

gperf.info

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Chapter 1

gperf.info

1.1 gperf.info

Introduction

This manual documents the GNU gperf perfect hash function generator utility, focusing on its features and how to use them, and how to report bugs.

Copying

GNU gperf General Public License says how you can copy and share gperf.

Contributors

People who have contributed to gperf.

Motivation

Static search structures and GNU GPERF.

Search Structures

Static search structures and GNU gperf

Description

High-level discussion of how GPERF functions.

Options

A description of options to the program.

Bugs

Known bugs and limitations with GPERF.

Projects

Things still left to do.

Implementation

Implementation Details for GNU GPERF.

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Material Referenced in this Report.

-- The Detailed Node Listing --

High-Level Description of GNU gperf

Input Format

Input Format to gperf

Output Format

Output Format for Generated C Code with gperf

Input Format to gperf

Declarations

struct Declarations and C Code Inclusion.

Keywords

Format for Keyword Entries.

Functions

Including Additional C Functions.

1.2 gperf.info/Copying

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signature of Ty Coon, 1 April 1989
Ty Coon, President of Vice

That's all there is to it!

1.3 gperf.info/Contributors

Contributors to GNU gperf Utility

- * The GNU gperf perfect hash function generator utility was originally written in GNU C++ by Douglas C. Schmidt. It is now also available in a highly-portable "old-style" C version. 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 modified, enhanced, and extended implementation of Keith's basic idea, created at the University of California, Irvine. Bugs, patches, and suggestions should be reported to schmidt at ics.uci.edu.
- * 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.

1.4 gperf.info/Motivation

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 $k \geq n$. If $k = n$ 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 Pascal, GNU Modula 3, and GNU indent. Complete C++ source code for gperf is available via anonymous ftp from ics.uci.edu. gperf also is

distributed along with the GNU libg++ library. A highly portable, functionally equivalent K&R C version of gperf is archived in comp.sources.unix, volume 20. Finally, a paper describing gperf's design and implementation in greater detail is available in the Second USENIX C++ Conference proceedings.

1.5 gperf.info/Search Structures

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 specified 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 modified at run-time.

Numerous static search structure implementations exist, e.g., arrays, linked lists, binary search trees, digital search tries, and hash tables. Different approaches offer trade-offs between space utilization and search time efficiency. For example, an n element sorted array is space efficient, 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 defined 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 effort building an optimal search structure once, if it subsequently receives heavy use multiple times. gperf removes the drudgery associated with constructing time- and space-efficient 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 Pascal, and GNU Modula 3. The latter two compilers are not yet part of the official GNU distribution. Each compiler utilizes gperf to automatically generate static search structures that efficiently identify their respective reserved keywords.

1.6 gperf.info/Description

High-Level Description of GNU gperf

Input Format

Input Format to gperf

Output Format

Output Format for Generated C Code with gperf

The perfect hash function generator gperf reads a set of "keywords" from a keyfile (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 characters 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.

1.7 gperf.info/Input Format

Input Format to gperf

=====

You can control the input keyfile 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, all sections of gperf's input are optional. The following sections describe the input format for each section.

Declarations

struct Declarations and C Code Inclusion.

Keywords

Format for Keyword Entries.

Functions

Including Additional C Functions.

1.8 gperf.info/Declarations

struct Declarations and C Code Inclusion

The keyword input file optionally contains a section for including arbitrary C declarations and definitions, as well as provisions for providing a user-supplied struct. If the `-t` option is enabled, you must provide a C struct as the last component in the declaration section from the keyfile file. The first field in this struct must be a `char *` identifier called "name," although it is possible to modify this field's name with the `-K` option described below.

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

```

struct months { 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 key words and other fields are a pair of consecutive percent signs, `%%`, appearing left justified in the first column, as in the UNIX utility `lex`.

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 months *months, int is_leap_year);
%}
struct months { char *name; int number; int days; int leap_days; };
%%
january,    1, 31, 31
february,   2, 28, 29
march,      3, 31, 31
...

```

It is possible to omit the declaration section entirely. In this case the keyfile begins directly with the first keyword line, e.g.:

```

january,    1, 31, 31
february,   2, 28, 29
march,      3, 31, 31
april,      4, 30, 30
...

```

1.9 gperf.info/Keywords

Format for Keyword Entries

The second keyfile 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.

The first field of each non-comment line is always the key itself. It should be given as a simple name, i.e., without surrounding string quotation marks, and be left-justified flush against the first column. 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 is not enabled these fields are simply ignored. All previous examples except the last one contain keyword attributes.

1.10 gperf.info/Functions

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.

1.11 gperf.info/Output Format

Output Format for Generated C Code with gperf
=====

Several options control how the generated C code appears on the

standard output. Two C function are generated. They are called `hash` and `in_word_set`, although you may modify the name for `in_word_set` 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:

```
static int hash (char *str, int len);
int in_word_set (char *str, int len);
```

By default, the generated hash function returns an integer value created by adding `len` to several user-specified `str` key 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`; its meaning and properties are described below. See

Implementation

. The relevant

key positions are specified via the `-k` option when running `gperf`, as detailed in the Options section below. See

Options

.

Two options, `-g` (assume you are compiling with GNU C and its inline feature) and `-a` (assume ANSI C-style function prototypes), alter the content of both the generated `hash` and `in_word_set` routines. However, function `in_word_set` may be modified more extensively, in response to your option settings. The options that affect the `in_word_set` structure are:

`-p`

Have function `in_word_set` return a pointer rather than a boolean.

`-t`

Make use of the user-defined struct.

`-S 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`, `-S`, and `-p` options are omitted the default action is to generate a `char *` array containing the keys, together with additional null 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 different keyword set characteristics.

1.12 gperf.info/Options

Options to the gperf Utility

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 -h option. Other options include:

- a
Generate ANSI Standard C code using function prototypes. The default is to use "classic" K&R C function declaration syntax.
 - c
Generates C code that uses the strncmp function to perform string comparisons. The default action is to use strcmp.
 - C
Makes the contents of all generated lookup tables constant, i.e., "readonly." Many compilers can generate more efficient code for this by putting the tables in readonly memory.
 - d
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.
 - D
Handle keywords whose key position sets hash to duplicate values. Duplicate hash values occur for two reasons:
 - * Since gperf does not backtrack it is possible for it to process all your input keywords without finding a unique mapping for each word. However, frequently only a very small number of duplicates occur, and the majority of keys still require one probe into the table.
 - * Sometimes a set of keys may have the same names, but possess different attributes. With the -D option gperf treats all these keys as part of an equivalence class and generates a perfect hash function with multiple comparisons for duplicate keys. 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.Option -D is extremely useful for certain large or highly redundant keyword sets, i.e., assembler instruction opcodes. 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.
 - e keyword delimiter list
Allows the user to provide a string containing delimiters
-

- used to separate keywords from their attributes. The default is `",\n"`. 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.
- E**
Define constant values using an enum local to the lookup function rather than with `#defines`. This also means that different lookup functions can reside in the same file. Thanks to James Clark (jjc at ai.mit.edu).
- f iteration amount**
Generate the perfect hash function "fast." This decreases gperf's running time at the cost of minimizing generated table-size. The iteration amount represents the number of times to iterate when resolving a collision. '0' means 'iterate by the number of keywords. This option is probably most useful when used in conjunction with options `-D` and/or `-S` for large keyword sets.
- g**
Assume a GNU compiler, e.g., `g++` or `gcc`. This makes all generated routines use the "inline" keyword to remove the cost of function calls. Note that `-g` does not imply `-a`, since other non-ANSI C compilers may have provisions for a function inline feature.
- G**
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).
- h**
Prints a short summary on the meaning of each program option. Aborts further program execution.
- H 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 file.
- i initial value**
Provides an initial value for the associate values array. Default is 0. Increasing the initial value helps inflate the final table size, possibly leading to more time efficient keyword lookups. Note that this option is not particularly useful when `-S` is used. Also, `-i` is overridden when the `-r` option is used.
- j jump value**
Affects the "jump value," i.e., how far to advance the associated character 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.
- k keys**
-

Allows selection of the character key positions used in the keywords' hash function. The allowable choices range between 1-126, 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 meta-character '*' causes the generated hash function to consider all character positions in each key, whereas '\$' instructs the hash function to use the "final character" of a key (this is the only way to use a character position greater than 126, 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 character in each key (which may differ for each key, obviously). Keys with length less than the indicated key positions work properly, since selected key positions exceeding the key length are simply not referenced in the hash function.

-K key name

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.

-l

Compare key lengths before trying a string comparison. This might cut down on the number of string comparisons made during the lookup, since keys with different 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 is not enabled), since the length table contains as many elements as there are entries in the lookup table.

-L generated language name

Instructs gperf to generate code in the language specified by the option's argument. Languages handled are currently C++ and C. The default is C.

-n

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.

-N lookup function name

Allows you to specify the name for the generated lookup function. Default name is 'in_word_set.' This option permits completely automatic generation of perfect hash functions, especially when multiple generated hash functions are used in the same application.

-o

Reorders the keywords by sorting the keywords so that frequently occurring key position set components appear first. A second reordering pass follows so that keys with "already

determined values" are placed towards the front of the keylist. This may decrease the time required to generate a perfect hash function for many keyword sets, and also produce more minimal perfect hash functions. The reason for this is that the reordering helps prune the search time by handling inevitable collisions early in the search process. On the other hand, if the number of keywords is very large using `-o` may increase gperf's execution time, since collisions will begin earlier and continue throughout the remainder of keyword processing. See Cichelli's paper from the January 1980 Communications of the ACM for details.

`-p`

Changes the return value of the generated function `in_word_set` from boolean (i.e., 0 or 1), to either type "pointer to user-defined struct," (if the `-t` option is enabled), or simply to char *, if `-t` is not enabled. This option is most useful when the `-t` option (allowing user-defined structs) is used. For example, it is possible to automatically generate the GNU C reserved word lookup routine with the options `-p` and `-t`.

`-r`

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. If gperf has difficulty with a certain keyword set try using `-r` or `-D`.

`-s size-multiple`

Affects 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 keys. If the `size-multiple` is negative the maximum associated value is calculated by dividing it into the total number of keys. For example, a value of 3 means "allow the maximum associated value to be about 3 times larger than the number of input keys."

Conversely, a value of -3 means "allow the maximum associated value to be about 3 times smaller than the number of input keys." Negative values are useful for limiting the overall size of the generated hash table, though this usually increases the number of duplicate hash values.

If 'generate switch' option `-S` 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 keys (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. In particular, setting this value too high slows down gperf's runtime, since it must search through a much larger range of

values. Judicious use of the `-f` option helps alleviate this overhead, however.

`-S` 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 keyfiles. 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`

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. Key words 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, and G++, Pascal, and Modula 2 and 3 reserved words are distributed with this release.

`-T`

Prevents the transfer of the type declaration to the output file. Use this option if the type is already defined elsewhere.

`-v`

Prints out the current version number.

`-Z` class name

Allow user to specify name of generated C++ class. Default name is `Perfect_Hash`.

1.13 gperf.info/Bugs

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.

However, since gperf does not backtrack no guaranteed solution occurs on every run. On the other hand, it is usually easy to obtain a solution by varying the option parameters. In

particular, try the `-r` option, and also try changing the default arguments to the `-s` and `-j` options. To guarantee a solution, use the `-D` and `-S` options, although the final results are not likely to be a perfect hash function anymore! Finally, use the `-f` option if you want gperf to generate the perfect hash function fast, with less emphasis on making it minimal.

- * 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 generated 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 key positions selected for a given key has an arbitrary limit of 126. This restriction should be removed, and if anyone considers this a problem write me and let me know so I can remove the constraint.
- * The C++ source code only compiles correctly with GNU G++, version 1.36 (and hopefully later versions). Porting to AT&T cfront would be tedious, but possible (and desirable). There is also a K&R C version available now. This should compile without change on most BSD systems, but may require a bit of work to run on SYSV, since gperf uses `alloca` in several places. Send mail to schmidt at ics.uci.edu for information.

1.14 gperf.info/Projects

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:

- * Make the algorithm more robust. At present, the program halts with an error diagnostic if it can't find a direct solution and the `-D` option is not enabled. A more comprehensive, albeit computationally expensive, approach would employ backtracking or enable alternative options and retry. It's not clear how helpful this would be, in general, since most search sets are rather small in practice.
- * 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). Again, 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 a C++ class or Ada package as the code output, in addition to the current C routines.

1.15 gperf.info/Implementation

Implementation Details of GNU gperf

A paper describing the high-level description of the data structures and algorithms used to implement gperf will soon be available. This paper is useful not only from a maintenance and enhancement perspective, but also because they demonstrate several clever and useful programming techniques, e.g., 'Iteration Number' boolean arrays, double hashing, a "safe" and efficient method for reading arbitrarily long input from a file, and a provably optimal algorithm for simultaneously determining both the minimum and maximum elements in a list.

1.16 gperf.info/Bibliography

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