User’s Guide to gperf 3.1

The GNU Perfect Hash Function Generator
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- The GNU gperf perfect hash function generator utility was written in GNU C++ by Douglas C. Schmidt. The general idea for the perfect hash function generator was inspired by Keith Bostic's algorithm written in C, and distributed to net.sources around 1984. The current program is a heavily modifed, enhanced, and extended implementation of Keith's basic idea, created at the University of California, Irvine. Bugs, patches, and suggestions should be reported to <bug-gperf@gnu.org>.
- Special thanks is extended to Michael Tiemann and Doug Lea, for providing a useful compiler, and for giving me a forum to exhibit my creation.

  In addition, Adam de Boor and Nels Olson provided many tips and insights that greatly helped improve the quality and functionality of gperf.
- Bruno Haible enhanced and optimized the search algorithm. He also rewrote the input routines and the output routines for better reliability, and added a testsuite.

1 Introduction

`gperf` is a perfect hash function generator written in C++. It transforms an n element user-specified keyword set W into a perfect hash function F. F uniquely maps keywords in W onto the range 0..k, where k >= n-1. If k = n-1 then F is a *minimal* perfect hash function. `gperf` generates a 0..k element static lookup table and a pair of C functions. These functions determine whether a given character string s occurs in W, using at most one probe into the lookup table.

`gperf` currently generates the reserved keyword recognizer for lexical analyzers in several production and research compilers and language processing tools, including GNU C, GNU C++, GNU Java, GNU Pascal, GNU Modula 3, and GNU indent. Complete C++ source code for `gperf` is available from `http://ftp.gnu.org/pub/gnu/gperf/`. A paper describing `gperf`'s design and implementation in greater detail is available in the Second USENIX C++ Conference proceedings or from `http://www.cs.wustl.edu/~schmidt/resume.html`.

2 Static search structures and GNU `gperf`

A *static search structure* is an Abstract Data Type with certain fundamental operations, e.g., *initialize*, *insert*, and *retrieve*. Conceptually, all insertions occur before any retrievals. In practice, `gperf` generates a *static* array containing search set keywords and any associated attributes speci fed by the user. Thus, there is essentially no execution-time cost for the insertions. It is a useful data structure for representing *static search sets*. Static search sets occur frequently in software system applications. Typical static search sets include compiler reserved words, assembler instruction opcodes, and built-in shell interpreter commands. Search set members, called *keywords*, are inserted into the structure only once, usually during program initialization, and are not generally modi fed at run-time.

Numerous static search structure implementations exist, e.g., arrays, linked lists, binary search trees, digital search tries, and hash tables. Di ferent approaches o fer trade-o fs between space utilization and search time e f ciency. For example, an n element sorted array is space e f cient, though the average-case time complexity for retrieval operations using binary search is proportional to log n. Conversely, hash table implementations often locate a table entry in constant time, but typically impose additional memory overhead and exhibit poor worst case performance.

Minimal perfect hash functions provide an optimal solution for a particular class of static search sets. A minimal perfect hash function is de fned by two properties:

- It allows keyword recognition in a static search set using at most *one* probe into the hash table. This represents the \perfect" property.
- The actual memory allocated to store the keywords is precisely large enough for the keyword set, and *no larger*. This is the \minimal" property.

For most applications it is far easier to generate *perfect* hash functions than *minimal perfect* hash functions. Moreover, non-minimal perfect hash functions frequently execute faster than minimal ones in practice. This phenomena occurs since searching a sparse keyword table increases the probability of locating a \null" entry, thereby reducing string comparisons. `gperf`'s default behavior generates *near-minimal* perfect hash functions for keyword sets. However, `gperf` provides many options that permit user control over the degree of minimality and perfection.

Static search sets often exhibit relative stability over time. For example, Ada's 63 reserved words have remained constant for nearly a decade. It is therefore frequently worthwhile to expend concerted e fort building an optimal search structure *once*, if it subsequently receives heavy use multiple times. `gperf` removes the drudgery associated with constructing time- and space-e f cient search structures by hand. It has proven a useful and practical tool for serious programming projects. Output from `gperf` is currently used in several production and research compilers, including GNU C, GNU C++, GNU Java, GNU Pascal, and GNU Modula 3. The latter two compilers are not yet part of the o f cial GNU distribution. Each compiler utilizes `gperf` to automatically generate static search structures that e f ciently identify their respective reserved keywords.

3 High-Level Description of GNU gperf

The perfect hash function generator `gperf` reads a set of \keywords" from an input file (or from the standard input by default). It attempts to derive a perfect hashing function that recognizes a member of the *static keyword set* with at most a single probe into the lookup table. If `gperf` succeeds in generating such a function it produces a pair of C source code routines that perform hashing and table lookup recognition. All generated C code is directed to the standard output. Command-line options described below allow you to modify the input and output format to `gperf`.

By default, `gperf` attempts to produce time-efficient code, with less emphasis on efficient space utilization. However, several options exist that permit trading-off execution time for storage space and vice versa. In particular, expanding the generated table size produces a sparse search structure, generally yielding faster searches. Conversely, you can direct `gperf` to utilize a C `switch` statement scheme that minimizes data space storage size. Furthermore, using a C `switch` may actually speed up the keyword retrieval time somewhat. Actual results depend on your C compiler, of course.

In general, `gperf` assigns values to the bytes it is using for hashing until some set of values gives each keyword a unique value. A helpful heuristic is that the larger the hash value range, the easier it is for `gperf` to find and generate a perfect hash function. Experimentation is the key to getting the most from `gperf`.

3.1 Input Format to gperf

You can control the input file format by varying certain command-line arguments, in particular the `-t' option. The input's appearance is similar to GNU utilities `flex` and `bison` (or UNIX utilities `lex` and `yacc`). Here's an outline of the general format:

```
declarations
%%
keywords
%%
functions
```

Unlike `flex` or `bison`, the declarations section and the functions section are optional. The following sections describe the input format for each section.

It is possible to omit the declaration section entirely, if the `-t' option is not given. In this case the input file begins directly with the first keyword line, e.g.:

```
january
february
march
april
...
```

3.1.1 Declarations

The keyword input file optionally contains a section for including arbitrary C declarations and definitions, `gperf` declarations that act like command-line options, as well as for providing a user-supplied `struct`.

3.1.1.1 User-supplied struct

If the '-t' option (or, equivalently, the '%struct-type' declaration) *is* enabled, you *must* provide a C struct as the last component in the declaration section from the input file. The first field in this struct must be of type char * or const char * if the '-P' option is not given, or of type int if the option '-P' (or, equivalently, the '%pic' declaration) is enabled. This first field must be called 'name', although it is possible to modify its name with the '-K' option (or, equivalently, the '%define slot-name' declaration) described below.

Here is a simple example, using months of the year and their attributes as input:

```
struct month { char *name; int number; int days; int leap_days; };
%%
january,   1, 31, 31
february,  2, 28, 29
march,     3, 31, 31
april,     4, 30, 30
may,       5, 31, 31
june,      6, 30, 30
july,      7, 31, 31
august,    8, 31, 31
september, 9, 30, 30
october,  10, 31, 31
november, 11, 30, 30
december, 12, 31, 31
```

Separating the struct declaration from the list of keywords and other fields are a pair of consecutive percent signs, '%%', appearing left justified in the first column, as in the UNIX utility lex.

If the struct has already been declared in an include file, it can be mentioned in an abbreviated form, like this:

```
struct month;
%%
january,   1, 31, 31
...
```

3.1.1.2 Gperf Declarations

The declaration section can contain gperf declarations. They influence the way gperf works, like command line options do. In fact, every such declaration is equivalent to a command line option. There are three forms of declarations:

1. Declarations without argument, like '%compare-lengths'.
2. Declarations with an argument, like '%switch=*count*'.
3. Declarations of names of entities in the output file, like '%define lookup-function-name *name*'.

When a declaration is given both in the input file and as a command line option, the command-line option's value prevails.

The following gperf declarations are available.

'%delimiters=*delimiter-list*'
: Allows you to provide a string containing delimiters used to separate keywords from their attributes. The default is ",". This option is essential if you want to use keywords that have embedded commas or newlines.

'%struct-type'
: Allows you to include a struct type declaration for generated code; see above for an example.

'%ignore-case'
: Consider upper and lower case ASCII characters as equivalent. The string comparison will use a case insignificant character comparison. Note that locale dependent case mappings are ignored.

'%language=*language-name*'
: Instructs gperf to generate code in the language specified by the option's argument. Languages handled are currently:

  'KR-C' Old-style K&R C. This language is understood by old-style C compilers and ANSI C compilers, but ANSI C compilers may flag warnings (or even errors) because of lacking 'const'.

  'C' Common C. This language is understood by ANSI C compilers, and also by old-style C compilers, provided that you #define const to empty for compilers which don't know about this keyword.

  'ANSI-C' ANSI C. This language is understood by ANSI C (C89, ISO C90) compilers, ISO C99 compilers, and C++ compilers.

  'C++' C++. This language is understood by C++ compilers.

  The default is ANSI-C.

'%define slot-name *name*'
: This declaration is only useful when option '-t' (or, equivalently, the '%struct-type' declaration) has been given. By default, the program assumes the structure component identifier for the keyword is 'name'. This option allows an arbitrary choice of identifier for this component, although it still must occur as the first field in your supplied struct.

'%define initializer-suffix *initializers*'
: This declaration is only useful when option '-t' (or, equivalently, the '%struct-type' declaration) has been given. It permits to specify initializers for the structure members following *slot-name* in empty hash table entries. The list of initializers should start with a comma. By default, the emitted code will zero-initialize structure members following *slot-name*.

'%define hash-function-name *name*'
: Allows you to specify the name for the generated hash function. Default name is 'hash'. This option permits the use of two hash tables in the same file.

'%define lookup-function-name *name*'
: Allows you to specify the name for the generated lookup function. Default name is 'in_word_set'. This option permits multiple generated hash functions to be used in the same application.

`%define class-name *name*'
: This option is only useful when option `-L C++' (or, equivalently, the `%language=C++' declaration) has been given. It allows you to specify the name of generated C++ class. Default name is Perfect_Hash.

`%7bit'
: This option specifes that all strings that will be passed as arguments to the generated hash function and the generated lookup function will solely consist of 7-bit ASCII characters (bytes in the range 0..127). (Note that the ANSI C functions isalnum and isgraph do *not* guarantee that a byte is in this range. Only an explicit test like `c >= 'A' && c <= 'Z'' guarantees this.)

`%compare-lengths'
: Compare keyword lengths before trying a string comparison. This option is mandatory for binary comparisons (see Section 3.3 [Binary Strings], page 22). It also might cut down on the number of string comparisons made during the lookup, since keywords with diferent lengths are never compared via strcmp. However, using `%compare-lengths' might greatly increase the size of the generated C code if the lookup table range is large (which implies that the switch option `-S' or `%switch' is not enabled), since the length table contains as many elements as there are entries in the lookup table.

`%compare-strncmp'
: Generates C code that uses the strncmp function to perform string comparisons. The default action is to use strcmp.

`%readonly-tables'
: Makes the contents of all generated lookup tables constant, i.e., \readonly". Many compilers can generate more efcient code for this by putting the tables in readonly memory.

`%enum'
: Defne constant values using an enum local to the lookup function rather than with #defnes. This also means that diferent lookup functions can reside in the same fle. Thanks to James Clark <jjc@ai.mit.edu>.

`%includes'
: Include the necessary system include fle, <string.h>, at the beginning of the code. By default, this is not done; the user must include this header fle himself to allow compilation of the code.

`%global-table'
: Generate the static table of keywords as a static global variable, rather than hiding it inside of the lookup function (which is the default behavior).

`%pic'
: Optimize the generated table for inclusion in shared libraries. This reduces the startup time of programs using a shared library containing the generated code. If the `%struct-type' declaration (or, equivalently, the option `-t') is also given, the frst feld of the user-defned struct must be of type `int', not `char *', because it will contain ofsets into the string pool instead of actual strings. To convert such an ofset to a string, you can use the expression `stringpool + *o*', where *o* is the ofset. The string pool name can be changed through the `%define string-pool-name' declaration.

`%define string-pool-name *name*'
: Allows you to specify the name of the generated string pool created by the declaration `%pic' (or, equivalently, the option `-P'). The default name is `stringpool'. This declaration permits the use of two hash tables in the same file, with `%pic' and even when the `%global-table' declaration (or, equivalently, the option `-G') is given.

`%null-strings'
: Use NULL strings instead of empty strings for empty keyword table entries. This reduces the startup time of programs using a shared library containing the generated code (but not as much as the declaration `%pic'), at the expense of one more test-and-branch instruction at run time.

`%define constants-prefix *prefix*'
: Allows you to specify a prefix for the constants TOTAL_KEYWORDS, MIN_WORD_LENGTH, MAX_WORD_LENGTH, and so on. This option permits the use of two hash tables in the same file, even when the option `-E' (or, equivalently, the `%enum' declaration) is not given or the option `-G' (or, equivalently, the `%global-table' declaration) is given.

`%define word-array-name *name*'
: Allows you to specify the name for the generated array containing the hash table. Default name is `wordlist'. This option permits the use of two hash tables in the same file, even when the option `-G' (or, equivalently, the `%global-table' declaration) is given.

`%define length-table-name *name*'
: Allows you to specify the name for the generated array containing the length table. Default name is `lengthtable'. This option permits the use of two length tables in the same file, even when the option `-G' (or, equivalently, the `%global-table' declaration) is given.

`%switch=*count*'
: Causes the generated C code to use a switch statement scheme, rather than an array lookup table. This can lead to a reduction in both time and space requirements for some input files. The argument to this option determines how many switch statements are generated. A value of 1 generates 1 switch containing all the elements, a value of 2 generates 2 tables with 1/2 the elements in each switch, etc. This is useful since many C compilers cannot correctly generate code for large switch statements. This option was inspired in part by Keith Bostic's original C program.

`%omit-struct-type'
: Prevents the transfer of the type declaration to the output file. Use this option if the type is already defined elsewhere.

3.1.1.3 C Code Inclusion

Using a syntax similar to GNU utilities flex and bison, it is possible to directly include C source text and comments verbatim into the generated output file. This is accomplished by enclosing the region inside left-justified surrounding `%{', `%}' pairs. Here is an input fragment based on the previous example that illustrates this feature:

```
%{
#include <assert.h>
/* This section of code is inserted directly into the output. */
int return_month_days (struct month *months, int is_leap_year);
%}
struct month { char *name; int number; int days; int leap_days; };
%%
january,   1, 31, 31
february,  2, 28, 29
march,     3, 31, 31
...
```

3.1.2 Format for Keyword Entries

The second input file format section contains lines of keywords and any associated attributes you might supply. A line beginning with `#' in the first column is considered a comment. Everything following the `#' is ignored, up to and including the following newline. A line beginning with `%' in the first column is an option declaration and must not occur within the keywords section.

The first field of each non-comment line is always the keyword itself. It can be given in two ways: as a simple name, i.e., without surrounding string quotation marks, or as a string enclosed in double-quotes, in C syntax, possibly with backslash escapes like \" or \234 or \xa8. In either case, it must start right at the beginning of the line, without leading whitespace. In this context, a "field" is considered to extend up to, but not include, the first blank, comma, or newline. Here is a simple example taken from a partial list of C reserved words:

```
# These are a few C reserved words, see the c.gperf file
# for a complete list of ANSI C reserved words.
unsigned
sizeof
switch
signed
if
default
for
while
return
```

Note that unlike `flex` or `bison` the first `%%' marker may be elided if the declaration section is empty.

Additional fields may optionally follow the leading keyword. Fields should be separated by commas, and terminate at the end of line. What these fields mean is entirely up to you; they are used to initialize the elements of the user-defined `struct` provided by you in the declaration section. If the `-t' option (or, equivalently, the `%struct-type' declaration) is *not* enabled these fields are simply ignored. All previous examples except the last one contain keyword attributes.

3.1.3 Including Additional C Functions

The optional third section also corresponds closely with conventions found in flex and bison. All text in this section, starting at the final '%%' and extending to the end of the input file, is included verbatim into the generated output file. Naturally, it is your responsibility to ensure that the code contained in this section is valid C.

3.1.4 Where to place directives for GNU indent.

If you want to invoke GNU indent on a gperf input file, you will see that GNU indent doesn't understand the '%%', '%{' and '%}' directives that control gperf's interpretation of the input file. Therefore you have to insert some directives for GNU indent. More precisely, assuming the most general input file structure

```
declarations part 1
%{
verbatim code
%}
declarations part 2
%%
keywords
%%
functions
```

you would insert '*INDENT-OFF*' and '*INDENT-ON*' comments as follows:

```
/* *INDENT-OFF* */
declarations part 1
%{
/* *INDENT-ON* */
verbatim code
/* *INDENT-OFF* */
%}
declarations part 2
%%
keywords
%%
/* *INDENT-ON* */
functions
```

3.2 Output Format for Generated C Code with gperf

Several options control how the generated C code appears on the standard output. Two C functions are generated. They are called hash and in_word_set, although you may modify their names with a command-line option. Both functions require two arguments, a string, char * *str*, and a length parameter, int *len*. Their default function prototypes are as follows:

unsigned int hash (*const char ** **str**, *size_t* **len**) [Function]

By default, the generated hash function returns an integer value created by adding *len* to several user-specified *str* byte positions indexed into an *associated values* table stored in a local static array. The associated values table is constructed internally by gperf and later output as a static local C array called `hash_table`. The relevant selected positions (i.e. indices into *str*) are specifed via the `-k` option when running gperf, as detailed in the *Options* section below (see Chapter 4 [Options], page 24).

`in_word_set` (*const char * **str**, size_t **len***) [Function]

If *str* is in the keyword set, returns a pointer to that keyword. More exactly, if the option `-t` (or, equivalently, the `%struct-type` declaration) was given, it returns a pointer to the matching keyword's structure. Otherwise it returns NULL.

If the option `-c` (or, equivalently, the `%compare-strncmp` declaration) is not used, *str* must be a NUL terminated string of exactly length *len*. If `-c` (or, equivalently, the `%compare-strncmp` declaration) is used, *str* must simply be an array of *len* bytes and does not need to be NUL terminated.

The code generated for these two functions is afected by the following options:

`-t`
`--struct-type`
: Make use of the user-defned struct.

`-S total-switch-statements`
`--switch=total-switch-statements`
: Generate 1 or more C switch statement rather than use a large, (and potentially sparse) static array. Although the exact time and space savings of this approach vary according to your C compiler's degree of optimization, this method often results in smaller and faster code.

If the `-t` and `-S` options (or, equivalently, the `%struct-type` and `%switch` declarations) are omitted, the default action is to generate a `char *` array containing the keywords, together with additional empty strings used for padding the array. By experimenting with the various input and output options, and timing the resulting C code, you can determine the best option choices for diferent keyword set characteristics.

3.3 Use of NUL bytes

By default, the code generated by gperf operates on zero terminated strings, the usual representation of strings in C. This means that the keywords in the input fle must not contain NUL bytes, and the *str* argument passed to hash or in_word_set must be NUL terminated and have exactly length *len*.

If option `-c` (or, equivalently, the `%compare-strncmp` declaration) is used, then the *str* argument does not need to be NUL terminated. The code generated by gperf will only access the frst *len*, not *len+1*, bytes starting at *str*. However, the keywords in the input fle still must not contain NUL bytes.

If option `-l` (or, equivalently, the `%compare-lengths` declaration) is used, then the hash table performs binary comparison. The keywords in the input fle may contain NUL bytes, written in string syntax as \000 or \x00, and the code generated by gperf will treat NUL like any other byte. Also, in this case the `-c` option (or, equivalently, the `%compare-strncmp` declaration) is ignored.

3.4 Controlling Identifiers

The identifers of the functions, tables, and constants defned by the code generated by gperf can be controlled through gperf declarations or the equivalent command-line options. This is useful for three purposes:

- Esthetics of the generated code.

  For this purpose, just use the available declarations or options at will.

- Controlling the exported identifers of a library.

  Assume you include code generated by gperf in a library, and to avoid collisions with other libraries, you want to ensure that all exported identifers of this library start with a certain prefx.

  By default, the only exported identifer is the lookup function. You can therefore use the option \`-N' (or, equivalently, the \`%define lookup-function-name' declaration).

  When you use the option \`-L C++' (or, equivalently, the \`%language=C++' declaration), the only exported entity is a class. You control its name through the option \`-Z' (or, equivalently, the \`%define class-name' declaration).

- Allowing multiple gperf generated codes in a single compilation unit.

  Assume you invoke gperf multiple times, with diferent input fles, and want the generated code to included from the same source fle. In this case, you have to customize not only the exported identifers, but also the names of functions with \`static' scope, types, and constants.

  By default, you will have to deal with the lookup function, the hash function, and the constants. You should therefore use the option \`-N' (or, equivalently, the \`%define lookup-function-name' declaration), the option \`-H' (or, equivalently, the \`%define hash-function-name' declaration), and the option \`--constants-prefix' (or, equivalently, the \`%define constants-prefix' declaration).

  If you use the option \`-G' (or, equivalently, the \`%global-table' declaration), you will also have to deal with the word array, the length table if present, and the string pool if present. This means: You should use the option \`-W' (or, equivalently, the \`%define word-array-name' declaration). If you use the option \`-l' (or, equivalently, the \`%compare-lengths' declaration), you should use the option \`--length-table-name' (or, equivalently, the \`%define length-table-name' declaration). If you use the option \`-P' (or, equivalently, the \`%pic' declaration), you should use the option \`-Q' (or, equivalently, the \`%define string-pool-name' declaration).

3.5 The Copyright of the Output

gperf is under GPL, but that does not cause the output produced by gperf to be under GPL. The reason is that the output contains only small pieces of text that come directly from gperf's source code { only about 7 lines long, too small for being signifcant {, and therefore the output is not a \work based on gperf" (in the sense of the GPL version 3).

On the other hand, the output produced by gperf contains essentially all of the input fle. Therefore the output is a \derivative work" of the input (in the sense of U.S. copyright law); and its copyright status depends on the copyright of the input. For most software licenses, the result is that the the output is under the same license, with the same copyright holder, as the input that was passed to gperf.

4 Invoking gperf

There are *many* options to `gperf`. They were added to make the program more convenient for use with real applications. \On-line" help is readily available via the `--help' option. Here is the complete list of options.

4.1 Specifying the Location of the Output File

`--output-file=*file*'
: Allows you to specify the name of the ﬁle to which the output is written to.

The results are written to standard output if no output ﬁle is speciﬁed or if it is `-'.

4.2 Options that affect Interpretation of the Input File

These options are also available as declarations in the input ﬁle (see Section 3.1.1.2 [Gperf Declarations], page 16).

`-e *keyword-delimiter-list*'
`--delimiters=*keyword-delimiter-list*'
: Allows you to provide a string containing delimiters used to separate keywords from their attributes. The default is ",". This option is essential if you want to use keywords that have embedded commas or newlines. One useful trick is to use -e'TAB', where TAB is the literal tab character.

`-t'
`--struct-type'
: Allows you to include a `struct` type declaration for generated code. Any text before a pair of consecutive `%%' is considered part of the type declaration. Keywords and additional ﬁelds may follow this, one group of ﬁelds per line. A set of examples for generating perfect hash tables and functions for Ada, C, C++, Pascal, Modula 2, Modula 3 and JavaScript reserved words are distributed with this release.

`--ignore-case'
: Consider upper and lower case ASCII characters as equivalent. The string comparison will use a case insigniﬁcant character comparison. Note that locale dependent case mappings are ignored. This option is therefore not suitable if a properly internationalized or locale aware case mapping should be used. (For example, in a Turkish locale, the upper case equivalent of the lowercase ASCII letter `i' is the non-ASCII character `capital i with dot above'.) For this case, it is better to apply an uppercase or lowercase conversion on the string before passing it to the `gperf` generated function.

4.3 Options to specify the Language for the Output Code

These options are also available as declarations in the input ﬁle (see Section 3.1.1.2 [Gperf Declarations], page 16).

`-L generated-language-name'
`--language=generated-language-name'

Instructs gperf to generate code in the language specifed by the option's argument. Languages handled are currently:

`KR-C' Old-style K&R C. This language is understood by old-style C compilers and ANSI C compilers, but ANSI C compilers may fag warnings (or even errors) because of lacking `const'.

`C' Common C. This language is understood by ANSI C compilers, and also by old-style C compilers, provided that you #define const to empty for compilers which don't know about this keyword.

`ANSI-C' ANSI C. This language is understood by ANSI C compilers and C++ compilers.

`C++' C++. This language is understood by C++ compilers.

The default is ANSI-C.

`-a' This option is supported for compatibility with previous releases of gperf. It does not do anything.

`-g' This option is supported for compatibility with previous releases of gperf. It does not do anything.

4.4 Options for fine tuning Details in the Output Code

Most of these options are also available as declarations in the input fle (see Section 3.1.1.2 [Gperf Declarations], page 16).

`-K slot-name'
`--slot-name=slot-name'

This option is only useful when option `-t' (or, equivalently, the `%struct-type' declaration) has been given. By default, the program assumes the structure component identifer for the keyword is `name'. This option allows an arbitrary choice of identifer for this component, although it still must occur as the frst feld in your supplied struct.

`-F initializers'
`--initializer-suffix=initializers'

This option is only useful when option `-t' (or, equivalently, the `%struct-type' declaration) has been given. It permits to specify initializers for the structure members following *slot-name* in empty hash table entries. The list of initializers should start with a comma. By default, the emitted code will zero-initialize structure members following *slot-name*.

`-H hash-function-name'
`--hash-function-name=hash-function-name'

Allows you to specify the name for the generated hash function. Default name is `hash'. This option permits the use of two hash tables in the same fle.

`-N lookup-function-name'
`--lookup-function-name=lookup-function-name'
: Allows you to specify the name for the generated lookup function. Default name is `in_word_set'. This option permits multiple generated hash functions to be used in the same application.

`-Z class-name'
`--class-name=class-name'
: This option is only useful when option `-L C++' (or, equivalently, the `%language=C++' declaration) has been given. It allows you to specify the name of generated C++ class. Default name is Perfect_Hash.

`-7'
`--seven-bit'
: This option specifes that all strings that will be passed as arguments to the generated hash function and the generated lookup function will solely consist of 7-bit ASCII characters (bytes in the range 0..127). (Note that the ANSI C functions isalnum and isgraph do *not* guarantee that a byte is in this range. Only an explicit test like `c >= 'A' && c <= 'Z'' guarantees this.) This was the default in versions of gperf earlier than 2.7; now the default is to support 8-bit and multibyte characters.

`-l'
`--compare-lengths'
: Compare keyword lengths before trying a string comparison. This option is mandatory for binary comparisons (see Section 3.3 [Binary Strings], page 22). It also might cut down on the number of string comparisons made during the lookup, since keywords with diferent lengths are never compared via strcmp. However, using `-l' might greatly increase the size of the generated C code if the lookup table range is large (which implies that the switch option `-S' or `%switch' is not enabled), since the length table contains as many elements as there are entries in the lookup table.

`-c'
`--compare-strncmp'
: Generates C code that uses the strncmp function to perform string comparisons. The default action is to use strcmp.

`-C'
`--readonly-tables'
: Makes the contents of all generated lookup tables constant, i.e., \readonly". Many compilers can generate more e f cient code for this by putting the tables in readonly memory.

`-E'
`--enum'
: Defne constant values using an enum local to the lookup function rather than with #defnes. This also means that diferent lookup functions can reside in the same fle. Thanks to James Clark <jjc@ai.mit.edu>.

`-I'
`--includes'
: Include the necessary system include fle, <string.h>, at the beginning of the code. By default, this is not done; the user must include this header fle himself to allow compilation of the code.

`-G'
`--global-table'
: Generate the static table of keywords as a static global variable, rather than hiding it inside of the lookup function (which is the default behavior).

`-P'
`--pic'
: Optimize the generated table for inclusion in shared libraries. This reduces the startup time of programs using a shared library containing the generated code. If the option `-t' (or, equivalently, the `%struct-type' declaration) is also given, the frst feld of the user-defned struct must be of type `int', not `char *', because it will contain ofsets into the string pool instead of actual strings. To convert such an ofset to a string, you can use the expression `stringpool + *o*', where *o* is the ofset. The string pool name can be changed through the option `--string-pool-name'.

`-Q *string-pool-name*'
`--string-pool-name=*string-pool-name*'
: Allows you to specify the name of the generated string pool created by option `-P'. The default name is `stringpool'. This option permits the use of two hash tables in the same fle, with `-P' and even when the option `-G' (or, equivalently, the `%global-table' declaration) is given.

`--null-strings'
: Use NULL strings instead of empty strings for empty keyword table entries. This reduces the startup time of programs using a shared library containing the generated code (but not as much as option `-P'), at the expense of one more test-and-branch instruction at run time.

`--constants-prefix=*prefix*'
: Allows you to specify a prefx for the constants TOTAL_KEYWORDS, MIN_WORD_LENGTH, MAX_WORD_LENGTH, and so on. This option permits the use of two hash tables in the same fle, even when the option `-E' (or, equivalently, the `%enum' declaration) is not given or the option `-G' (or, equivalently, the `%global-table' declaration) is given.

`-W *hash-table-array-name*'
`--word-array-name=*hash-table-array-name*'
: Allows you to specify the name for the generated array containing the hash table. Default name is `wordlist'. This option permits the use of two hash tables in the same fle, even when the option `-G' (or, equivalently, the `%global-table' declaration) is given.

`--length-table-name=*length-table-array-name*'
: Allows you to specify the name for the generated array containing the length table. Default name is `lengthtable'. This option permits the use of two

length tables in the same file, even when the option '-G' (or, equivalently, the '%global-table' declaration) is given.

'-S *total-switch-statements*'
'--switch=*total-switch-statements*'
: Causes the generated C code to use a switch statement scheme, rather than an array lookup table. This can lead to a reduction in both time and space requirements for some input files. The argument to this option determines how many switch statements are generated. A value of 1 generates 1 switch containing all the elements, a value of 2 generates 2 tables with 1/2 the elements in each switch, etc. This is useful since many C compilers cannot correctly generate code for large switch statements. This option was inspired in part by Keith Bostic's original C program.

'-T'
'--omit-struct-type'
: Prevents the transfer of the type declaration to the output file. Use this option if the type is already defined elsewhere.

'-p'
: This option is supported for compatibility with previous releases of gperf. It does not do anything.

4.5 Options for changing the Algorithms employed by gperf

'-k *selected-byte-positions*'
'--key-positions=*selected-byte-positions*'
: Allows selection of the byte positions used in the keywords' hash function. The allowable choices range between 1-255, inclusive. The positions are separated by commas, e.g., '-k 9,4,13,14'; ranges may be used, e.g., '-k 2-7'; and positions may occur in any order. Furthermore, the wildcard '*' causes the generated hash function to consider all byte positions in each keyword, whereas '$' instructs the hash function to use the "final byte" of a keyword (this is the only way to use a byte position greater than 255, incidentally).

For instance, the option '-k 1,2,4,6-10,'$'' generates a hash function that considers positions 1,2,4,6,7,8,9,10, plus the last byte in each keyword (which may be at a different position for each keyword, obviously). Keywords with length less than the indicated byte positions work properly, since selected byte positions exceeding the keyword length are simply not referenced in the hash function.

This option is not normally needed since version 2.8 of gperf; the default byte positions are computed depending on the keyword set, through a search that minimizes the number of byte positions.

'-D'
'--duplicates'
: Handle keywords whose selected byte sets hash to duplicate values. Duplicate hash values can occur if a set of keywords has the same names, but possesses different attributes, or if the selected byte positions are not well chosen. With the -D option gperf treats all these keywords as part of an equivalence class

and generates a perfect hash function with multiple comparisons for duplicate keywords. It is up to you to completely disambiguate the keywords by modifying the generated C code. However, gperf helps you out by organizing the output.

Using this option usually means that the generated hash function is no longer perfect. On the other hand, it permits gperf to work on keyword sets that it otherwise could not handle.

`-m *iterations*'
`--multiple-iterations=*iterations*'

Perform multiple choices of the `-i' and `-j' values, and choose the best results. This increases the running time by a factor of *iterations* but does a good job minimizing the generated table size.

`-i *initial-value*'
`--initial-asso=*initial-value*'

Provides an initial *value* for the associate values array. Default is 0. Increasing the initial value helps inf ate the f nal table size, possibly leading to more time e f cient keyword lookups. Note that this option is not particularly useful when `-S' (or, equivalently, `%switch') is used. Also, `-i' is overridden when the `-r' option is used.

`-j *jump-value*'
`--jump=*jump-value*'

A f ects the \jump value", i.e., how far to advance the associated byte value upon collisions. *Jump-value* is rounded up to an odd number, the default is 5. If the *jump-value* is 0 gperf jumps by random amounts.

`-n'
`--no-strlen'

Instructs the generator not to include the length of a keyword when computing its hash value. This may save a few assembly instructions in the generated lookup table.

`-r'
`--random'

Utilizes randomness to initialize the associated values table. This frequently generates solutions faster than using deterministic initialization (which starts all associated values at 0). Furthermore, using the randomization option generally increases the size of the table.

`-s *size-multiple*'
`--size-multiple=*size-multiple*'

A f ects the size of the generated hash table. The numeric argument for this option indicates \how many times larger or smaller" the maximum associated value range should be, in relationship to the number of keywords. It can be written as an integer, a f oating-point number or a fraction. For example, a value of 3 means \allow the maximum associated value to be about 3 times larger than the number of input keywords". Conversely, a value of 1/3 means \allow the maximum associated value to be about 3 times smaller than the number of input keywords". Values smaller than 1 are useful for limiting the overall size of the generated hash table, though the option '-m' is better at this purpose.

If 'generate switch' option '-S' (or, equivalently, '%switch') is *not* enabled, the maximum associated value influences the static array table size, and a larger table should decrease the time required for an unsuccessful search, at the expense of extra table space.

The default value is 1, thus the default maximum associated value about the same size as the number of keywords (for efficiency, the maximum associated value is always rounded up to a power of 2). The actual table size may vary somewhat, since this technique is essentially a heuristic.

4.6 Informative Output

'-h'
'--help' Prints a short summary on the meaning of each program option. Aborts further program execution.

'-v'
'--version'
Prints out the current version number.

'-d'
'--debug' Enables the debugging option. This produces verbose diagnostics to "standard error" when gperf is executing. It is useful both for maintaining the program and for determining whether a given set of options is actually speeding up the search for a solution. Some useful information is dumped at the end of the program when the '-d' option is enabled.

5 Known Bugs and Limitations with `gperf`

The following are some limitations with the current release of `gperf`:

- The `gperf` utility is tuned to execute quickly, and works quickly for small to medium size data sets (around 1000 keywords). It is extremely useful for maintaining perfect hash functions for compiler keyword sets. Several recent enhancements now enable `gperf` to work efficiently on much larger keyword sets (over 15,000 keywords). When processing large keyword sets it helps greatly to have over 8 megs of RAM.
- The size of the generate static keyword array can get *extremely* large if the input keyword file is large or if the keywords are quite similar. This tends to slow down the compilation of the generated C code, and *greatly* inflates the object code size. If this situation occurs, consider using the '`-S`' option to reduce data size, potentially increasing keyword recognition time a negligible amount. Since many C compilers cannot correctly generate code for large switch statements it is important to qualify the *-S* option with an appropriate numerical argument that controls the number of switch statements generated.
- The maximum number of selected byte positions has an arbitrary limit of 255. This restriction should be removed, and if anyone considers this a problem write me and let me know so I can remove the constraint.

6 Things Still Left to Do

It should be \relatively" easy to replace the current perfect hash function algorithm with a more exhaustive approach; the perfect hash module is essential independent from other program modules. Additional worthwhile improvements include:

- Another useful extension involves modifying the program to generate \minimal" perfect hash functions (under certain circumstances, the current version can be rather extravagant in the generated table size). This is mostly of theoretical interest, since a sparse table often produces faster lookups, and use of the `-S' `switch` option can minimize the data size, at the expense of slightly longer lookups (note that the gcc compiler generally produces good code for `switch` statements, reducing the need for more complex schemes).
- In addition to improving the algorithm, it would also be useful to generate an Ada package as the code output, in addition to the current C and C++ routines.

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