

# File indexing and searching for Plan 9

*Francisco J Ballesteros  
Laboratorio de Sistemas  
Universidad Rey Juan Carlos*

## ABSTRACT

In Plan9 most resources are provided as files, including regular on disk stored files. When the set of files grow, it is important to be able to quickly locate files based on their contents. This paper describes the set of tools documented in *tags(1)*, which provides file indexing and content based searching for Plan 9, using a file system to provide the search interface.

## 1. Introduction

It is common today in most systems to be able to search files based on their content. MacOSX has the Spotlight tool, Google supplies a file indexing and searching tool for various systems including Windows and Linux, and UNIX has since long ago tools like *whereis* and *Glimpse* [2] that permit searching files by name or by content. There are many other content-based tools. See [4] for a survey or [3] for tools used for string matching.

The native version for Plan 9 of such tool was missing, although APE can be used to port others from other systems. In fact, *Seft* [1], another search tool, is an APE port already available at sources. We describe here our second attempt at providing content based file searching for Plan 9, after early experiments in Plan B with *adb(1)*, a simple tag database.

Content based searching requires solving two problems: (1) indexing file contents and (2) searching the indexes to execute queries. How both things are done depends on the type of searches to be supported. The tools described here provide only exact word matching. Approximate text matching would require different techniques [3] and has not been considered yet.

For exact word queries, it is important to be able to extract the words of interest (probably all) from a file. The appropriate way of doing this is specific for each type of file. Therefore, the indexer has to be modular and permit the addition of specific word extractors for different file types.

Regarding searching, there is a compromise between maintaining the database in memory, leading to fast searches and to high memory consumption, and maintaining most of it on disk, which leads to slower searches but minimizes memory consumption.

Another issue is that on Plan 9, as of today, it is not uncommon for a user to have multiple terminals. At the very least, it is very common (by design) to have multiple terminals sharing a central file server and several CPU servers. This may be exploited to use (otherwise idle) machines to help in file searching, while keeping most of the terminal resources available for other uses.

It is also important for the indexer to support quick updates to the index, or changes to the file system would not be able to get incorporated quickly to the database, and users would miss most recent changes, as made to the file system. Considering that many searches refer to things just made, this is an issue.

In Plan 9 users rearrange their namespaces so that they incorporate possibly many file trees, from different servers. However, an indexing tool must keep file paths in a consistent way for all name spaces. Also, it is important to run the indexer utility close to the file server, to reduce I/O latency. As a result, the search database is best associated to a particular file tree (at a single file server), instead of being associated to a namespace. In that way the database used determines the file tree where the files reside, and paths are not ambiguous anymore (because they are not a function of the client's name space).

## 2. Data structures

The set of tools described in *tags(1)* builds upon two data structures:

- 1 A trie that maps words to file qids.
- 2 A hash table that maps qids to file names.

We keep the index and file names apart because Qids are more compact. Qids are used as values in the trie, instead of using strings. This permits the Trie to be more compact, which is important because the memory occupied by the database is significant. The more compact it is, the better. This can be done because the database refers to a file tree at a particular server, to keep paths meaningful as said before.

The trie is stored in a single file, e.g., `/lib/sys.trie.db`, and is fully read on main memory by tools that use it. The hash table is kept at a separate file, e.g., `/lib/sys.hash.db`, and is also entirely read onto main memory by the tool supporting it.

All words used to lookup files are kept in the trie. This means all words contained in text files, and all words extracted from other file types. As an aid, each file is considered to contain the path elements present on its name. This allows, for example, looking for `sys` and `src` to focus a search on system source files.

Each node in the trie represents a prefix (or a full word). The root node corresponds to the empty word. A trie node is described by the following structure:

```
typedef struct Trie Trie;
typedef struct Tent Tent;

struct Tent {
    Rune    r;
    Trie*   t;
};

struct Trie {
    Tent*   ents;    // ents[i].r are runes for children
    int     nents;   // ents[i].t are children
    int     aents;   // # of ents allocated
    uulong* vals;    // values for this prefix
    int     nvals;   // # of values in use
    ulong*  svals;   // small values (fit in a long)
    int     nsvals;  // # of small values in use
};
```

A node `t` maintains pointers (in `t->ents[i].t`) to child nodes that represent longer words sharing the prefix represented by `t`. Each link to a child node is labeled by `t->ents[i].r`, the rune that has to be added to the prefix represented by `t` to

obtain the prefix represented by the child.

For example, the prefix *a* representing either the word *a* or all the words starting with *a* would be represented by the child  $t \rightarrow \text{ents}[i].t$  of the root node, provided that  $t \rightarrow \text{ents}[i].r$  in the root node contains the rune *a*. Figure 1 depicts an example trie keeping the words (and their prefixes) *hi*, *hello* and *so*.

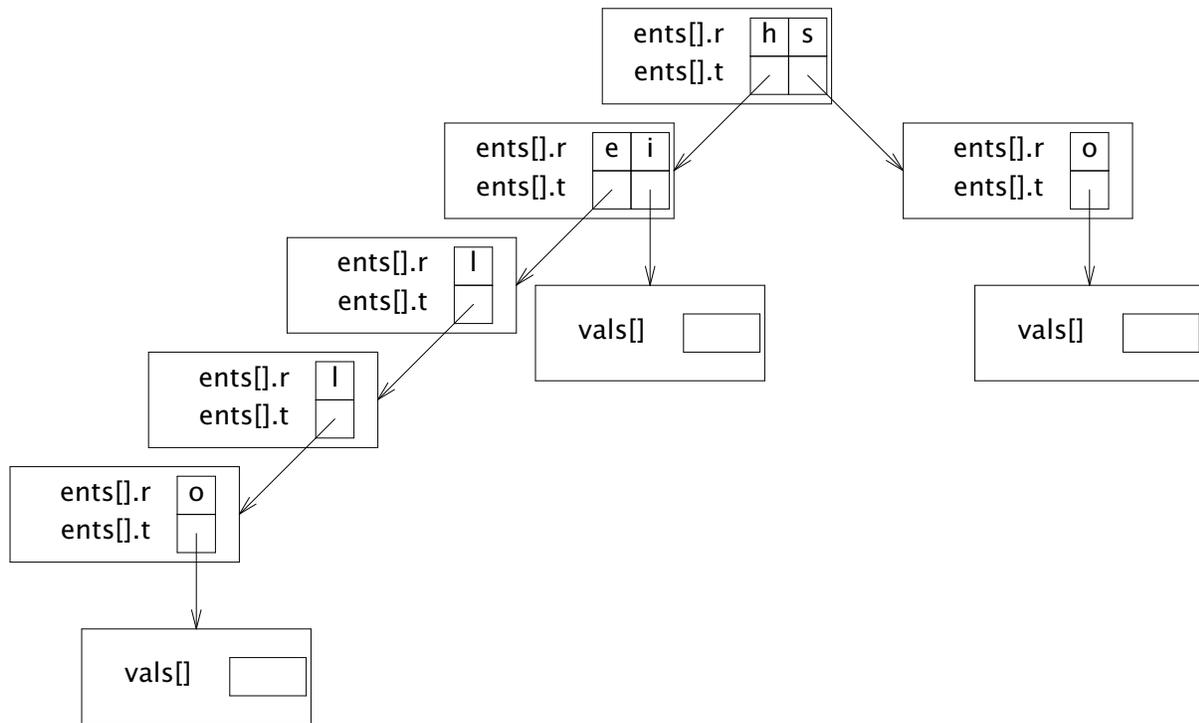


Fig. 1: A trie with three words: *hi*, *hello*, and *so*.

The trie is used to map words to Qids. Each node  $t$  that (besides being a prefix) represents a valid word (a key for a set of files) contains in  $t \rightarrow \text{vals}$  an array of Qids. For example, in the figure, the two nodes holding the *o* rune would point to further trie nodes, used just to contain the Qids for files tagged with *hello* and *so*. In the same way, the entry for *i* in the left child of the root node would point to another trie node used just to contain the Qids for files tagged with *hi*. All nodes in the figure are similar, but we do not show empty arrays, for clarity.

Both *ents* and *vals* arrays are grown dynamically, as more space is needed. For *ents*, *nents* records the number of entries used and *aents* records the number of allocated entries (because in the future we might allow to delete entries in this array). For *vals* we grow the array in chunks of *Incr* nodes (a constant in the program) and there is no need to keep *avals*. The array  $t \rightarrow \text{svals}$  is an optimization, discussed later.

Note that this implementation leads to a flat trie, whose depth is only as long as the longest word. Other implementations would use inner trees (mixed within the trie) to keep children conceptually contained at a single node in the trie.

We thought that it was best to keep the entire database in memory, to permit fast searching. That is considering that memory is cheap and that we may also be able to use the memory of a shared machine to keep the database there. Nevertheless, the database must be kept as compact as feasible while on memory to avoid consuming all the memory available. Therefore, using a single array to keep all the pointers to the children

(and all the values) seemed a sensible thing to do. It permits a compact representation.

Both arrays are kept sorted, which means that searches on them are still logarithmic. Additions to the trie are not that frequent and they do not require fast response times, compared to searches (which are interactive).

Many Qids fit in a `long` value, and the trie stores them in `svals` instead of doing it in `vals`. That way we use half the size for such Qids, at the expense of maintaining two more words at each node in the Trie, to maintain the array. We tried both with and without this optimization and the difference is about 50 Mbytes of main memory for our system database. In the future, if many Qids use the high long of their path, the two extra words may turn into a penalty. Searching time is not affected by this optimization.

The data structure mapping Qids to paths is a simple hash table. There is not much to say about it, other than showing the structure itself:

```
typedef struct Ent Ent;

struct Ent {
    uulong  qid;
    char*   path;
    Ent*    next;    // in hash
};

Ent*      hash[Nhash];
```

Searching for lines matching the given query relies on a double search. First, the inverted index implemented by the trie reports the files relevant to the query. Second, `grep(1)` is used to search such files and show relevant lines.

One point of interest in both data structures is that neither one supports removal of entries. Removing qids from the trie would require iteration over all the nodes in the trie, which is utterly expensive. Instead, the tool searching the hash table checks that files being looked up still exist, before printing their paths. If they are removed they are simply discarded.

When a file no longer contains a tag, it may still be indexed by the tag. In any case, the tag is related to the file (because it did contain it). The search interface relies on `grep(1)` to show lines that match the query on the files retrieved from the database. If a tag is no longer in a file, no lines will be shown for such tag. This makes the problem of old tags mostly irrelevant.

From time to time, (e.g., once per month), the database may be regenerated to clean it up. That is the price for avoiding the time to remove entries while re-indexing files.

### 3. Tools

The software for indexing and searching files is split into different tools, as described in `mktags(1)`. This is their synopsis:

```
mktags [ -d ] dbpath file...
[ DB= dbpath ] looktags [ -n ] tag...
tagfiles [ -d ] triepath file...
rdtrie triepath [ tag... ]
qhash [ -dv ] hashpath [ qid... ]
qhash [ -dv ] -a hashpath [ qid path... ]
qhash [ -dv ] -c hashpath file...
```

**tagfs** [ **-abcD** ] [ **-s** *srv* ] [ **-m** *mnt* ] *triepath*

The first two programs are Rc scripts providing the primary user interface. The other programs provide the actual software for indexing and searching.

*Mktags* creates a database named *dbpath* that maps from tags (words) to file names. Only given files are indexed (including subdirectories as well). Any word in the path name for a file, and any word contained in the file (for most files) becomes a valid search tag for the file. The resulting database is made of two files: a trie and a hash table. The name of the trie has the suffix *.trie.db* and the name of the hash has the suffix *.hash.db*. The path to the database files without their suffix is considered the name of the database.

By convention, there is a system wide data base at */lib/sys* (that is, */lib/sys.trie.db* and */lib/sys.hash.db* ) and a per-user data base at *\$home/lib/\$user* (that is, *\$home/lib/\$user.trie.db* and *\$home/lib/\$user.hash.db*).

*Looktags* searches the system and user databases for files that match the query specified by its arguments. By default, only file names are printed. Flag *-n* instructs *looktags* to run *grep(1)* to print some of the matching lines.

A query is made of lists of tags separated by the “:” character, each as a distinct argument. A file matches the query if it is associated to (contains) all the tags in one of the lists. For example,

```
looktags a b c : d e
```

would search for files either matching all of a, b, and c or matching all of d and e.

*Looktags* can be instructed to use a different database by defining the *DB* environment variable to contain a list of names for the databases to be used (without any file name suffixes).

*Qhash* maintains a file name hash table in the database. This data structure is used to translate Qids into file names.

The first invocation syntax (without using flags *-a* or *-c*) can be used to retrieve path names for the given *qids* in the command line. This is used by *looktags* to obtain paths for matching files. Under flag *-a* the program *qhash* adds the following argument pairs (each with a *qid* and *path*) to the *hash* file. Under flag *-c* *qhash* retrieves Qids and (absolute) path names for *file(s)* mentioned as arguments (recurring for directories), and adds them to the database. This is used by *mktags* to create/update the hash file in the data base.

## In memory databases

*Rdtrie* can be used to inspect and query the Trie in the database. The Trie data structure keeps all the known tags in a trie, maintaining a list of Qids for each tag.

Without any *tag* argument in the command line, *rdtrie* reads and prints the entire Trie file, *trie*. Otherwise, *rdtrie* reads *trie* and then interprets any following arguments as a query. Qids matching the query are printed in the standard output. *Looktags* relies on this program to execute its query.

To speed up searches, the trie part of the database can be kept in memory using *tagfs*. For example, if the database is named */a/b/dbname*, *looktags* searches first for a file named */srv/dbname.tagfs* (to reach a server holding an in-memory version of the trie part of the database), and uses it when available. Otherwise, *looktags* looks for the host identified by *\$search* in the *ndb(6)* database. Should it be found, *looktags* imports its */srv* directory to look for */srv/dbname.tagfs* on it. This is used to share an in-memory database among several machines sharing a network. Only as a last resort would *looktags* read the database by itself to execute the query.

*Tagfs* can also be used to update a Trie, besides being an alternative to *rdtrie* to perform searches. The directory served by *tagfs* contains a `ctl` file that can be read to gather statistics about the Trie and can be written to modify the trie. A write of the string `sync` writes the in-memory database back to its file. A write of the form

```
tag qid tag...
```

adds *tag* to *qid* in the trie (but does not update the on-disk database).

A query can be made by creating a file, writing the query into it (being careful to separate different tags and `:` characters with white space), and then reading from the same file the list of *qids* that match the query. The query file is removed as soon as it is closed after having read from it.

## Modularity

*Tagfiles* tags every file mentioned as an argument (recurring for directories) using the Trie stored in the given *trie* argument. *Mktags* relies on this program.

For each file indexed, *tagfiles* uses every word in its path name as a valid tag to search for the file. Also, *tagfiles* looks at the file name suffix and uses *file(1)* to determine the type of file and pick a particular indexing method. For text files, *tagfiles* reads entire file contents and associates each word contained in the file as a tag to search for the file. For other types of file, *tagfiles* tries to execute external programs to extract the list of tags for each file. Should the appropriate external program not exist, *tagfiles* would still try to index the file as text when appropriate.

The following programs may be executed by *tagfiles* to obtain tags for files. They are expected to write tags for the file given as an argument, one per line:

- *tagc* to tag C source.
- *taglimbo* to tag Limbo source.
- *taghtml* to tag HTML files.
- *tagman* to tag manual pages
- *tagrc* to tag Rc scripts
- *tagtroff* to tag roff source.
- *tagdoc* to tag Microsoft Office documents, including rich text format.
- *tagpdf* to tag Adobe PDF files.
- *tageps* to tag Adobe EPS files.
- *tagps* to tag PostScript files.

## 4. Examples of use

Create the per-user and the system database:

```
; mktags $home/lib/$user $home /mail/box/$user/msgs  
; mktags /lib/sys /cfg /rc /sys
```

Look for files mentioning either `list append` or `queue append`, then repeat que query but using an alternate database kept at `/lib/other.trie.db` and `/lib/other.hash.db`:

```
; looktags list append : queue append  
; DB=/lib/other looktags list append : queue append
```

Add (or update!) tags for files under `/usr/prof` to the personal database:

```
; tagfiles $home/lib/$user.trie.db /usr/prof  
; qhash -c $home/lib/$user.hash.db /usr/prof
```

Place the system database in memory so that `looktags` can be faster, and add the tag `yoyoba` to file with `qid 8345f`

```
; tagfs /lib/sys.trie.db
; echo tag 8345f yoyoba >/mnt/tags/ctl
; echo sync >/mnt/tags/ctl
```

Make the system database at `whale.lsub.org` available to other hosts: First, edit `/lib/ndb/local` to contain `search=whale.lsub.org` for the network entry. Second, at `whale`:

```
whale% tagfs /lib/sys.trie.db
whale% chmod a+rw /srv/sys.tagfs
```

Now from other hosts, `looktags` may use Whale's in-memory database.

## 5. Heuristics

The most important heuristic is the one used by `tagtext` in `tagfiles` to determine which pieces of text are words. In particular, words of less than three characters are ignored. Also, pieces of non-blank text of more than 50 characters are considered as non-text (see for example encoded attachments in mails). The remaining text is parsed to locate alphanumeric words to be used as tags.

## 6. Performance

We have not really made any performance measurements for the tool. In part because it is good enough to fit our needs. Nevertheless, we include some concrete measures here to give a glimpse of its behavior. The implementation contains 1876 lines of C code (not counting library functions used).

An important measure is the size for the database. This is what `ps` says for our system database and that for the author:

```
; rx whale ps | grep tagfs
elf          383      0:27   0:13   148736K Pread   tagfs
nemo         915      55:36 13:42   236808K Pread   tagfs
```

The personal database includes all mail besides indexing more than 300 Mbytes of (mostly text) files.

A search for files including `tags` and `doc` as tags takes 3.58 seconds (real time), and reports a total of 31 files in the system:

```
; time looktags tags doc
/mail/box/nemo/messages/200102/a.997/text
/usr/nemo/doc/os/9intro/ch10.ms
/usr/nemo/doc/os/9intro/index
/sys/src/cmd/tags/tagfiles.c
...
0.28u 0.06s 3.58r          looktags tags doc
```

Using flag `-n` to ask for a listing of matching lines in these files (besides searching for them) takes 3.95 seconds of real time.

Adding `nemo` as another required tag makes the request take 1.66 seconds of real time.

All these measures are not implying anything regarding performance. They are not controlled experiments, but it can be seen that the set of tools behaves well enough for actual use.

## References

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