```
/* bstree */
/* lang=C++11 */

/* binary search tree */


#ifndef CF_DEBUGS
#define CF_DEBUGS       0               /* compile-time debugging */
#endif


/* revision history:

        = 2013-03-03, David A›D› Morano
        Originally written for Rightcore Network Services.

*/

/* Copyright ' 2013 David A›D› Morano.  All rights reserved. */

/******************************************************************************

        Binary-Search-Tree (without rebalancing)

        Notes:

        Q. How do we handle iterative traversal?

        A. There are at least three popular ways to handle iterative traveral:

        1. maintain a stack of pointers to previous node at each level of the
           tree; space would be O(depth)

        2. use a so-called "threaded" tree structure where each dangling
           right-side node (with no additional right-child) actually
           has a pointer to its in-order successor

        3. use the "parent" method where each node has a pointer to its own
           parent; we use this method below

        The "parent" scheme:

        If we find that there is no right-child (from our current node), we
        traverse back up to our parent, checking (at each step) if we (the
        current node) is equal to the right-child node of our parent. If we
        arrive at our parent from its left-child, then our parent becomes the
        next current node. If we arrive at our parent from its right-child node,
        then we continue to go up in the tree until we either arrive at our
        parent from a left-child or we reach the top of the tree (the parent
        itself has no parent). At any node, we try to go down a right-child (if
        it exists) and then its left-child, if it exists.

        This, so-called, "parent" scheme uses up an extra pointer-amount of
        space in each node, O(n) more space, but even though the "stack" scheme
        only uses up O(depth), we prefer the "parent" scheme since we do not
        have to go through the trouble if instantiating a stack in the first
        place.

        For reference, here is a stack solution (pseudo code):

        class iterator {
            stack<node> stack = new stack<node> ;
            node        n ;
            iterator(node an) : n(an) { } ;
            iterator &findnext() {
                iterator        it(nullptr) ;
```

```
                while (n != NULL) {
                    stack.push(n) ;
                    n = n->left ;
                }
                n = stack.pop() ;
                it = n ;
                n = n->right ;
                return it ;
            } ;
        } ;


**************************************************************************/

#ifndef BSTREE_INCLUDE
#define BSTREE_INCLUDE  1


#include        <envstandards.h>        /* MUST be first to configure */
#include        <sys/types.h>
#include        <limits.h>
#include        <cinttypes>
#include        <new>
#include        <initializer_list>
#include        <algorithm>
#include        <functional>
#include        <stack>
#include        <vector>
#include        <vsystem.h>
#include        <localmisc.h>


/* external subroutines */

#if     CF_DEBUGS
extern "C" int  debugprintf(cchar *,...) ;
extern "C" int  strlinelen(cchar *,cchar *,int) ;
#endif


/* local structures */

template <typename T,typename Comp = std::less<T>>
class bstree ;

template <typename T,typename Comp = std::less<T>>
class bstree_iter ;

template <typename T,typename Comp = std::less<T>>
class bstree_node {
        bstree_node<T,Comp>     *parent = NULL ;
        bstree_node<T,Comp>     *left = NULL ;
        bstree_node<T,Comp>     *right = NULL ;
        T                       val ;
        void SetVal(const T v) {
            val = v ;
        } ;
public:
        bstree_node(T av) : val(av) {
        } ;
        bstree_node(const bstree_node<T> &other) = delete ;
        bstree_node &operator = (const bstree_node<T> &other) = delete ;
        ~bstree_node() {
        } ;
        friend bstree<T,Comp> ;
        friend bstree_iter<T,Comp> ;
```

```
} ; /* end class (bstree_node) */

template <typename T,typename Comp>
class bstree_iter {
        typedef bstree_node<T,Comp>     nodetype ;
        bstree_node<T,Comp>     *n = NULL ;
        mutable T               defval ;
        bstree_iter<T,Comp>     &findnext(int) ;
        typedef bstree_iter     bit ;
public:
        bstree_iter() { } ;
        bstree_iter(bstree_node<T,Comp>* an) : n(an) { } ;
        bstree_iter(const bstree_iter<T,Comp> &it) {
            if (this != &it) {
                n = it.n ;
            }
        } ;
        bstree_iter(bstree_iter<T,Comp> &&it) {
            if (this != &it) {
                n = it.n ;
                it.n = NULL ;
            }
        } ;
        bstree_iter<T,Comp> &operator = (const bstree_iter<T,Comp> &it) {
            if (this != &it) {
                n = it.n ;
            }
            return (*this) ;
        } ;
        bstree_iter<T,Comp> &operator = (bstree_iter<T,Comp> &&it) {
            if (this != &it) {
                n = it.n ;
                it.n = NULL ;
            }
            return (*this) ;
        } ;
        bstree_iter<T,Comp> &operator = (const bstree_iter<T,Comp> *ip) {
            if (this != ip) {
                n = ip->n ;
            }
            return (*this) ;
        } ;
        bstree_iter<T,Comp> &operator = (const bstree_node<T,Comp> *nn) {
            n = nn ;
            return (*this) ;
        } ;
        ~bstree_iter() {
            n = NULL ;
        } ;
        void setnode(bstree_node<T,Comp> *nn) {
            n = nn ;
        } ;
        T &operator * () const {
            T &rv = defval ;
            if (n != NULL) {
                rv = n->val ;
            }
            return rv ;
        } ;
        bstree_iter<T,Comp> &operator ++ () { /* pre-increment */
            return findnext(1) ;
        } ;
        bstree_iter<T,Comp>  &operator ++ (int) { /* post-increment */
            return findnext(1) ;
        } ;
        bstree_iter<T,Comp> &operator += (int inc) {
```

```
            return findnext(inc) ;
        } ;
        bstree_iter<T,Comp> &operator + (int inc) {
            return findnext(inc) ;
        } ;
        operator int() const {
            return (n != nullptr) ;
        } ;
        operator bool() const {
            return (n != nullptr) ;
        } ;
        friend bool operator == (const bstree_iter<T,Comp> &i1,
                const bstree_iter<T,Comp> &i2) {
            return (i1.n == i2.n) ;
        } ;
        friend bool operator != (const bstree_iter<T,Comp> &i1,
                const bstree_iter<T,Comp> &i2) {
            return (i1.n != i2.n) ;
        } ;
        friend bstree<T,Comp> ;
} ; /* end class (bstree_iter) */

template <typename T,typename Comp>
bstree_iter<T,Comp> &bstree_iter<T,Comp>::findnext(int inc) {
        if (n != NULL) {
            if (inc > 1) {
                findnext(1) ;
                findnext(inc-1) ;
            } else if (inc > 0) {
                if (n->right != NULL) {
                    n = n->right ;
                    while (n->left != NULL) {
                        n = n->left ;
                    }
                } else {
                    bstree_node<T,Comp> *p = n->parent ;
                    while ((p != NULL) && (n == p->right)) {
                        n = p ;
                        p = p->parent;
                    }
                    n = p ;
                }
            } /* end if (inc) */
        } /* end if (not-NULL) */
        return (*this) ;
} /* end method (bstree_iterator::findnext) */

struct bstree_depth {
        int             min = INT_MAX ;
        int             max = 0 ;
        void clear() {
            min = INT_MAX ;
            max = 0 ;
        } ;
} ;

template <typename T,typename Comp>
class bstree {
        bstree_node<T,Comp>     *root = NULL ;
        Comp                    keycmp ;
        int                     c = 0 ;
        typedef                 bstree_node<T,Comp> nodetype ;
        bstree_iter<T,Comp> FindNodeByVal(nodetype *n,const T &v) const {
            bstree_iter<T,Comp> it ;
            if (root != NULL) {
                if (keycmp(v,n->val)) { /* less */
```

```
            if (n->left != NULL) {
                it = FindNodeByVal(n->left,v) ;
            }
        } else if (keyequal(n->val,v)) { /* equal */
            it.setnode(n) ;
        } else {
            if (n->right != NULL) {
                it = FindNodeByVal(n->right,v) ;
            }
        }
    } /* end if non-null root) */
    return it ;
} ;
void ReplaceUsInParent(nodetype *np,nodetype *c) {
    nodetype *p = np->parent ;
    if (p->left == np) {
        p->left = c ;
    } else {
        p->right = c ;
    }
    if (c != NULL) c->parent = p ;
} ;
nodetype *GetChild(nodetype *np) const {
    return (np->left != NULL) ? np->left : np->right ;
} ;
nodetype *FindMinNode(nodetype *np) const {
    while (np->left != NULL) {
        np = np->left ;
    }
    return np ;
}
int delnodes(bstree_node<T,Comp> *n) {
    int i = 0 ;
    if (n != NULL) {
        i += 1 ;
        c += delnodes(n->left) ;
        c += delnodes(n->right) ;
        delete n ;
    }
    return i ;
} ;
int insert(bstree_node<T,Comp> *n,bstree_node<T,Comp> *nn) {
    int         d = 0 ;
    if (keycmp(nn->val,n->val)) {
        if (n->left != NULL) {
            d = insert(n->left,nn) ;
        } else {
            nn->parent = n ;
            n->left = nn ;
        }
    } else {
        if (n->right != NULL) {
            d = insert(n->right,nn) ;
        } else {
            nn->parent = n ;
            n->right = nn ;
        }
    }
    return d ;
} ;
int walk(std::vector<T> &vl,bstree_node<T,Comp> *n) const {
    int i = 0 ;
    if (n != NULL) {
        if (n->left) {
            i += walk(vl,n->left) ;
        }
```

```
            vl.push_back(n->val) ;
            i += 1 ;
            if (n->right) {
                i += walk(vl,n->right) ;
            }
        }
        return i ;
    } ;
    bool keyequal(const T &v1,const T &v2) const { /* equal */
        bool f = TRUE ;
        f = f && (! keycmp(v1,v2)) ;
        f = f && (! keycmp(v2,v1)) ;
        return f ;
    } ;
public:
    typedef         bstree_iter<T,Comp> iterator ;
    typedef         T value_type ;
    bstree() {
    } ;
    bstree(const bstree<T,Comp> &al) {
        if (this != &al) {
            bstree_node<T,Comp>     *an = al.root ;
            if (root != NULL) clear() ;
            while (an != NULL) {
                add(an->val) ;
                an = an->next ;
            }
        }
    } ;
    bstree(bstree<T,Comp> &&al) {
        if (this != &al) {
            if (root != NULL) clear() ;
            root = al.root ;
            c = al.c ;
            al.root = NULL ;
            al.c = 0 ;
        }
    } ;
    bstree &operator = (const bstree<T,Comp> &al) {
        if (this != &al) {
            bstree_node<T,Comp>     *an = al.root ;
            if (root != NULL) clear() ;
            while (an != NULL) {
                add(an->val) ;
                an = an->next ;
            }
        }
        return (*this) ;
    } ;
    bstree &operator = (bstree<T,Comp> &&al) {
        if (this != &al) {
            if (root != NULL) clear() ;
            root = al.root ;
            c = al.c ;
            al.root = NULL ;
            al.c = 0 ;
        }
        return (*this) ;
    } ;
    bstree(const std::initializer_list<T> &list) {
        if (root != NULL) clear() ;
        for (const T &v : list) {
            add(v) ;
        }
    } ;
    bstree &operator = (const std::initializer_list<T> &list) {
```

```
    if (root != NULL) clear() ;
    for (const T &v : list) {
        add(v) ;
    }
    return (*this) ;
} ;
bstree &operator += (const std::initializer_list<T> &list) {
    for (const T &v : list) {
        add(v) ;
    }
    return (*this) ;
} ;
bstree &operator += (const T v) {
    add(v) ;
    return (*this) ;
} ;
~bstree() {
    if (root != NULL) {
        delnodes(root) ;
        root = NULL ;
    }
    c = 0 ;
} ;
int clear() {
    int         rc = c ;
    if (root != NULL) {
        delnodes(root) ;
        root = NULL ;
    }
    c = 0 ;
    return rc ;
} ;
int add(const T v) {
    bstree_node<T,Comp> *nn = new bstree_node<T,Comp>(v) ;
    int                 rc = -1 ;
    if (nn != NULL) {
        if (root != NULL) {
            insert(root,nn) ;
        } else {
            root = nn ;
        }
        rc = ++c ;
    }
    return rc ;
} ;
int add(const std::initializer_list<T> il) {
    for (const T &v : il) {
        add(v) ;
    }
    return c ;
} ;
bstree &operator = (const std::initializer_list<T> il) {
    for (const T &v : il) {
        add(v) ;
    }
    return (*this) ;
} ;
int add(const bstree<T,Comp> &other) {
    for(const T &v : other) {
        add(v) ;
    }
    return c ;
} ;
int del(iterator it) {
    int         rc = -1 ;
    if (it) {
```

```
        nodetype        *n = it.n ; /* friend */
        nodetype        *l, *r ;
        l = n->left ;
        r = n->right ;
        if ((l != NULL) || (r != NULL)) { /* one or two children */
            if ((l != NULL) && (r != NULL)) { /* two children */
                nodetype *np = FindMinNode(n->right) ;
                n->SetVal(np->val) ;
                ReplaceUsInParent(np,np->right) ;
                delete np ;
            } else { /* one child */
                nodetype        *child = GetChild(n) ;
                if (n->parent != NULL) {
                    ReplaceUsInParent(n,child) ;
                } else {
                    root = child ;
                    if (child != NULL) child->parent = NULL ;
                }
                it.setnode(child) ;
                delete n ;
            }
        } else { /* leaf node */
            if (n->parent != NULL) {
                ReplaceUsInParent(n,NULL) ;
                it.setnode(n->parent) ;
            } else {
                root = NULL ;
                it.setnode(nullptr) ;
            }
            delete n ;
        }
        rc = --c ;
    } /* end if (iterator not at end) */
    return rc ;
} ;
int delval(const T &v) {
    int         rc = -1 ;
    if (root != NULL) {
        iterator        it ;
        if (it = FindNodeByVal(root,v)) {
            rc = del(it) ;
        }
    }
    return rc ;
} ;
int topval(const T **rpp) const {
    if (root != NULL) {
        bstree_node<T,Comp>     *n = root ;
        *rpp = &n->val ;
    } else {
        *rpp = NULL ;
    }
    return c ;
} ;
int minval(const T **rpp) const {
    if (root != NULL) {
        bstree_node<T,Comp>     *n = root ;
        while (n->left != NULL) {
            n = n->left ;
        }
        *rpp = &n->val ;
    } else {
        *rpp = NULL ;
    }
    return c ;
} ;
```

```
        int maxval(const T **rpp) const {
            if (root != NULL) {
                bstree_node<T,Comp>     *n = root ;
                while (n->right != NULL) {
                    n = n->right ;
                }
                *rpp = &n->val ;
            } else {
                *rpp = NULL ;
            }
            return c ;
        } ;
        int count() const {
            return c ;
        } ;
        int empty() const {
            return (c == 0) ;
        } ;
        operator int() const {
            return (c != 0) ;
        } ;
        operator bool() const {
            return (c != 0) ;
        } ;
        int storevec(std::vector<T> &vl) {
            int c = 0 ;
            if (root != NULL) {
                c = walk(vl,root) ;
            }
            return c ;
        } ;
        iterator begin() const {
            iterator it ;
            if (root != NULL) {
                bstree_node<T,Comp>     *n = root ;
                while (n->left != NULL) {
                    n = n->left ;
                }
                it = iterator(n) ;
            }
            return it ;
        } ;
        iterator end() const {
            iterator it ;
            return it ;
        } ;
        iterator find(const T& v) const {
            iterator it ;
            if (root != NULL) {
                it = FindNodeByVal(root,v) ;
            }
            return it ;
        } ;
        int depth(bstree_depth *resp) {
            int         d = 0 ;
            if (resp != NULL) resp->clear() ;
            d = depthrecurse(resp,0,root) ;
            return d ;
        } ; /* end method (depth) */
        int depthrecurse(bstree_depth *resp,int i,bstree_node<T,Comp> *rp) {
            int         d = 0 ;
#if     CF_DEBUGS
            debugprintf("bstree::depthrecurse: ent i=%u\n",i) ;
#endif
            if (rp != NULL) {
                int     d_left = depthrecurse(resp,(i+1),rp->left) ;
```

```
                int     d_right = depthrecurse(resp,(i+1),rp->right) ;
                d = 1 ;
                d += std::max(d_left,d_right) ;
            } else {
                if (resp != NULL) {
                     resp->min = std::min(resp->min,i) ;
                     resp->max = std::max(resp->max,i) ;
                }
            }
#if     CF_DEBUGS
            debugprintf("bstree::depthrecurse: ret d=%u\n",d) ;
#endif
            return d ;
    } ; /* end method (depthrecurse) */
} ; /* end class (bstree) */

#endif /* BSTREE_INCLUDE */
```