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* dttreeset(Dt_t* dt, int minp, int balance);
Dtdisc_t* dtdisc(Dt_t* dt, const Dtdisc_t* disc, int type);
Dt_method_t* dtmethod(Dt_t* dt, const Dtmethod_t* meth);
Dt_t* dtview(Dt_t* dt, Dt_t* view);
Dt_t* dtopen(const Dtdisc_t* disc, const Dtmethod_t* meth);
int dtclose(Dt_t* dt);
void dtclear(Dt);

STORAGE METHODS
Dtmethod_t* Dtset;
Dtmethod_t* Dtbag;
Dtmethod_t* Dtoset;
Dtmethod_t* Dtobag;
Dtmethod_t* Dtlist;
Dtmethod_t* Dtstack;
Dtmethod_t* Dtqueue;
Dtmethod_t* Dtdequeue;

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);
int dtwalk(Dt_t* dt, int (*userf)(Dt_t*, void*, void*), void*);
Dtlink_t* dtflatten(Dt_t* dt);
Dtlink_t* dtlink(Dt_t* dt, 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* dtvhere(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.

**int dttreerset(Dt_t* dt, int minp, int balance)**

This function only applies to dictionaries operated under the method Dtoset which uses top-down splay trees (see below). It returns 0 on success and -1 on error.

**minp:** This parameter defines the minimum path length before a search path is adjusted. For example, minp equal 0 would mean that search paths are always adjusted. If minp is negative, the minimum search path is internally computed based on a function of the current dictionary size. This computed value is such that if the tree is balanced, it will never require adjusting.

**balance:**

If this is non-zero, the tree will be made balanced.

**STORAGE METHODS**

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

**Dtoset**

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

**Dtobag**

Objects are unordered. Dtoset keeps unique objects. Dtoset 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.

**Dtdequeue**

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:

```c
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 Dtoset 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:
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:
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 Dtoset, 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)**

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 Dtbag, 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 Dtbag, 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., Dtoset 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* dtnext(Dt_t* dt)
This returns the dictionary that dt is viewing, if any.
int dtcount(Dt_t* dt)
This returns the number of dictionaries that view dt.
Dt_t* dtwhere(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 Dtoset 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 Dtoset 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 Dtoset 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. Dtoset and Dtobag are based on top-down splay trees. Dtlist, Dtstack and Dtqueue are based on doubly linked list.

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