

**NAME****Cdt** – container data types**SYNOPSIS**`#include <cdt.h>`**DICTIONARY TYPES**

```
Dt_t;
Dtdisc_t;
Dtmethod_t;
Dtlink_t;
Dtstat_t;
```

**DICTIONARY CONTROL**

```
Dt_t*      dtopen(const Dtdisc_t* disc, const Dtmethod_t* meth);
int        dtclose(Dt_t* dt);
void       dtclear(dt);
Dtmethod_t* dtmethod(Dt_t* dt, const Dtmethod_t* meth);
Dtdisc_t*   dtdisc(Dt_t* dt, const Dtdisc_t* disc, int type);
Dt_t*      dtview(Dt_t* dt, Dt_t* view);
```

**STORAGE METHODS**

```
Dtmethod_t* Dtset;
Dtmethod_t* Dtbag;
Dtmethod_t* Dtset;
Dtmethod_t* Dtobag;
Dtmethod_t* Dtlist;
Dtmethod_t* Dtstack;
Dtmethod_t* Dtqueue;
Dtmethod_t* Dtdeque;
```

**DISCIPLINE**

```
#define DTOFFSET(struct_s, member)
#define DTDISC(disc, key, size, link, makef, freef, comparf, hashf, memoryf, eventf)
typedef void*      (*Dtmake_f)(Dt_t*, void*, Dtdisc_t*);
typedef void       (*Dtfree_f)(Dt_t*, void*, Dtdisc_t*);
typedef int        (*Dtcompar_f)(Dt_t*, void*, void*, Dtdisc_t*);
typedef unsigned int (*Dthash_f)(Dt_t*, void*, Dtdisc_t*);
typedef void*      (*Dtmemory_f)(Dt_t*, void*, size_t, Dtdisc_t*);
typedef int        (*Dtevent_f)(Dt_t*, int, void*, Dtdisc_t*);
```

**OBJECT OPERATIONS**

```
void* dtinsert(Dt_t* dt, void* obj);
void* dtappend(Dt_t* dt, void* obj);
void* dtdelete(Dt_t* dt, void* obj);
void* dtattach(Dt_t* dt, void* obj);
void* dtdetach(Dt_t* dt, void* obj);
void* dtsearch(Dt_t* dt, void* obj);
void* dtmatch(Dt_t* dt, void* key);
void* dtfirst(Dt_t* dt);
void* dtnext(Dt_t* dt, void* obj);
void* dtlast(Dt_t* dt);
void* dtprev(Dt_t* dt, void* obj);
void* dtfinger(Dt_t* dt);
void* dtrenew(Dt_t* dt, void* obj);
int   dtwalk(Dt_t* dt, int (*userf)(Dt_t*, void*, void*), void*);
Dtlink_t* dtflatten(Dt_t* dt);
Dtlink_t* dtlink(Dt_t*, Dtlink_t* link);
```

```

void*    dtobj(Dt_t* dt, Dtlink_t* link);
Dtlink_t* dtextract(Dt_t* dt);
int      dtrestore(Dt_t* dt, Dtlink_t* link);

#define DTTREESEARCH(Dt_t* dt, void* obj, action)
#define DTTREEMATCH(Dt_t* dt, void* key, action)

```

## DICTIONARY STATUS

```

Dt_t*    dtvnext(Dt_t* dt);
int      dtvcount(Dt_t* dt);
Dt_t*    dtvwhere(Dt_t* dt);
int      dtsize(Dt_t* dt);
int      dtstat(Dt_t* dt, Dtstat_t*, int all);

```

## HASH FUNCTIONS

```

unsigned int dtstrhash(unsigned int h, char* str, int n);
unsigned int dtcharhash(unsigned int h, unsigned char c);

```

## DESCRIPTION

*Cdt* manages run-time dictionaries using standard container data types: unordered set/multiset, ordered set/multiset, list, stack, and queue.

## DICTIONARY TYPES

### **Dt\_t**

This is the type of a dictionary handle.

### **Dtdisc\_t**

This defines the type of a discipline structure which describes object lay-out and manipulation functions.

### **Dtmethod\_t**

This defines the type of a container method.

### **Dtlink\_t**

This is the type of a dictionary object holder (see `dtdisc()`).

### **Dtstat\_t**

This is the type of a structure to return dictionary statistics (see `dtstat()`).

## DICTIONARY CONTROL

### **Dt\_t\* dtopen(const Dtdisc\_t\* disc, const Dtmethod\_t\* meth)**

This creates a new dictionary. `disc` is a discipline structure to describe object format. `meth` specifies a manipulation method. `dtopen()` returns the new dictionary or `NULL` on error. See also the events `DT_OPEN` and `DT_ENDOPEN` below.

### **int dtclose(Dt\_t\* dt)**

This deletes `dt` and its objects. Note that `dtclose()` fails if `dt` is being viewed by some other dictionaries (see `dtview()`). `dtclose()` returns 0 on success and -1 on error. See also the events `DT_CLOSE` and `DT_ENDCLOSE` below.

### **void dtclear(Dt\_t\* dt)**

This deletes all objects in `dt` without closing `dt`.

### **Dtmethod\_t dtmethod(Dt\_t\* dt, const Dtmethod\_t\* meth)**

If `meth` is `NULL`, `dtmethod()` returns the current method. Otherwise, it changes the storage method of `dt` to `meth`. Object order remains the same during a method switch among `Dtlist`, `Dtstack`, `Dtqueue` and `Dtdeque`. Switching to and from `Dtset`/`Dtbag` and `Dtoset`/`Dtobag` may cause objects to be rehashed, reordered, or removed as the case requires. `dtmethod()` returns the previous method or `NULL` on error.

### **Dtdisc\_t\* dtdisc(Dt\_t\* dt, const Dtdisc\_t\* disc, int type)**

If `disc` is `NULL`, `dtdisc()` returns the current discipline. Otherwise, it changes the discipline of `dt` to `disc`. Objects may be rehashed, reordered, or removed as appropriate. `type` can be any bit combination

of DT\_SAMECMP and DT\_SAMEHASH. DT\_SAMECMP means that objects will compare exactly the same as before thus obviating the need for reordering or removing new duplicates. DT\_SAMEHASH means that hash values of objects remain the same thus obviating the need to rehash. `dtdisc()` returns the previous discipline on success and NULL on error.

### **Dt\_t\* dtview(Dt\_t\* dt, Dt\_t\* view)**

A viewpath allows a search or walk starting from a dictionary to continue to another. `dtview()` first terminates any current view from `dt` to another dictionary. Then, if `view` is NULL, `dtview` returns the terminated view dictionary. If `view` is not NULL, a viewpath from `dt` to `view` is established. `dtview()` returns `dt` on success and NULL on error.

It is an error to have dictionaries on a viewpath with different storage methods. In addition, dictionaries on the same view path should treat objects in a consistent manner with respect to comparison or hashing. If not, undefined behaviors may result.

## **STORAGE METHODS**

Storage methods are of type `Dtmethod_t*`. *Cdt* supports the following methods:

### **Dtset**

#### **Dtobag**

Objects are ordered by comparisons. `Dtset` keeps unique objects. `Dtobag` allows repeatable objects.

### **Dtset**

#### **Dtbag**

Objects are unordered. `Dtset` keeps unique objects. `Dtbag` allows repeatable objects and always keeps them together (note the effect on dictionary walking.) These methods use a hash table with chaining to manage the objects. See also the event DT\_HASHSIZE below on how to manage hash table resizing when objects are inserted.

### **Dtlist**

Objects are kept in a list. The call `dtinsert()` inserts a new object in front of *the current object* (see `dtfinger()`) if it is defined or at list front if no current object is defined. Similarly, the call `dtappend()` appends a new object after *the current object* (see `dtfinger()`) if it is defined or at list end if no current object is defined.

### **Dtdeque**

Objects are kept in a deque. This is similar to `Dtlist` except that objects are always inserted at the front and appended at the tail of the list.

### **Dtstack**

Objects are kept in a stack, i.e., in reverse order of insertion. Thus, the last object inserted is at stack top and will be the first to be deleted.

### **Dtqueue**

Objects are kept in a queue, i.e., in order of insertion. Thus, the first object inserted is at queue head and will be the first to be deleted.

## **DISCIPLINE**

Object format and associated management functions are defined in the type `Dtdisc_t`:

```
typedef struct
{
    int      key, size;
    int      link;
    Dtmake_f makef;
    Dtfree_f  freef;
    Dtcompar_f comparf;
    Dthash_f  hashf;
    Dtmemory_f memoryf;
    Dtevent_f eventf;
} Dtdisc_t;
```

**int key, size**

Each object `obj` is identified by a key used for object comparison or hashing. `key` should be non-negative and defines an offset into `obj`. If `size` is negative, the key is a null-terminated string with starting address `*(void**) ((char*)obj+key)`. If `size` is zero, the key is a null-terminated string with starting address `(void*) ((char*)obj+key)`. Finally, if `size` is positive, the key is a byte array of length `size` starting at `(void*) ((char*)obj+key)`.

**int link**

Let `obj` be an object to be inserted into `dt` as discussed below. If `link` is negative, an internally allocated object holder is used to hold `obj`. Otherwise, `obj` should have a `Dtlink_t` structure embedded `link` bytes into it, i.e., at address `(Dtlink_t*) ((char*)obj+link)`.

**void\* (\*makef)(Dt\_t\* dt, void\* obj, Dtdisc\_t\* disc)**

If `makef` is not NULL, `dtinsert(dt, obj)` or `dtappend()` will call it to make a copy of `obj` suitable for insertion into `dt`. If `makef` is NULL, `obj` itself will be inserted into `dt`.

**void (\*freef)(Dt\_t\* dt, void\* obj, Dtdisc\_t\* disc)**

If not NULL, `freef` is used to destroy data associated with `obj`.

**int (\*comparf)(Dt\_t\* dt, void\* key1, void\* key2, Dtdisc\_t\* disc)**

If not NULL, `comparf` is used to compare two keys. Its return value should be `<0`, `=0`, or `>0` to indicate whether `key1` is smaller, equal to, or larger than `key2`. All three values are significant for method `Dtset` and `Dtobag`. For other methods, a zero value indicates equality and a non-zero value indicates inequality. If `(*comparf)()` is NULL, an internal function is used to compare the keys as defined by the `Dtdisc_t.size` field.

**unsigned int (\*hashf)(Dt\_t\* dt, void\* key, Dtdisc\_t\* disc)**

If not NULL, `hashf` is used to compute the hash value of `key`. It is required that keys compared equal will also have same hash values. If `hashf` is NULL, an internal function is used to hash the key as defined by the `Dtdisc_t.size` field.

**void\* (\*memoryf)(Dt\_t\* dt, void\* addr, size\_t size, Dtdisc\_t\* disc)**

If not NULL, `memoryf` is used to allocate and free memory. When `addr` is NULL, a memory segment of size `size` is requested. If `addr` is not NULL and `size` is zero, `addr` is to be freed. If `addr` is not NULL and `size` is positive, `addr` is to be resized to the given size. If `memoryf` is NULL, `malloc(3)` is used.

**int (\*eventf)(Dt\_t\* dt, int type, void\* data, Dtdisc\_t\* disc)**

If not NULL, `eventf` announces various events. Each event may have particular handling of the return values from `eventf`. But a negative return value typically means failure. Following are the events:

**DT\_OPEN:**

`dt` is being opened. If `eventf` returns negative, the opening process terminates with failure. If `eventf` returns zero, the opening process proceeds in a default manner. A positive return value indicates special treatment of memory as follows. If `*(void**)data` is set to point to some memory segment as discussed in `memoryf`, that segment of memory is used to start the dictionary. If `*(void**)data` is NULL, all memory including that of the dictionary handle itself will be allocated via `memoryf`.

**DT\_ENDOPEN:**

This event announces that `dtopen()` has successfully opened a dictionary and is about to return. The data argument of `eventf` should be the new dictionary handle itself.

**DT\_CLOSE:**

`dt` is about to be closed. If `eventf` returns negative, the closing process stops immediately and `dtclose()` returns -1. Objects in the dictionary are deleted only if `eventf` returns zero. The dictionary handle itself is processed as follows. If it was allocated via `malloc()`, it will be freed. If it was allocated via `memoryf` (see `dtopen()`) and `eventf` returns 0, a call to `memoryf` will be issued to attempt freeing the handle. Otherwise, nothing will be done to its memory.

As should be clear from their description, the events `DT_OPEN` and `DT_CLOSE` are designed to be

used along with `memoryf` to manage the allocation and deallocation of dictionary and object memory across dictionaries. In fact, they can be used to manage dictionaries based on shared and/or persistent memory.

**DT\_ENDCLOSE:**

This event announces that `dtclose()` has successfully closed a dictionary and is about to return.

**DT\_DISC:**

The discipline of `dt` is being changed to a new one given in `(Dtdisc_t*) data`.

**DT\_METH:**

The method of `dt` is being changed to a new one given in `(Dtmethod_t*) data`.

**DT\_HASHSIZE:**

The hash table (for `Dtset` and `Dtbag`) is being resized. In this case, `*(int*) data` has the current size of the table. The application can set the new table size by first changing `*(int*) data` to the desired size, then return a positive value. The application can also fix the table size at the current value forever by setting `*(int*) data` to a negative value, then again return a positive value. A non-positive return value from the event handling function means that `Cdt` will be responsible for choosing the hash table size.

**#define DTOFFSET(struct\_s,member)**

This macro function computes the offset of `member` from the start of structure `struct_s`. It is useful for getting the offset of a `Dtlink_t` embedded inside an object.

**#define DTDISC(disc,key,size,link,makef,freef,comparf,hashf,memoryf,eventf)**

This macro function initializes the discipline pointed to by `disc` with the given values.

## OBJECT OPERATIONS

**void\* dtinsert(Dt\_t\* dt, void\* obj)**

**void\* dtappend(Dt\_t\* dt, void\* obj)**

These functions add an object prototyped by `obj` into `dt`. `dtinsert()` and `dtappend()` perform the same function for all methods except for `Dtlist`. See `Dtlist` for details. If there is an existing object in `dt` matching `obj` and the storage method is `Dtset` or `Dtset`, `dtinsert()` and `dtappend()` will simply return the matching object. Otherwise, a new object is inserted according to the method in use. See `Dtdisc_t.makef` for object construction. The new object or a matching object as noted will be returned on success while `NULL` is returned on error.

**void\* dtdelete(Dt\_t\* dt, void\* obj)**

If `obj` is `NULL`, methods `Dtstack` and `Dtqueue` delete respectively stack top or queue head while other methods do nothing. If `obj` is not `NULL`, there are two cases. If the method in use is not `Dtbag` or `Dtobag`, the first object matching `obj` is deleted. On the other hand, if the method in use is `Dtbag` or `Dtobag`, the library check to see if `obj` is in the dictionary and delete it. If `obj` is not in the dictionary, some object matching it will be deleted. See `Dtdisc_t.freef` for object destruction. `dtdelete()` returns the deleted object (even if it was deallocated) or `NULL` on error.

**void\* dtattach(Dt\_t\* dt, void\* obj)**

This function is similar to `dtinsert()` but `obj` itself will be inserted into `dt` even if a discipline function `makef` is defined.

**void\* dtdetach(Dt\_t\* dt, void\* obj)**

This function is similar to `dtdelete()` but the object to be deleted from `dt` will not be freed (via the discipline `freef` function).

**void\* dtsearch(Dt\_t\* dt, void\* obj)**

**void\* dtmatch(Dt\_t\* dt, void\* key)**

These functions find an object matching `obj` or `key` either from `dt` or from some dictionary accessible from `dt` via a viewpath (see `dtview()`.) `dtsearch()` and `dtmatch()` return the matching object or `NULL` on failure.

**void\* dtfirst(Dt\_t\* dt)**

**void\* dtnext(Dt\_t\* dt, void\* obj)**

dtfirst() returns the first object in dt. dtnext() returns the object following obj. Objects are ordered based on the storage method in use. For Dtset and Dtobag, objects are ordered by object comparisons. For Dtstack, objects are ordered in reverse order of insertion. For Dtqueue, objects are ordered in order of insertion. For Dtlist, objects are ordered by list position. For Dtset and Dtbag, objects are ordered by some internal order (more below). Thus, objects in a dictionary or a viewpath can be walked using a for(;;) loop as below.

```
for(obj = dtfirst(dt); obj; obj = dtnext(dt, obj))
```

When a dictionary uses Dtset or Dtbag, the object order is determined upon a call to dtfirst()/dtlast(). This order is frozen until a call dtnext()/dtprev() returns NULL or when these same functions are called with a NULL object argument. It is important that a dtfirst()/dtlast() call be balanced by a dtnext()/dtprev() call as described. Nested loops will require multiple balancing, once per loop. If loop balancing is not done carefully, either performance is degraded or unexpected behaviors may result.

**void\* dtlast(Dt\_t\* dt)**

**void\* dtprev(Dt\_t\* dt, void\* obj)**

dtlast() and dtprev() are like dtfirst() and dtnext() but work in reverse order. Note that dictionaries on a viewpath are still walked in order but objects in each dictionary are walked in reverse order.

**void\* dtfinger(Dt\_t\* dt)**

This function returns the *current object* of dt, if any. The current object is defined after a successful call to one of dtsearch(), dtmatch(), dtinsert(), dtfirst(), dtnext(), dtlast(), or dtprev(). As a side effect of this implementation of Cdt, when a dictionary is based on Dtset and Dtobag, the current object is always defined and is the root of the tree.

**void\* dtrenew(Dt\_t\* dt, void\* obj)**

This function repositions and perhaps rehashes an object obj after its key has been changed. dtrenew() only works if obj is the current object (see dtfinger()).

**dtwalk(Dt\_t\* dt, int (\*userf)(Dt\_t\*, void\*, void\*), void\* data)**

This function calls (\*userf)(walk, obj, data) on each object in dt and other dictionaries viewable from it. walk is the dictionary containing obj. If userf() returns a <0 value, dtwalk() terminates and returns the same value. dtwalk() returns 0 on completion.

**Dtlink\_t\* dtflatten(Dt\_t\* dt)**

**Dtlink\_t\* dtlink(Dt\_t\* dt, Dtlink\_t\* link)**

**void\* dtobj(Dt\_t\* dt, Dtlink\_t\* link)**

Using dtfirst()/dtnext() or dtlast()/dtprev() to walk a single dictionary can incur significant cost due to function calls. For efficient walking of a single directory (i.e., no viewpathing), dtflatten() and dtlink() can be used. Objects in dt are made into a linked list and walked as follows:

```
for(link = dtflatten(dt); link; link = dtlink(dt, link) )
```

Note that dtflatten() returns a list of type Dtlink\_t\*, not void\*. That is, it returns a dictionary holder pointer, not a user object pointer (although both are the same if the discipline field link is zero.) The macro function dtlink() returns the dictionary holder object following link. The macro function dtobj(dt, link) returns the user object associated with link. Beware that the flattened object list is unflattened on any dictionary operations other than dtlink().

**Dtlink\_t\* dtextract(Dt\_t\* dt)**

**int dtrestore(Dt\_t\* dt, Dtlink\_t\* link)**

dtextract() extracts all objects from dt and makes it appear empty. dtrestore() repopulates dt with objects previously obtained via dtextract(). dtrestore() will fail if dt is not empty. These functions can be used to share a same dt handle among many sets of objects. They are useful to reduce dictionary overhead in an application that creates many concurrent dictionaries. It is important that the same discipline and method are in use at both extraction and restoration. Otherwise, undefined behaviors may result.

```
#define DTTREESEARCH(Dt_t* dt, void* obj, action)
```

```
#define DTTREEMATCH(Dt_t* dt, void* key, action)
```

These macro functions are analogues of `dtsearch()` and `dtmatch()` but they can only be used on a dictionary based on a binary search tree, i.e., `Dtset` or `Dtobag`.

`obj` or `key`:

These are used to find a matching object. If there is no match, the result is `NULL`.

`action`:

The matching object `o` (which may be `NULL`) will be processed as follow:

```
action (o);
```

Since `action` is used verbatim, it can be any C code fragment combinable with `(o)` to form a syntactically correct C statement. For example, suppose that the matching object is an integer, the below code accumulates the integer value in a variable `total`:

```
DTTREEMATCH(dt, key, total += (int));
```

## DICTIONARY INFORMATION

```
Dt_t* dtvnext(Dt_t* dt)
```

This returns the dictionary that `dt` is viewing, if any.

```
int dtvcount(Dt_t* dt)
```

This returns the number of dictionaries that view `dt`.

```
Dt_t* dtvwhere(Dt_t* dt)
```

This returns the dictionary `v` viewable from `dt` where an object was found from the most recent search or walk operation.

```
int dtsize(Dt_t* dt)
```

This function returns the number of objects stored in `dt`.

```
int dtstat(Dt_t *dt, Dtstat_t* st, int all)
```

This function reports dictionary statistics. If `all` is non-zero, all fields of `st` are filled. Otherwise, only the `dt_type` and `dt_size` fields are filled. It returns 0 on success and -1 on error.

`Dtstat_t` contains the below fields:

```
int dt_type:
```

This is one of `DT_SET`, `DT_BAG`, `DT_OSET`, `DT_OBAG`, `DT_LIST`, `DT_STACK`, and `DT_QUEUE`.

```
int dt_size:
```

This contains the number of objects in the dictionary.

```
int dt_n:
```

For `Dtset` and `Dtbag`, this is the number of non-empty chains in the hash table. For `Dtset` and `Dtobag`, this is the deepest level in the tree (counting from zero.) Each level in the tree contains all nodes of equal distance from the root node. `dt_n` and the below two fields are undefined for other methods.

```
int dt_max:
```

For `Dtbag` and `Dtset`, this is the size of a largest chain. For `Dtset` and `Dtobag`, this is the size of a largest level.

```
int* dt_count:
```

For `Dtset` and `Dtbag`, this is the list of counts for chains of particular sizes. For example, `dt_count[1]` is the number of chains of size 1. For `Dtset` and `Dtobag`, this is the list of sizes of the levels. For example, `dt_count[1]` is the size of level 1.

**HASH FUNCTIONS****unsigned int dtcharhash(unsigned int h, char c)****unsigned int dtstrhash(unsigned int h, char\* str, int n)**

These functions compute hash values from bytes or strings. `dtcharhash()` computes a new hash value from byte `c` and seed value `h`. `dtstrhash()` computes a new hash value from string `str` and seed value `h`. If `n` is positive, `str` is a byte array of length `n`; otherwise, `str` is a null-terminated string.

**IMPLEMENTATION NOTES**

`Dtset` and `Dtbag` are based on hash tables with move-to-front collision chains. `Dtset` and `Dtobag` are based on top-down splay trees. `Dtlist`, `Dtstack` and `Dtqueue` are based on doubly linked list.

**AUTHOR**

Kiem-Phong Vo, [kp@research.att.com](mailto:kp@research.att.com)