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## References

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<http://www.aleksey.com/pipermail/xmlsec/2003/005488.html>

<http://www.aleksey.com/pipermail/xmlsec/attachments/20030729/0e25648e/attachment.htm>

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# Klib: a Generic Library in C

## <a name="overview"></a>Overview

Klib is a standalone and lightweight C library distributed under [MIT/X11 license][1]. Most components are independent of external libraries, except the standard C library, and independent of each other. To use a component of this library, you only need to copy a couple of files to your source code tree without worrying about library dependencies.

Klib strives for efficiency and a small memory footprint. Some components, such as khash.h, kbtree.h, ksort.h and kvec.h, are among the most efficient implementations of similar algorithms or data structures in all programming languages, in terms of both speed and memory use.

A new documentation is available [here](http://attractivechaos.github.io/klib/) which includes most information in this README file.

#### Common components

- \* [khash.h][khash]: generic [hash table][2] with open addressing.
- \* [kbtree.h][kbtree]:  
generic search tree based on [B-tree][3].
- \* [kavl.h][kavl]: generic intrusive [AVL tree][wiki-avl].
- \* [ksort.h][ksort]: generic sort, including [introsort][4], [merge sort][5], [heap sort][6], [comb sort][7], [Knuth shuffle][8] and the [k-small][9] algorithm.
- \* [kseq.h][kseq]: generic stream buffer and a [FASTA][10]/[FASTQ][11] format parser.
- \* kvec.h: generic dynamic array.
- \* klist.h: generic single-linked list and [memory pool][12].
- \* kstring.{h,c}: basic string library.
- \* kmath.{h,c}: numerical routines including [MT19937-64][13] [pseudorandom generator][14], basic [nonlinear programming][15] and a few special math functions.
- \* [ketopt.h][ketopt]: portable command-line argument parser with getopt\\_long-like API.

#### Components for more specific use cases

- \* ksa.c: constructing [suffix arrays][16] for strings with multiple sentinels, based on a revised [SAIS algorithm][17].
- \* knetfile.{h,c}: random access to remote files on HTTP or FTP.
- \* kopen.c: smart stream opening.
- \*
- khmm.{h,c}: basic [HMM][18] library.
- \* ksw.{h,c}: Striped [Smith-Waterman algorithm][19].
- \* knhx.{h,c}: [Newick tree format][20] parser.

## <a name="methodology"></a>Methodology

For the implementation of generic [containers][21], klib extensively uses C macros. To use these data structures, we usually need to instantiate methods by expanding a long macro. This makes the source code look unusual or even ugly and adds difficulty to debugging. Unfortunately, for efficient generic programming in C that lacks [template][22], using macros is the only solution. Only with macros, we can write a generic container which, once instantiated, compete with a type-specific container in efficiency. Some generic libraries in C, such as [Glib][23], use the `void\*` type to implement containers. These implementations are usually slower and use more memory than klib (see [this benchmark][31]).

To effectively use klib, it is important to understand how it achieves generic programming. We will use the hash table library as an example:

```
#include "khash.h"
KHASH_MAP_INIT_INT(m32, char)    // instantiate structs and methods
int main() {
    int ret, is_missing;
    khint_t k;
    khash_t(m32) *h = kh_init(m32); // allocate a hash table
    k = kh_put(m32, h, 5, &ret);    // insert a key to the hash table
    if (!ret) kh_del(m32, h, k);
    kh_value(h, k) = 10;           // set the value
    k = kh_get(m32, h, 10);        // query the hash table
    is_missing = (k == kh_end(h)); // test if the key is present
    k = kh_get(m32, h, 5);
    kh_del(m32, h, k);             // remove a key-value pair
    for (k = kh_begin(h); k != kh_end(h); ++k) // traverse
        if (kh_exist(h, k))        // test if a bucket contains data
            kh_value(h, k) = 1;
    kh_destroy(m32, h);           // deallocate the hash table
    return 0;
}
```

In this example, the second line instantiates a hash table with `unsigned` as the key type and `char` as the value type. `m32` names such a type of hash table. All types and functions associated with this name are macros, which will be explained later. Macro `kh\_init()` initiates a hash table and `kh\_destroy()` frees it. `kh\_put()` inserts a key and returns the iterator (or the position) in the hash table. `kh\_get()` and `kh\_del()` get a key and delete an element, respectively. Macro `kh\_exist()` tests if an iterator (or a position) is filled with data.

An immediate question is this piece of code does not look like a valid C program (e.g. lacking semicolon, assignment to an `_apparent_` function call and `_apparent_undefined`m32` 'variable'`). To understand why the code is correct, let's go a bit further into the source code of `kh hash.h`, whose skeleton looks like:

```
#define KHASH_INIT(name, SCOPE, key_t, val_t, is_map, _hashf, _hasheq) \
typedef struct { \
    int n_buckets, size, n_occupied, upper_bound; \
    unsigned *flags; \
\
    key_t *keys; \
    val_t *vals; \
} kh_##name##_t; \
SCOPE inline kh_##name##_t *init_##name() { \
    return (kh_##name##_t*)calloc(1, sizeof(kh_##name##_t)); \
} \
SCOPE inline int get_##name(kh_##name##_t *h, key_t k) \
... \
SCOPE inline void destroy_##name(kh_##name##_t *h) { \
    if (h) { \
        free(h->keys); free(h->flags); free(h->vals); free(h); \
    } \
}

#define _int_hf(key) (unsigned)(key)
#define _int_heq(a, b) (a == b)
#define khash_t(name) kh_##name##_t
#define kh_value(h, k) ((h)->vals[k])
#define kh_begin(h, k) 0
#define kh_end(h) ((h)->n_buckets)
#define kh_init(name) init_##name()
#define kh_get(name, h, k) get_##name(h, k)
#define kh_destroy(name, h) destroy_##name(h)
...
#define KHASH_MAP_INIT_INT(name, val_t) \
    KHASH_INIT(name, static, unsigned, val_t, is_map, _int_hf, _int_heq)
```

`KHASH_INIT()` is a huge macro defining all the structs and methods.

When this

macro is called, all the code inside it will be inserted by the [C preprocess][37] to the place where it is called. If the macro is called multiple times, multiple copies of the code will be inserted. To avoid naming conflict of hash tables with different key-value types, the library uses [token concatenation][36], which is a preprocessor feature whereby we can substitute part of a symbol based on the parameter of the macro. In the end, the C preprocessor will generate the following code and feed it to the compiler (macro `kh_exist(h,k)` is a little complex and not expanded for simplicity):

```

typedef struct {
    int n_buckets, size, n_occupied, upper_bound;
    unsigned *flags;
    unsigned *keys;
    char *vals;
} kh_m32_t;
static inline kh_m32_t *init_m32() {
    return (kh_m32_t*)calloc(1, sizeof(kh_m32_t));
}
static inline int get_m32(kh_m32_t *h, unsigned k)
...
static inline void destroy_m32(kh_m32_t *h) {
    if (h) {

free(h->keys); free(h->flags); free(h->vals); free(h);
    }
}

int main() {
    int ret, is_missing;
    khint_t k;
    kh_m32_t *h = init_m32();
    k = put_m32(h, 5, &ret);
    if (!ret) del_m32(h, k);
    h->vals[k] = 10;
    k = get_m32(h, 10);
    is_missing = (k == h->n_buckets);
    k = get_m32(h, 5);
    del_m32(h, k);
    for (k = 0; k != h->n_buckets; ++k)
        if (kh_exist(h, k)) h->vals[k] = 1;
    destroy_m32(h);
    return 0;
}

```

This is the C program we know.

From this example, we can see that macros and the C preprocessor plays a key role in klib. Klib is fast partly because the compiler knows the key-value type at the compile time and is able to optimize the code to the same level as type-specific code. A generic library written with `void\*` will not get such performance boost.

Massively inserting code upon instantiation may remind us of C++'s slow compiling speed and huge binary size when STL/boost is in use. Klib is much better in this respect due to its small code size and component

independency.

Inserting several hundreds lines of code won't make compiling obviously slower.

```
## <a name="resources"></a>Resources
```

\* Library documentation, if present, is available in the header files. Examples can be found in the [test/][24] directory.

\* **Obsolete** documentation of the hash table library can be found at

[SourceForge][25]. This README is partly adapted from the old documentation.

\* [Blog post][26] describing the hash table library.

\* [Blog post][27] on why using `void\*` for generic programming may be inefficient.

\* [Blog post][28] on the generic stream buffer.

\* [Blog post][29] evaluating the performance of `kvec.h`.

\* [Blog post][30] arguing B-tree may be a better data structure than a binary search tree.

\* [Blog post][31] evaluating the performance of `khash.h` and `kbtrees.h` among many other implementations.

[An older version][33] of the benchmark is also available.

\* [Blog post][34] benchmarking internal sorting algorithms and implementations.

\* [Blog post][32]

on the k-small algorithm.

\* [Blog post][35] on the Hooke-Jeeve's algorithm for nonlinear programming.

[1]: [http://en.wikipedia.org/wiki/MIT\\_License](http://en.wikipedia.org/wiki/MIT_License)

[2]: [https://en.wikipedia.org/wiki/Hash\\_table](https://en.wikipedia.org/wiki/Hash_table)

[3]: <http://en.wikipedia.org/wiki/B-tree>

[4]: <http://en.wikipedia.org/wiki/Introsort>

[5]: [http://en.wikipedia.org/wiki/Merge\\_sort](http://en.wikipedia.org/wiki/Merge_sort)

[6]: <http://en.wikipedia.org/wiki/Heapsort>

[7]: [http://en.wikipedia.org/wiki/Comb\\_sort](http://en.wikipedia.org/wiki/Comb_sort)

[8]: [http://en.wikipedia.org/wiki/Fisher-Yates\\_shuffle](http://en.wikipedia.org/wiki/Fisher-Yates_shuffle)

[9]: [http://en.wikipedia.org/wiki/Selection\\_algorithm](http://en.wikipedia.org/wiki/Selection_algorithm)

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[12]: [http://en.wikipedia.org/wiki/Memory\\_pool](http://en.wikipedia.org/wiki/Memory_pool)

[13]: [http://en.wikipedia.org/wiki/Mersenne\\_twister](http://en.wikipedia.org/wiki/Mersenne_twister)

[14]: [http://en.wikipedia.org/wiki/Pseudorandom\\_generator](http://en.wikipedia.org/wiki/Pseudorandom_generator)

[15]: [http://en.wikipedia.org/wiki/Nonlinear\\_programming](http://en.wikipedia.org/wiki/Nonlinear_programming)

[16]: [http://en.wikipedia.org/wiki/Suffix\\_array](http://en.wikipedia.org/wiki/Suffix_array)

[17]: <https://sites.google.com/site/yuta256/sais>

[18]: [http://en.wikipedia.org/wiki/Hidden\\_Markov\\_model](http://en.wikipedia.org/wiki/Hidden_Markov_model)

[19]: [http://en.wikipedia.org/wiki/Smith-Waterman\\_algorithm](http://en.wikipedia.org/wiki/Smith-Waterman_algorithm)

[20]:

[http://en.wikipedia.org/wiki/Newick\\_format](http://en.wikipedia.org/wiki/Newick_format)

[21]: [http://en.wikipedia.org/wiki/Container\\_\(abstract\\_data\\_type\)](http://en.wikipedia.org/wiki/Container_(abstract_data_type))

[22]: [http://en.wikipedia.org/wiki/Template\\_\(C%2B%2B\)](http://en.wikipedia.org/wiki/Template_(C%2B%2B))

[23]: <http://en.wikipedia.org/wiki/GLib>

[24]: <https://github.com/attractivechaos/klib/tree/master/test>

[25]: <http://klib.sourceforge.net/>

[26]: <http://attractivechaos.wordpress.com/2008/09/02/implementing-generic-hash-library-in-c/>

[27]: <http://attractivechaos.wordpress.com/2008/10/02/using-void-in-generic-c-programming-may-be-inefficient/>  
[28]: <http://attractivechaos.wordpress.com/2008/10/11/a-generic-buffered-stream-wrapper/>  
[29]: <http://attractivechaos.wordpress.com/2008/09/19/c-array-vs-c-vector/>  
[30]: <http://attractivechaos.wordpress.com/2008/09/24/b-tree-vs-binary-search-tree/>  
[31]: <http://attractivechaos.wordpress.com/2008/10/07/another-look-at-my-old-benchmark/>  
[32]: <http://attractivechaos.wordpress.com/2008/09/13/calculating-median/>  
[33]: <http://attractivechaos.wordpress.com/2008/08/28/comparison-of-hash-table-libraries/>  
[34]:  
<http://attractivechaos.wordpress.com/2008/08/28/comparison-of-internal-sorting-algorithms/>  
[35]: <http://attractivechaos.wordpress.com/2008/08/24/derivative-free-optimization-dfo/>  
[36]: [http://en.wikipedia.org/wiki/C\\_preprocessor#Token\\_concatenation](http://en.wikipedia.org/wiki/C_preprocessor#Token_concatenation)  
[37]: [http://en.wikipedia.org/wiki/C\\_preprocessor](http://en.wikipedia.org/wiki/C_preprocessor)

[wiki-avl]: [https://en.wikipedia.org/wiki/AVL\\_tree](https://en.wikipedia.org/wiki/AVL_tree)

[kbtree]:

<http://attractivechaos.github.io/klib/#Kbtree%3A%20generic%20ordered%20map:%5B%5BKbtree%3A%20generic%20ordered%20map%5D%5D>

[khash]:

<http://attractivechaos.github.io/klib/#Khash%3A%20generic%20hash%20table:%5B%5BKhash%3A%20generic%20hash%20table%5D%5D>

[kseq]:

<http://attractivechaos.github.io/klib/#Kseq%3A%20stream%20buffer%20and%20FASTA%2FQ%20parser:%5B%5BKseq%3A%20stream%20buffer%20and%20FASTA%2FQ%20parser%5D%5D>

[ksort]: <http://attractivechaos.github.io/klib/#Ksort%3A%20sorting%2C%20shuffling%2C%20heap%20and%20k-small:%5B%5BKsort%3A%20sorting%2C%20shuffling%2C%20heap%20and%20k-small%5D%5D>

[kavl]:

<http://attractivechaos.github.io/klib/#KAVL%3A%20generic%20intrusive%20AVL%20tree>

[ketopt]: <http://attractivechaos.github.io/klib/#Ketopt%3A%20parsing%20command-line%20arguments>

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## 1.12 cre2 0.3.1-0.3.1

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That's all there is to it!  
getopt.c - my re-implementation of getopt.  
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