When joining tables, column name comparison to determine whether deduplication is required is now case-insensitive.
- Error message improved when no automatic format detection is attempted for streamed tables.
- Setting `istream=true` is now less likely to cause a "Can't re-read stream" error.

Version 1.2 (7 July 2006)

Column-oriented Storage

New features for permitting column-oriented storage (`colfits` format, new `startable.storage` policy "`sideways`") have been introduced. These can provide considerable efficiency improvements for certain tasks when working with very large (and especially wide) tables.

New VO commands

Added two new commands for querying Virtual Observatory services:

- `multicone` - Makes multiple cone search queries to the same service
- `regquery` - Queries the VO registry

These tasks are experimental and may be modified or renamed in future releases.

Other items

- `transpose` filter added.
- Added flux conversion functions (Jansky<->magnitude).
- ISO-8601 strings now permit times of 24:00:00 as they should.

Version 1.2-1 (3 August 2006)

- Tab-Separated Table (TST) format now supported for reading and writing.
- New `setparam` and `clearparams` filters.
- Added ICRS coordinate system for `addskycoords`.
- TUCDnn header cards now used in FITS files to transmit UCDs (non-standard mechanism).
- Efficiency improvements for column-oriented access.

Version 1.3 (5 October 2006)

Table Concatenation

The old `tcat` command has been replaced by more capable `tcat` and `tcatn` commands. Between them these provide concatenation of an unlimited number of homogeneous or heterogeneous input tables. Additional columns may be added to indicate which of the input tables given output rows originated from.

Parameter value indirection

Certain parameters (`in` in `tcat`, `cmd` and friends) may now be specified in the form "@filename". This indicates that the value for the parameter is to be obtained by reading it from the named file. This is useful if a very long value is required for the parameter in question. The `script` parameter of `tpipe` has therefore been withdrawn, since it did just the same thing.

MySpace access

Direct access to the MySpace virtual file system is now provided by use of `ivo:-` or `myspace:`-type URLs.

Conversion functions

- Time conversion functions between MJD and Decimal Year have been added (Section 7.5.7).

- `toHex` and `fromHex` numeric conversion functions have been added (Section 7.5.9).

Documentation improvements

- The HTML version of SUN/256 now uses CSS to provide better highlighting of `commands` etc.
- The Output Modes and Processing Filter sections are now split into subsections to make the table of contents clearer.
- The Command Reference section now has only one level of subsection listed in the table of contents to make it clearer.

Other new features and improvements

- Added `-J` flag to `stilts` script for passing flags directly to Java.
- Added new `out` parameter to `votlint`.
- Added `-ifndim` and `-ifshape` flags to explodeall filter.
- The `exact` match mode in `tmatch2` now copes with array-valued columns.
- Added `force` parameter to `multicone` task as a workaround for some broken services.
- Added Sample (as opposed to Population) Standard Deviation/Variance calculation options to the `stats` filter.
- Improved CEA description file output - now contains details of all tasks rather than just a few, as well as various improvements in documentation etc.

Bug fixes

- Fixed erroneous complaints from `votlint` about `utype` attribute on RESOURCE elements.
- Fixed a couple of minor crossmatching bugs (which wouldn't have affected results).

Version 1.3-1 (Starlink Hokulei release)

- New command `tjoin` introduced.
- Output to MySpace can now be streamed, if running under J2SE1.5 or later.
- Slight changes to parameters for `votlint` and `votcopy`.
- Fixed bug in handling of single quotes in FITS file metadata.
- Added `-bench` flag to `stilts` command.
- Various scalability improvements for use with very large (Tb?) files.
- Improved efficiency for `text` and `ascii` output formats (now one-pass not two-pass).
- Improved CEA app-description file, including especially option lists for things like input and output formats.
- Added README.cea file to distribution.
- Fixed problem which could mis-report VOTable out of memory errors as Broken Pipe.
- Added Vega<->AB magnitude conversion constants to Fluxes functions.
- Added `duptag` parameters to tmatch2 task for customised renaming of columns with duplicated names.
- Added hyperbolic trig functions to Maths class (`sinh`, `cosh`, `tanh` and inverses).
- Added cosmology distance calculations in class Distances.
- Added `funcs` task, a browser for expression language function documentation.
- Added `-checkversion` to list of `stilts` flags.

Version 1.3-2 (6 July 2007)

- Added optional `table` parameter to `calc` command (for access to table parameters).
- Can use table parameter names in expressions using `param$` notation (Section 7.2).
- Can reference columns/parameters by UCD by using `ucd$` notation in expressions (Section 7.1) and as column identifiers (Section 5.2).

- Improved deduplication of column names when joining tables.
- Fix error in output of FITS table `TNULL` *n* header cards - write them as numeric not string values.
- Improve error message for broken CSV files.
- Modified JDBC handling so that MySQL and PostgreSQL do not run out of heap memory when streaming large datasets for input. Think I've done the same for SQL Server, but this is not tested.
- Improve error reporting in the presence of a deficient JVM (such as GNU `gcj`).
- Add locale-specific `formatDecimalLocal` functions in class Formats.
- Add `fluxToLuminosity` and `luminosityToFlux` functions in class Fluxes.
- Fix bug which was causing NullPointerExceptions in the `transpose` filter.

Version 1.3-3 (4 Sep 2007)

- Experimental, and currently undocumented, `sqlcone` task introduced, along with some classes in package `uk.ac.starlink.ttools.cone` designed for library use by AstroGrid DSA code.
- CEA description of `tmatch2 params` parameter now has `minoccurs=0`, since that can be true for exact matches.

Version 1.3-4 (10 Sep 2007)

- Fixed VotCopy bug.

Version 1.3-5 (30 Oct 2007)

- Added `-stdout` and `-stderr` flags to `stilts` command.
- Some bugs fixed in generation of CEA `app-description.xml` file.
- Documentation provided for `sqlcone` command.
- Fixed error in `fluxToLuminosity` function.