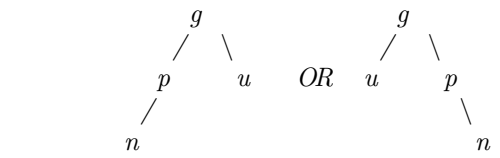
rbtree.cm

```
/*
    ========================================================================

    Copyright (c) 2012-2016 Seppo Laakko
    http://sourceforge.net/projects/cmajor/

    Distributed under the GNU General Public License, version 3 (GPLv3).
    (See accompanying LICENSE.txt or http://www.gnu.org/licenses/gpl.html
        )

    ========================================================================
    */

// Copyright (c) 1994
// Hewlett-Packard Company
// Copyright (c) 1996
// Silicon Graphics Computer Systems, Inc.
// Copyright (c) 2009 Alexander Stepanov and Paul McJones

using System;
using System.Support;
using System.Concepts;

namespace System.Collections
{
    public class RedBlackTreeNodeBase
    {
        public enum Color { red, black }
        public typedef RedBlackTreeNodeBase Node;

        public nothrow RedBlackTreeNodeBase(Node* parent_): color(Color.
            black), parent(parent_), left(null), right(null)
        {
        }
        public virtual nothrow ~RedBlackTreeNodeBase()
        {
            if (left != null && left != this)
            {
                delete left;
            }
            if (right != null && right != this)
            {
                delete right;
            }
        }
        public nothrow inline Color GetColor() const
        {
            return color;
        }
        public nothrow inline void SetColor(Color color_)
        {
```

```
        color = color_;
    }
    public nothrow inline Node* Parent() const
    {
        return parent;
    }
    public nothrow inline Node*& ParentRef()
    {
        return parent;
    }
    public nothrow inline void SetParent(Node* parent_)
    {
        parent = parent_;
    }
    public nothrow inline Node* Left() const
    {
        return left;
    }
    public nothrow inline Node*& LeftRef()
    {
        return left;
    }
    public nothrow inline void SetLeft(Node* left_)
    {
        left = left_;
    }
    public nothrow inline Node* Right() const
    {
        return right;
    }
    public nothrow inline Node*& RightRef()
    {
        return right;
    }
    public nothrow inline void SetRight(Node* right_)
    {
        right = right_;
    }
    public nothrow inline bool IsHeaderNode() const
    {
        return color == Color.red && parent != null && parent->parent
            == this;
    }
    public static nothrow inline Node* Min(Node* n)
    {
        #assert(n != null);
        while (n->Left() != null)
        {
            n = n->Left();
        }
        return n;
    }
    public static nothrow inline Node* Max(Node* n)
```

```
        {
            #assert(n != null);
            while (n->Right() != null)
            {
                n = n->Right();
            }
            return n;
        }
        public static nothrow inline Node* Prev(Node* n)
        {
            #assert(n != null);
            if (n->IsHeaderNode())
            {
                return n->Right();  // rightmost
            }
            else if (n->Left() != null)
            {
                return Max(n->Left());
            }
            else
            {
                Node* u = n->Parent();
                while (n == u->Left())
                {
                    n = u;
                    u = u->Parent();
                }
                return u;
            }
        }
        public static nothrow inline Node* Next(Node* n)
        {
            #assert(n != null);
            if (n->Right() != null)
            {
                return Min(n->Right());
            }
            else
            {
                Node* u = n->Parent();
                while (n == u->Right())
                {
                    n = u;
                    u = u->Parent();
                }
                if (n->Right() != u)
                {
                    return u;
                }
                return n;
            }
        }
        /*
```

REBALANCE–AFTER–INSERT:




```
*/
public static nothrow void RebalanceAfterInsert(Node* n, Node*&
    root)
{
    #assert(n != null);
    n->SetColor(Color.red);
    while (n != root && n->Parent()->GetColor() == Color.red)
    {
        if (n->Parent() == n->Parent()->Parent()->Left())
        {
            Node* u = n->Parent()->Parent()->Right();
            if (u != null && u->GetColor() == Color.red)
            {
                n->Parent()->SetColor(Color.black);
                u->SetColor(Color.black);
                n->Parent()->Parent()->SetColor(Color.red);
                n = n->Parent()->Parent();
            }
            else
            {
                if (n == n->Parent()->Right())
                {
                    n = n->Parent();
                    RotateLeft(n, root);
                }
                n->Parent()->SetColor(Color.black);
                n->Parent()->Parent()->SetColor(Color.red);
                RotateRight(n->Parent()->Parent(), root);
            }
        }
        else
        {
            Node* u = n->Parent()->Parent()->Left();
            if (u != null && u->GetColor() == Color.red)
            {
                n->Parent()->SetColor(Color.black);
                u->SetColor(Color.black);
                n->Parent()->Parent()->SetColor(Color.red);
                n = n->Parent()->Parent();
            }
            else
            {
                if (n == n->Parent()->Left())
                {
                    n = n->Parent();
```

```
                    RotateRight(n, root);
                }
                n->Parent()->SetColor(Color.black);
                n->Parent()->Parent()->SetColor(Color.red);
                RotateLeft(n->Parent()->Parent(), root);
            }
        }
    }
    root->SetColor(Color.black);
}
/*
    REBALANCE-FOR-REMOVE:
*/
public static nothrow Node* RebalanceForRemove(Node* z, Node*&
    root, Node*& leftmost, Node*& rightmost)
{
    #assert(z != null);
    Node* y = z;
    Node* x = null;
    Node* p = null;
    if (y->Left() == null)  // z has at most one non-null child.
        y == z
    {
        x = y->Right();      // x might be null
    }
    else
    {
        if (y->Right() == null) // z has exactly one non-null
            child. y == z
        {
            x = y->Left();       // x is not null
        }
        else                     // z has two non-null children.
            set y to z's successor. x might be null.
        {
            y = y->Right();
            while (y->Left() != null)
            {
                y = y->Left();
            }
            x = y->Right();
        }
    }
    if (y != z)      // relink y in place of z. y is z's successor
    {
        z->Left()->SetParent(y);
        y->SetLeft(z->Left());
        if (y != z->Right())
        {
            p = y->Parent();
            if (x != null)
            {
                x->SetParent(y->Parent());
```

```
                }
                y->Parent()->SetLeft(x);      // y must be child of
                    left
                y->SetRight(z->Right());
                z->Right()->SetParent(y);
            }
            else
            {
                p = y;
            }
            if (root == z)
            {
                root = y;
            }
            else if (z->Parent()->Left() == z)
            {
                z->Parent()->SetLeft(y);
            }
            else
            {
                z->Parent()->SetRight(y);
            }
            y->SetParent(z->Parent());
            Color c = y->GetColor();
            y->SetColor(z->GetColor());
            z->SetColor(c);
            y = z;
            // y now points to node to be actually deleted
        }
        else     // y == z
        {
            p = y->Parent();
            if (x != null)
            {
                x->SetParent(y->Parent());
            }
            if (root == z)
            {
                root = x;
            }
            else
            {
                if (z->Parent()->Left() == z)
                {
                    z->Parent()->SetLeft(x);
                }
                else
                {
                    z->Parent()->SetRight(x);
                }
            }
            if (leftmost == z)
            {
```

```
            if (z->Right() == null) // z->Left() must be null
                also
            {
                leftmost = z->Parent();
            }
            else
            {
                leftmost = Min(x);
            }
        }
        if (rightmost == z)
        {
            if (z->Left() == null)
            {
                rightmost = z->Parent();
            }
            else
            {
                rightmost = Max(x);
            }
        }
    }
    if (y->GetColor() != Color.red)
    {
        while (x != root && (x == null || x->GetColor() == Color.
            black))
        {
            if (x == p->Left())
            {
                Node* w = p->Right();
                if (w->GetColor() == Color.red)
                {
                    w->SetColor(Color.black);
                    p->SetColor(Color.red);
                    RotateLeft(p, root);
                    w = p->Right();
                }
                if ((w->Left() == null || w->Left()->GetColor()
                    == Color.black) &&
                    (w->Right() == null || w->Right()->GetColor()
                        == Color.black))
                {
                    w->SetColor(Color.red);
                    x = p;
                    p = p->Parent();
                }
                else
                {
                    if (w->Right() == null || w->Right()->
                        GetColor() == Color.black)
                    {
                        if (w->Left() != null)
                        {
```

```
                    w->Left()->SetColor(Color.black);
                }
                w->SetColor(Color.red);
                RotateRight(w, root);
                w = p->Right();
            }
            w->SetColor(p->GetColor());
            p->SetColor(Color.black);
            if (w->Right() != null)
            {
                w->Right()->SetColor(Color.black);
            }
            RotateLeft(p, root);
            break;
        }
    }
    else    // same as above, with right <-> left
    {
        Node* w = p->Left();
        if (w->GetColor() == Color.red)
        {
            w->SetColor(Color.black);
            p->SetColor(Color.red);
            RotateRight(p, root);
            w = p->Left();
        }
        if ((w->Right() == null || w->Right()->GetColor()
            == Color.black) &&
            (w->Left() == null || w->Left()->GetColor()
               == Color.black))
        {
            w->SetColor(Color.red);
            x = p;
            p = p->Parent();
        }
        else
        {
            if (w->Left() == null || w->Left()->GetColor
                () == Color.black)
            {
                if (w->Right() != null)
                {
                    w->Right()->SetColor(Color.black);
                }
                w->SetColor(Color.red);
                RotateLeft(w, root);
                w = p->Left();
            }
            w->SetColor(p->GetColor());
            p->SetColor(Color.black);
            if (w->Left() != null)
            {
                w->Left()->SetColor(Color.black);
```

```
                        }
                        RotateRight(p, root);
                        break;
                    }
                }
            }
        }
        if (x != null)
        {
            x->SetColor(Color.black);
        }
        return y;
    }
    /*  ROTATE LEFT:
              n                   u
             / \                 / \
            a   u      =>       n   c
               / \             / \
              b   c           a   b
    */
    private static nothrow void RotateLeft(Node* n, Node*& root)
    {
        #assert(n != null);
        Node* u = n->Right();
        #assert(u != null);
        n->SetRight(u->Left());
        if (u->Left() != null)
        {
            u->Left()->SetParent(n);
        }
        u->SetParent(n->Parent());
        if (n == root)
        {
            root = u;
        }
        else if (n == n->Parent()->Left())
        {
            n->Parent()->SetLeft(u);
        }
        else
        {
            n->Parent()->SetRight(u);
        }
        u->SetLeft(n);
        n->SetParent(u);
    }
    /*  ROTATE RIGHT:
            n                   u
           / \                 / \
          u   c       =>      a   n
         / \                     / \
        a   b                   b   c
    */
```

```
        private static nothrow void RotateRight(Node* n, Node*& root)
        {
            #assert(n != null);
            Node* u = n->Left();
            #assert(u != null);
            n->SetLeft(u->Right());
            if (u->Right() != null)
            {
                u->Right()->SetParent(n);
            }
            u->SetParent(n->Parent());
            if (n == root)
            {
                root = u;
            }
            else if (n == n->Parent()->Right())
            {
                n->Parent()->SetRight(u);
            }
            else
            {
                n->Parent()->SetLeft(u);
            }
            u->SetRight(n);
            n->SetParent(u);
        }
        private Color color;
        private Node* parent;
        private Node* left;
        private Node* right;
    }

    public class RedBlackTreeNode<T>: RedBlackTreeNodeBase
    {
        public typedef T ValueType;

        public RedBlackTreeNode(const ValueType& value_, Node* parent_):
            base(parent_), value(value_) {}
        public nothrow const ValueType& Value() const { return value; }
        public nothrow ValueType& Value() { return value; }
        private ValueType value;
    }

    public class RedBlackTreeNodeIterator<T, R, P>
    {
        public typedef T ValueType;
        public typedef R ReferenceType;
        public typedef P PointerType;
        private typedef RedBlackTreeNodeIterator<ValueType, ReferenceType
            , PointerType> Self;
        private typedef RedBlackTreeNode<ValueType> Node;

        public nothrow RedBlackTreeNodeIterator(): node(null)
```

```
        {
        }
        public nothrow RedBlackTreeNodeIterator(Node* node_): node(node_)
        {
        }
        public nothrow ReferenceType operator*() const
        {
            #assert(node != null);
            return node->Value();
        }
        public nothrow PointerType operator->() const
        {
            #assert(node != null);
            return &(node->Value());
        }
        public nothrow Self& operator++()
        {
            #assert(node != null);
            node = cast<Node*>(Node.Next(node));
            return *this;
        }
        public nothrow Self& operator--()
        {
            #assert(node != null);
            node = cast<Node*>(Node.Prev(node));
            return *this;
        }
        public nothrow inline Node* GetNode() const
        {
            return node;
        }
        private Node* node;
    }

    public nothrow inline bool operator==<T, R, P>(const
        RedBlackTreeNodeIterator<T, R, P>& left, const
        RedBlackTreeNodeIterator<T, R, P>& right)
    {
        return left.GetNode() == right.GetNode();
    }

    public class RedBlackTree<KeyType, ValueType, KeyOfValue, Compare>
        where KeyType is Semiregular and ValueType is Semiregular and
            KeySelectionFunction<KeyOfValue, KeyType, ValueType> and
            Compare is Relation and Compare.Domain is KeyType
    {
        private typedef RedBlackTree<KeyType, ValueType, KeyOfValue,
            Compare> Self;
        public typedef RedBlackTreeNodeIterator<ValueType, const
            ValueType&, const ValueType*> ConstIterator;
        public typedef RedBlackTreeNodeIterator<ValueType, ValueType&,
            ValueType*> Iterator;
        private typedef RedBlackTreeNode<ValueType> Node;
```

```
private typedef RedBlackTreeNodeBase NodeBase;

public RedBlackTree(): header(), count(0), keyOf(), comp()
{
    Init();
}
public RedBlackTree(const Self& that): header(), count(0), keyOf
    (), comp() where ValueType is Copyable
{
    Init();
    CopyFrom(that);
}
public default nothrow RedBlackTree(Self&& that) where ValueType
    is Movable;
public void operator=(const Self& that) where ValueType is
    Copyable
{
    Clear();
    CopyFrom(that);
}
public default nothrow void operator=(Self&& that) where
    ValueType is Movable;
private void CopyFrom(const Self& that) where ValueType is
    Copyable
{
    if (that.Root() != null)
    {
        SetRoot(Copy(that.Root(), header.GetPtr()));
        SetLeftmost(cast<Node*>(Node.Min(Root())));
        SetRightmost(cast<Node*>(Node.Max(Root())));
        count = that.Count();
    }
}
public nothrow ~RedBlackTree()
{
    Clear();
}
public nothrow ConstIterator Begin() const
{
    return ConstIterator(Leftmost());
}
public nothrow Iterator Begin()
{
    return Iterator(Leftmost());
}
public nothrow ConstIterator CBegin() const
{
    return ConstIterator(Leftmost());
}
public nothrow ConstIterator End() const
{
    return ConstIterator(header.GetPtr());
}
```

```
public nothrow Iterator End()
{
    return Iterator(header.GetPtr());
}
public nothrow ConstIterator CEnd() const
{
    return ConstIterator(header.GetPtr());
}
public nothrow inline int Count() const
{
    #assert(count >= 0);
    return count;
}
public nothrow inline bool IsEmpty() const
{
    #assert(count >= 0);
    return count == 0;
}
public nothrow void Clear()
{
    if (header.IsNull())
    {
        return;
    }
    Node* root = Root();
    if (root != null)
    {
        delete root;
        SetRoot(null);
    }
    SetLeftmost(header.GetPtr());
    SetRightmost(header.GetPtr());
    count = 0;
}
public nothrow Iterator Find(const KeyType& key)
{
    Node* x = Root();
    while (x != null)
    {
        if (Comp(key, KeyOf(x->Value())))
        {
            x = cast<Node*>(x->Left());
        }
        else if (Comp(KeyOf(x->Value()), key))
        {
            x = cast<Node*>(x->Right());
        }
        else
        {
            return Iterator(x);
        }
    }
    return End();
```

```
        }
        public nothrow ConstIterator Find(const KeyType& key) const
        {
            Node* x = Root();
            while (x != null)
            {
                if (Comp(key, KeyOf(x->Value())))
                {
                    x = cast<Node*>(x->Left());
                }
                else if (Comp(KeyOf(x->Value()), key))
                {
                    x = cast<Node*>(x->Right());
                }
                else
                {
                    return ConstIterator(x);
                }
            }
            return CEnd();
        }
        public nothrow ConstIterator CFind(const KeyType& key) const
        {
            Node* x = Root();
            while (x != null)
            {
                if (Comp(key, KeyOf(x->Value())))
                {
                    x = cast<Node*>(x->Left());
                }
                else if (Comp(KeyOf(x->Value()), key))
                {
                    x = cast<Node*>(x->Right());
                }
                else
                {
                    return ConstIterator(x);
                }
            }
            return CEnd();
        }
        public Pair<Iterator, bool> Insert(const ValueType& value) where
            ValueType is Copyable
        {
            Node* x = Root();
            Node* p = header.GetPtr();
            bool comp = true;
            while (x != null)
            {
                p = x;
                comp = Comp(KeyOf(value), KeyOf(x->Value()));
                if (comp)
                {
```

```
                x = cast<Node*>(x->Left());
            }
            else
            {
                x = cast<Node*>(x->Right());
            }
        }
        Iterator j = p;
        if (comp)
        {
            if (j == Begin())
            {
                return MakePair(Insert(x, p, value), true);
            }
            else
            {
                --j;
            }
        }
        if (Comp(KeyOf(j.GetNode()->Value()), KeyOf(value)))
        {
            return MakePair(Insert(x, p, value), true);
        }
        return MakePair(j, false);
    }
    private Iterator Insert(Node* x, Node* p, const ValueType& value)
        where ValueType is Copyable
    {
        Node* n = new Node(value, p);
        if (p == header.GetPtr() || x != null || Comp(KeyOf(value),
            KeyOf(p->Value())))
        {
            p->SetLeft(n);
            if (p == header.GetPtr())
            {
                SetRoot(n);
                SetRightmost(n);
            }
            else if (p == Leftmost())
            {
                SetLeftmost(n);
            }
        }
        else
        {
            p->SetRight(n);
            if (p == Rightmost())
            {
                SetRightmost(n);
            }
        }
        Node.RebalanceAfterInsert(n, RootRef());
        ++count;
```

```
        return Iterator(n);
    }
    public nothrow bool Remove(const KeyType& key)
    {
        Node* n = Root();
        while (n != null)
        {
            if (Comp(key, KeyOf(n->Value())))
            {
                n = cast<Node*>(n->Left());
            }
            else if (Comp(KeyOf(n->Value()), key))
            {
                n = cast<Node*>(n->Right());
            }
            else
            {
                break;
            }
        }
        if (n != null)
        {
            if (count == 1)
            {
                Clear();
            }
            else
            {
                Remove(Iterator(n));
            }
            return true;
        }
        return false;
    }
    public nothrow void Remove(Iterator pos)
    {
        Node* toRemove = cast<Node*>(Node.RebalanceForRemove(pos.
            GetNode(), RootRef(), LeftmostRef(), RightmostRef()));
        toRemove->SetLeft(null);
        toRemove->SetRight(null);
        delete toRemove;
        --count;
    }
    private nothrow inline const KeyType& KeyOf(const ValueType&
        value) const
    {
        return keyOf(value);
    }
    private nothrow inline bool Comp(const KeyType& left, const
        KeyType& right) const
    {
        return comp(left, right);
    }
```

```
        private nothrow inline Node* Root()
        {
            return cast<Node*>(header->Parent());
        }
        private nothrow inline NodeBase*& RootRef()
        {
            return header->ParentRef();
        }
        private nothrow inline void SetRoot(Node* root)
        {
            header->SetParent(root);
        }
        private nothrow inline Node* Leftmost()
        {
            return cast<Node*>(header->Left());
        }
        private nothrow inline NodeBase*& LeftmostRef()
        {
            return header->LeftRef();
        }
        private nothrow inline void SetLeftmost(Node* lm)
        {
            header->SetLeft(lm);
        }
        private nothrow inline Node* Rightmost()
        {
            return cast<Node*>(header->Right());
        }
        private nothrow inline NodeBase*& RightmostRef()
        {
            return header->RightRef();
        }
        private nothrow inline void SetRightmost(Node* rm)
        {
            header->SetRight(rm);
        }
        private void Init()
        {
            header.Reset(new Node(ValueType(), null));
            header->SetColor(Node.Color.red);
            SetLeftmost(header.GetPtr());
            SetRightmost(header.GetPtr());
        }
        private Node* Copy(Node* x, Node* p)
        {
            #assert(x != null && p != null);
            Node* top = CloneNode(x, p);
            if (x->Right() != null)
            {
                top->SetRight(Copy(cast<Node*>(x->Right()), top));
            }
            p = top;
            x = cast<Node*>(x->Left());
```

```
            while (x != null)
            {
                Node* y = CloneNode(x, p);
                p->SetLeft(y);
                if (x->Right() != null)
                {
                    y->SetRight(Copy(cast<Node*>(x->Right()), y));
                }
                p = y;
                x = cast<Node*>(x->Left());
            }
            return top;
        }
        private Node* CloneNode(Node* x, Node* p) const
        {
            #assert(x != null && p != null);
            Node* clone = new Node(x->Value(), p);
            clone->SetColor(x->GetColor());
            return clone;
        }
        private UniquePtr<Node> header;
        private int count;
        private KeyOfValue keyOf;
        private Compare comp;
    }
}
```