

**NAME**

**Cdt** – container data types

**SYNOPSIS**

```
#include <graphviz/cdt.h>
```

**DICTIONARY TYPES**

```
Void_t*;
Dt_t;
Dtdisc_t;
Dtmethod_t;
Dtlink_t;
Dtstat_t;
```

**DICTIONARY CONTROL**

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

**DISCIPLINE**

```
typedef Void_t*   (*Dtmake_f)(Dt_t*, Void_t*, Dtdisc_t*);
typedef void      (*Dtfree_f)(Dt_t*, Void_t*, Dtdisc_t*);
typedef int       (*Dtcompar_f)(Dt_t*, Void_t*, Void_t*, Dtdisc_t*);
typedef unsigned int (*Dthash_f)(Dt_t*, Void_t*, Dtdisc_t*);
typedef Void_t*   (*Dtmemory_f)(Dt_t*, Void_t*, size_t, Dtdisc_t*);
typedef int       (*Dtevent_f)(Dt_t*, int, Void_t*, Dtdisc_t*);
```

**OBJECT OPERATIONS**

```
Void_t* dtinsert(Dt_t* dt, Void_t* obj);
Void_t* dtdelete(Dt_t* dt, Void_t* obj);
Void_t* dtsearch(Dt_t* dt, Void_t* obj);
Void_t* dtmatch(Dt_t* dt, Void_t* key);
Void_t* dtfirst(Dt_t* dt);
Void_t* dtnext(Dt_t* dt, Void_t* obj);
Void_t* dtlast(Dt_t* dt);
Void_t* dtprev(Dt_t* dt, Void_t* obj);
Void_t* dtfinger(Dt_t* dt);
Void_t* dtrenew(Dt_t* dt, Void_t* obj);
int      dtwalk(Dt_t* dt, int (*userf)(Dt_t*, Void_t*, Void_t*), Void_t*);
Dtlink_t* dtflatten(Dt_t* dt);
Dtlink_t* dtlink(Dt_t*, Dtlink_t* link);
Void_t* dtobj(Dt_t* dt, Dtlink_t* link);
Dtlink_t* dtextract(Dt_t* dt);
int      dtrestore(Dt_t* dt, Dtlink_t* link);
```

**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****Void\_t\***

This type is used to pass objects between *Cdt* and application code. *Void\_t* is defined as *void* for ANSI-C and C++ and *char* for other compilation environments.

**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(Dtdisc\_t\* disc, 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.

**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.

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

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

**Dtmethod\_t dtmethod(Dt\_t\* dt, 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* and *Dtqueue*. 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, 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.

If two dictionaries on the same viewpath have the same values for the discipline fields `Dtdisc_t.link`, `Dtdisc_t.key`, `Dtdisc_t.size`, and `Dtdisc_t.hashf`, it is expected that key hashing will be the same. If not, undefined behaviors may result during a search or a walk.

## **STORAGE METHODS**

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

### **Dtoset**

### **Dtobag**

Objects are ordered by comparisons. `Dtoset` 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.)

### **Dtlist**

Objects are kept in a list. New objects are inserted either in front of *current object* (see `dtfinger()`) if this is defined or at list front if there is no current object.

### **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_t**)((char*)obj+key)`. If `size` is zero, the key is a null-terminated string with starting address `(Void_t*)((char*)obj+key)`. Finally, if `size` is positive, the key is a byte array of length `size` starting at `(Void_t*)((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\_t\* (\*makef)(Dt\_t\* dt, Void\_t\* obj, Dtdisc\_t\* disc)**

If makef is not NULL, dtinsert(dt,obj) 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\_t\* obj, Dtdisc\_t\* disc)**

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

**int (\*comparf)(Dt\_t\* dt, Void\_t\* key1, Void\_t\* 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\_t\* 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\_t\* (\*memoryf)(Dt\_t\* dt, Void\_t\* 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. When dictionaries share memory, a record of the first allocated memory segment should be kept so that it can be used to initialize new dictionaries (see below.)

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

If not NULL, eventf announces various events. If it returns a negative value, the calling operation will terminate with failure. Unless noted otherwise, a non-negative return value let the calling function proceed normally. Following are the events:

**DT\_OPEN:**

dt is being opened. If eventf returns zero, the opening process proceeds normally. A positive return value indicates that dt uses memory already initialized by a different dictionary. In that case, \*(Void\_t\*\*)data should be set to the first allocated memory segment as discussed in memoryf. dtopen() may fail if this segment is not returned or if it has not been properly initialized.

**DT\_CLOSE:**

dt is being closed.

**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.

**OBJECT OPERATIONS****Void\_t\* dtinsert(Dt\_t\* dt, Void\_t\* obj)**

This inserts an object prototyped by obj into dt. If there is an existing object in dt matching obj and the storage method is Dtset or Dtset, dtinsert() 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. dtinsert() returns the new object, a matching object as noted, or NULL on error.

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

If obj is not NULL, the first object matching it is deleted. If obj is NULL, methods Dtstack and Dtqueue delete respectively stack top or queue head while other methods do nothing. See Dtdisc\_t.freef for object destruction. dtdelete() returns the deleted object (even if it was deallocated) or NULL on error.

**Void\_t\* dtsearch(Dt\_t\* dt, Void\_t\* obj)****Void\_t\* dtmatch(Dt\_t\* dt, Void\_t\* 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\_t\* dtfirst(Dt\_t\* dt)****Void\_t\* dtnext(Dt\_t\* dt, Void\_t\* 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 use some internal ordering which may change on any search, insert, or delete operations. Therefore, these operations should not be used during a walk on a dictionary using either Dtset or Dtbag.

Objects in a dictionary or a viewpath can be walked using a for(;;) loop as below. Note that only one loop can be used at a time per dictionary. Concurrent or nested loops may result in unexpected behaviors.

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

**Void\_t\* dtlast(Dt\_t\* dt)****Void\_t\* dtprev(Dt\_t\* dt, Void\_t\* 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\_t\* 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\_t\* dtrenew(Dt\_t\* dt, Void\_t\* 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\_t\*, Void\_t\*), Void\_t\* 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\_t\* 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\_t\*. That is, it returns a dictionary holder pointer, not a user object pointer (although both are the same if the discipline field link is non-negative.) 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 concurrently many dictionaries. It is important that the same discipline and method are in use at both extraction and restoration. Otherwise, undefined behaviors may result.

## 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, [kpv@research.att.com](mailto:kpv@research.att.com)