./Platform.Collections.Methods/GenericCollectionMethodsBase.cs

```
using System.Collections.Generic;
using System.Runtime.CompilerServices;
using Platform.Numbers;

#pragma warning disable CS1591 // Missing XML comment for publicly visible type or member

namespace Platform.Collections.Methods
{
    public abstract class GenericCollectionMethodsBase<TElement>
    {
        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual TElement GetZero() => Integer<TElement>.Zero;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual bool EqualToZero(TElement value) => EqualityComparer.Equals(value,
        ↪  Zero);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual bool AreEqual(TElement first, TElement second) =>
        ↪  EqualityComparer.Equals(first, second);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual bool GreaterThanZero(TElement value) => Comparer.Compare(value, Zero)
        ↪  > 0;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual bool GreaterThan(TElement first, TElement second) =>
        ↪  Comparer.Compare(first, second) > 0;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual bool GreaterOrEqualThanZero(TElement value) => Comparer.Compare(value,
        ↪  Zero) >= 0;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual bool GreaterOrEqualThan(TElement first, TElement second) =>
        ↪  Comparer.Compare(first, second) >= 0;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual bool LessOrEqualThanZero(TElement value) => Comparer.Compare(value,
        ↪  Zero) <= 0;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual bool LessOrEqualThan(TElement first, TElement second) =>
        ↪  Comparer.Compare(first, second) <= 0;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual bool LessThanZero(TElement value) => Comparer.Compare(value, Zero) < 0;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual bool LessThan(TElement first, TElement second) =>
        ↪  Comparer.Compare(first, second) < 0;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual TElement Increment(TElement value) =>
        ↪  Arithmetic<TElement>.Increment(value);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual TElement Decrement(TElement value) =>
        ↪  Arithmetic<TElement>.Decrement(value);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual TElement Add(TElement first, TElement second) =>
        ↪  Arithmetic<TElement>.Add(first, second);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual TElement Subtract(TElement first, TElement second) =>
        ↪  Arithmetic<TElement>.Subtract(first, second);

        protected readonly TElement Zero;
        protected readonly TElement One;
        protected readonly TElement Two;
        protected readonly EqualityComparer<TElement> EqualityComparer;
        protected readonly Comparer<TElement> Comparer;

        protected GenericCollectionMethodsBase()
        {
            EqualityComparer = EqualityComparer<TElement>.Default;
```

```
            Comparer = Comparer<TElement>.Default;
            Zero = GetZero(); //-V3068
            One = Increment(Zero); //-V3068
            Two = Increment(One); //-V3068
        }
    }
}
```

./Platform.Collections.Methods/Lists/CircularDoublyLinkedListMethods.cs

```
#pragma warning disable CS1591 // Missing XML comment for publicly visible type or member

namespace Platform.Collections.Methods.Lists
{
    public abstract class CircularDoublyLinkedListMethods<TElement> :
    ↪ DoublyLinkedListMethodsBase<TElement>
    {
        public void AttachBefore(TElement baseElement, TElement newElement)
        {
            var baseElementPrevious = GetPrevious(baseElement);
            SetPrevious(newElement, baseElementPrevious);
            SetNext(newElement, baseElement);
            if (AreEqual(baseElement, GetFirst()))
            {
                SetFirst(newElement);
            }
            SetNext(baseElementPrevious, newElement);
            SetPrevious(baseElement, newElement);
            IncrementSize();
        }

        public void AttachAfter(TElement baseElement, TElement newElement)
        {
            var baseElementNext = GetNext(baseElement);
            SetPrevious(newElement, baseElement);
            SetNext(newElement, baseElementNext);
            if (AreEqual(baseElement, GetLast()))
            {
                SetLast(newElement);
            }
            SetPrevious(baseElementNext, newElement);
            SetNext(baseElement, newElement);
            IncrementSize();
        }

        public void AttachAsFirst(TElement element)
        {
            var first = GetFirst();
            if (EqualToZero(first))
            {
                SetFirst(element);
                SetLast(element);
                SetPrevious(element, element);
                SetNext(element, element);
                IncrementSize();
            }
            else
            {
                AttachBefore(first, element);
            }
        }

        public void AttachAsLast(TElement element)
        {
            var last = GetLast();
            if (EqualToZero(last))
            {
                AttachAsFirst(element);
            }
            else
            {
                AttachAfter(last, element);
            }
        }

        public void Detach(TElement element)
        {
            var elementPrevious = GetPrevious(element);
            var elementNext = GetNext(element);
```

```
            if (AreEqual(elementNext, element))
            {
                SetFirst(Zero);
                SetLast(Zero);
            }
            else
            {
                SetNext(elementPrevious, elementNext);
                SetPrevious(elementNext, elementPrevious);
                if (AreEqual(element, GetFirst()))
                {
                    SetFirst(elementNext);
                }
                if (AreEqual(element, GetLast()))
                {
                    SetLast(elementPrevious);
                }
            }
            SetPrevious(element, Zero);
            SetNext(element, Zero);
            DecrementSize();
        }
    }
}
```

./Platform.Collections.Methods/Lists/DoublyLinkedListMethodsBase.cs

```
using System.Runtime.CompilerServices;

#pragma warning disable CS1591 // Missing XML comment for publicly visible type or member

namespace Platform.Collections.Methods.Lists
{
    /// <remarks>
    /// Based on <a href="https://en.wikipedia.org/wiki/Doubly_linked_list">doubly linked list</a> implementation.
    /// </remarks>
    public abstract class DoublyLinkedListMethodsBase<TElement> : GenericCollectionMethodsBase<TElement>
    {
        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract TElement GetFirst();

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract TElement GetLast();

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract TElement GetPrevious(TElement element);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract TElement GetNext(TElement element);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract TElement GetSize();

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract void SetFirst(TElement element);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract void SetLast(TElement element);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract void SetPrevious(TElement element, TElement previous);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract void SetNext(TElement element, TElement next);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract void SetSize(TElement size);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected void IncrementSize() => SetSize(Increment(GetSize()));

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected void DecrementSize() => SetSize(Decrement(GetSize()));
    }
}
```

./Platform.Collections.Methods/Lists/OpenDoublyLinkedListMethods.cs

```
#pragma warning disable CS1591 // Missing XML comment for publicly visible type or member

namespace Platform.Collections.Methods.Lists
{
    public abstract class OpenDoublyLinkedListMethods<TElement> :
    ↪ DoublyLinkedListMethodsBase<TElement>
    {
        public void AttachBefore(TElement baseElement, TElement newElement)
        {
            var baseElementPrevious = GetPrevious(baseElement);
            SetPrevious(newElement, baseElementPrevious);
            SetNext(newElement, baseElement);
            if (EqualToZero(baseElementPrevious))
            {
                SetFirst(newElement);
            }
            else
            {
                SetNext(baseElementPrevious, newElement);
            }
            SetPrevious(baseElement, newElement);
            IncrementSize();
        }

        public void AttachAfter(TElement baseElement, TElement newElement)
        {
            var baseElementNext = GetNext(baseElement);
            SetPrevious(newElement, baseElement);
            SetNext(newElement, baseElementNext);
            if (EqualToZero(baseElementNext))
            {
                SetLast(newElement);
            }
            else
            {
                SetPrevious(baseElementNext, newElement);
            }
            SetNext(baseElement, newElement);
            IncrementSize();
        }

        public void AttachAsFirst(TElement element)
        {
            var first = GetFirst();
            if (EqualToZero(first))
            {
                SetFirst(element);
                SetLast(element);
                SetPrevious(element, Zero);
                SetNext(element, Zero);
                IncrementSize();
            }
            else
            {
                AttachBefore(first, element);
            }
        }

        public void AttachAsLast(TElement element)
        {
            var last = GetLast();
            if (EqualToZero(last))
            {
                AttachAsFirst(element);
            }
            else
            {
                AttachAfter(last, element);
            }
        }

        public void Detach(TElement element)
        {
            var elementPrevious = GetPrevious(element);
            var elementNext = GetNext(element);
            if (EqualToZero(elementPrevious))
            {
```

```
                SetFirst(elementNext);
            }
            else
            {
                SetNext(elementPrevious, elementNext);
            }
            if (EqualToZero(elementNext))
            {
                SetLast(elementPrevious);
            }
            else
            {
                SetPrevious(elementNext, elementPrevious);
            }
            SetPrevious(element, Zero);
            SetNext(element, Zero);
            DecrementSize();
        }
    }
}
```

./Platform.Collections.Methods/Trees/RecursionlessSizeBalancedTreeMethods.cs

```
#pragma warning disable CS1591 // Missing XML comment for publicly visible type or member

namespace Platform.Collections.Methods.Trees
{
    public abstract class RecursionlessSizeBalancedTreeMethods<TElement> :
    ↪ SizedBinaryTreeMethodsBase<TElement>
    {
        protected override void AttachCore(ref TElement root, TElement node)
        {
            while (true)
            {
                ref var left = ref GetLeftReference(root);
                var leftSize = GetSizeOrZero(left);
                ref var right = ref GetRightReference(root);
                var rightSize = GetSizeOrZero(right);
                if (FirstIsToTheLeftOfSecond(node, root)) // node.Key less than root.Key
                {
                    if (EqualToZero(left))
                    {
                        IncrementSize(root);
                        SetSize(node, One);
                        left = node;
                        return;
                    }
                    if (FirstIsToTheLeftOfSecond(node, left)) // node.Key less than left.Key
                    {
                        if (GreaterThan(Increment(leftSize), rightSize))
                        {
                            RightRotate(ref root);
                        }
                        else
                        {
                            IncrementSize(root);
                            root = ref left;
                        }
                    }
                    else  // node.Key greater than left.Key
                    {
                        var leftRightSize = GetSizeOrZero(GetRight(left));
                        if (GreaterThan(Increment(leftRightSize), rightSize))
                        {
                            if (EqualToZero(leftRightSize) && EqualToZero(rightSize))
                            {
                                SetLeft(node, left);
                                SetRight(node, root);
                                SetSize(node, Add(leftSize, Two)); // Two (2) - node the size of
                                ↪  root and a node itself
                                SetLeft(root, Zero);
                                SetSize(root, One);
                                root = node;
                                return;
                            }
                            LeftRotate(ref left);
                            RightRotate(ref root);
                        }
                        else
                        {
```

```
                            IncrementSize(root);
                            root = ref left;
                        }
                    }
                }
                else // node.Key greater than root.Key
                {
                    if (EqualToZero(right))
                    {
                        IncrementSize(root);
                        SetSize(node, One);
                        right = node;
                        return;
                    }
                    if (FirstIsToTheRightOfSecond(node, right)) // node.Key greater than
                    ↪ right.Key
                    {
                        if (GreaterThan(Increment(rightSize), leftSize))
                        {
                            LeftRotate(ref root);
                        }
                        else
                        {
                            IncrementSize(root);
                            root = ref right;
                        }
                    }
                    else // node.Key less than right.Key
                    {
                        var rightLeftSize = GetSizeOrZero(GetLeft(right));
                        if (GreaterThan(Increment(rightLeftSize), leftSize))
                        {
                            if (EqualToZero(rightLeftSize) && EqualToZero(leftSize))
                            {
                                SetLeft(node, root);
                                SetRight(node, right);
                                SetSize(node, Add(rightSize, Two)); // Two (2) - node the size
                                ↪  of root and a node itself
                                SetRight(root, Zero);
                                SetSize(root, One);
                                root = node;
                                return;
                            }
                            RightRotate(ref right);
                            LeftRotate(ref root);
                        }
                        else
                        {
                            IncrementSize(root);
                            root = ref right;
                        }
                    }
                }
            }
        }

        protected override void DetachCore(ref TElement root, TElement node)
        {
            while (true)
            {
                ref var left = ref GetLeftReference(root);
                var leftSize = GetSizeOrZero(left);
                ref var right = ref GetRightReference(root);
                var rightSize = GetSizeOrZero(right);
                if (FirstIsToTheLeftOfSecond(node, root)) // node.Key less than root.Key
                {
                    var decrementedLeftSize = Decrement(leftSize);
                    if (GreaterThan(GetSizeOrZero(GetRight(right)), decrementedLeftSize))
                    {
                        LeftRotate(ref root);
                    }
                    else if (GreaterThan(GetSizeOrZero(GetLeft(right)), decrementedLeftSize))
                    {
                        RightRotate(ref right);
                        LeftRotate(ref root);
                    }
                    else
                    {
```

```
                        DecrementSize(root);
                        root = ref left;
                    }
                }
                else if (FirstIsToTheRightOfSecond(node, root)) // node.Key greater than root.Key
                {
                    var decrementedRightSize = Decrement(rightSize);
                    if (GreaterThan(GetSizeOrZero(GetLeft(left)), decrementedRightSize))
                    {
                        RightRotate(ref root);
                    }
                    else if (GreaterThan(GetSizeOrZero(GetRight(left)), decrementedRightSize))
                    {
                        LeftRotate(ref left);
                        RightRotate(ref root);
                    }
                    else
                    {
                        DecrementSize(root);
                        root = ref right;
                    }
                }
                else // key equals to root.Key
                {
                    if (GreaterThanZero(leftSize) && GreaterThanZero(rightSize))
                    {
                        TElement replacement;
                        if (GreaterThan(leftSize, rightSize))
                        {
                            replacement = GetRightest(left);
                            DetachCore(ref left, replacement);
                        }
                        else
                        {
                            replacement = GetLeftest(right);
                            DetachCore(ref right, replacement);
                        }
                        SetLeft(replacement, left);
                        SetRight(replacement, right);
                        SetSize(replacement, Add(leftSize, rightSize));
                        root = replacement;
                    }
                    else if (GreaterThanZero(leftSize))
                    {
                        root = left;
                    }
                    else if (GreaterThanZero(rightSize))
                    {
                        root = right;
                    }
                    else
                    {
                        root = Zero;
                    }
                    ClearNode(node);
                    return;
                }
            }
        }
    }
}
```

./Platform.Collections.Methods/Trees/SizeBalancedTreeMethods.cs

```
using System;

#pragma warning disable CS1591 // Missing XML comment for publicly visible type or member

namespace Platform.Collections.Methods.Trees
{
    public abstract class SizeBalancedTreeMethods<TElement> :
    ↪ SizedBinaryTreeMethodsBase<TElement>
    {
        protected override void AttachCore(ref TElement root, TElement node)
        {
            if (EqualToZero(root))
            {
                root = node;
                IncrementSize(root);
            }
```

```
            else
            {
                IncrementSize(root);
                if (FirstIsToTheLeftOfSecond(node, root))
                {
                    AttachCore(ref GetLeftReference(root), node);
                    LeftMaintain(ref root);
                }
                else
                {
                    AttachCore(ref GetRightReference(root), node);
                    RightMaintain(ref root);
                }
            }
        }

        protected override void DetachCore(ref TElement root, TElement nodeToDetach)
        {
            ref var currentNode = ref root;
            ref var parent = ref root;
            var replacementNode = Zero;
            while (!AreEqual(currentNode, nodeToDetach))
            {
                DecrementSize(currentNode);
                if (FirstIsToTheLeftOfSecond(nodeToDetach, currentNode))
                {
                    parent = ref currentNode;
                    currentNode = ref GetLeftReference(currentNode);
                }
                else if (FirstIsToTheRightOfSecond(nodeToDetach, currentNode))
                {
                    parent = ref currentNode;
                    currentNode = ref GetRightReference(currentNode);
                }
                else
                {
                    throw new InvalidOperationException("Duplicate link found in the tree.");
                }
            }
            var nodeToDetachLeft = GetLeft(nodeToDetach);
            var node = GetRight(nodeToDetach);
            if (!EqualToZero(nodeToDetachLeft) && !EqualToZero(node))
            {
                var leftestNode = GetLeftest(node);
                DetachCore(ref GetRightReference(nodeToDetach), leftestNode);
                SetLeft(leftestNode, nodeToDetachLeft);
                node = GetRight(nodeToDetach);
                if (!EqualToZero(node))
                {
                    SetRight(leftestNode, node);
                    SetSize(leftestNode, Increment(Add(GetSize(nodeToDetachLeft),
                    ↪  GetSize(node))));
                }
                else
                {
                    SetSize(leftestNode, Increment(GetSize(nodeToDetachLeft)));
                }
                replacementNode = leftestNode;
            }
            else if (!EqualToZero(nodeToDetachLeft))
            {
                replacementNode = nodeToDetachLeft;
            }
            else if (!EqualToZero(node))
            {
                replacementNode = node;
            }
            if (AreEqual(root, nodeToDetach))
            {
                root = replacementNode;
            }
            else if (AreEqual(GetLeft(parent), nodeToDetach))
            {
                SetLeft(parent, replacementNode);
            }
            else if (AreEqual(GetRight(parent), nodeToDetach))
            {
                SetRight(parent, replacementNode);
            }
```

```
94              ClearNode(nodeToDetach);
95          }
96
97          private void LeftMaintain(ref TElement root)
98          {
99              if (!EqualToZero(root))
100             {
101                 var rootLeftNode = GetLeft(root);
102                 if (!EqualToZero(rootLeftNode))
103                 {
104                     var rootRightNode = GetRight(root);
105                     var rootRightNodeSize = GetSize(rootRightNode);
106                     var rootLeftNodeLeftNode = GetLeft(rootLeftNode);
107                     if (!EqualToZero(rootLeftNodeLeftNode) &&
108                         (EqualToZero(rootRightNode) ||
                            ↪ GreaterThan(GetSize(rootLeftNodeLeftNode), rootRightNodeSize)))
109                     {
110                         RightRotate(ref root);
111                     }
112                     else
113                     {
114                         var rootLeftNodeRightNode = GetRight(rootLeftNode);
115                         if (!EqualToZero(rootLeftNodeRightNode) &&
116                             (EqualToZero(rootRightNode) ||
                                ↪ GreaterThan(GetSize(rootLeftNodeRightNode), rootRightNodeSize)))
117                         {
118                             LeftRotate(ref GetLeftReference(root));
119                             RightRotate(ref root);
120                         }
121                         else
122                         {
123                             return;
124                         }
125                     }
126                     LeftMaintain(ref GetLeftReference(root));
127                     RightMaintain(ref GetRightReference(root));
128                     LeftMaintain(ref root);
129                     RightMaintain(ref root);
130                 }
131             }
132         }
133
134         private void RightMaintain(ref TElement root)
135         {
136             if (!EqualToZero(root))
137             {
138                 var rootRightNode = GetRight(root);
139                 if (!EqualToZero(rootRightNode))
140                 {
141                     var rootLeftNode = GetLeft(root);
142                     var rootLeftNodeSize = GetSize(rootLeftNode);
143                     var rootRightNodeRightNode = GetRight(rootRightNode);
144                     if (!EqualToZero(rootRightNodeRightNode) &&
145                         (EqualToZero(rootLeftNode) ||
                            ↪ GreaterThan(GetSize(rootRightNodeRightNode), rootLeftNodeSize)))
146                     {
147                         LeftRotate(ref root);
148                     }
149                     else
150                     {
151                         var rootRightNodeLeftNode = GetLeft(rootRightNode);
152                         if (!EqualToZero(rootRightNodeLeftNode) &&
153                             (EqualToZero(rootLeftNode) ||
                                ↪ GreaterThan(GetSize(rootRightNodeLeftNode), rootLeftNodeSize)))
154                         {
155                             RightRotate(ref GetRightReference(root));
156                             LeftRotate(ref root);
157                         }
158                         else
159                         {
160                             return;
161                         }
162                     }
163                     LeftMaintain(ref GetLeftReference(root));
164                     RightMaintain(ref GetRightReference(root));
165                     LeftMaintain(ref root);
166                     RightMaintain(ref root);
167                 }
```

```
            }
        }
    }
}
```

./Platform.Collections.Methods/Trees/SizedAndThreadedAVLBalancedTreeMethods.cs

```
using System;
using System.Runtime.CompilerServices;
using System.Text;
#if USEARRAYPOOL
using Platform.Collections;
#endif

#pragma warning disable CS1591 // Missing XML comment for publicly visible type or member

namespace Platform.Collections.Methods.Trees
{
    /// <summary>
    /// Combination of Size, Height (AVL), and threads.
    /// </summary>
    /// <remarks>
    /// Based on: <a href="https://github.com/programmatom/TreeLib/blob/master/TreeLib/TreeLib/Generated/AVLTreeList.cs">TreeLib.AVLTreeList</a>.
    /// Which itself based on: <a href="https://github.com/GNOME/glib/blob/master/glib/gtree.c">GNOME/glib/gtree</a>.
    /// </remarks>
    public abstract class SizedAndThreadedAVLBalancedTreeMethods<TElement> : SizedBinaryTreeMethodsBase<TElement>
    {
        private const int MaxPath = 92;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected override TElement GetRightest(TElement current)
        {
            var currentRight = GetRightOrDefault(current);
            while (!EqualToZero(currentRight))
            {
                current = currentRight;
                currentRight = GetRightOrDefault(current);
            }
            return current;
        }

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected override TElement GetLeftest(TElement current)
        {
            var currentLeft = GetLeftOrDefault(current);
            while (!EqualToZero(currentLeft))
            {
                current = currentLeft;
                currentLeft = GetLeftOrDefault(current);
            }
            return current;
        }

        public override bool Contains(TElement node, TElement root)
        {
            while (!EqualToZero(root))
            {
                if (FirstIsToTheLeftOfSecond(node, root)) // node.Key < root.Key
                {
                    root = GetLeftOrDefault(root);
                }
                else if (FirstIsToTheRightOfSecond(node, root)) // node.Key > root.Key
                {
                    root = GetRightOrDefault(root);
                }
                else // node.Key == root.Key
                {
                    return true;
                }
            }
            return false;
        }

        protected override void PrintNode(TElement node, StringBuilder sb, int level)
        {
            base.PrintNode(node, sb, level);
            sb.Append(' ');
```

```
            sb.Append(GetLeftIsChild(node) ? 'l' : 'L');
            sb.Append(GetRightIsChild(node) ? 'r' : 'R');
            sb.Append(' ');
            sb.Append(GetBalance(node));
        }

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected void IncrementBalance(TElement node) => SetBalance(node,
        ↪  (sbyte)(GetBalance(node) + 1));

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected void DecrementBalance(TElement node) => SetBalance(node,
        ↪  (sbyte)(GetBalance(node) - 1));

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected override TElement GetLeftOrDefault(TElement node) => GetLeftIsChild(node) ?
        ↪  GetLeft(node) : default;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected override TElement GetRightOrDefault(TElement node) => GetRightIsChild(node) ?
        ↪  GetRight(node) : default;

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract bool GetLeftIsChild(TElement node);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract void SetLeftIsChild(TElement node, bool value);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract bool GetRightIsChild(TElement node);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract void SetRightIsChild(TElement node, bool value);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract sbyte GetBalance(TElement node);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected abstract void SetBalance(TElement node, sbyte value);

        protected override void AttachCore(ref TElement root, TElement node)
        {
            unchecked
            {
                // TODO: Check what is faster to use simple array or array from array pool
                // TODO: Try to use stackalloc as an optimization (requires code generation,
                ↪  because of generics)
#if USEARRAYPOOL
                var path = ArrayPool.Allocate<TElement>(MaxPath);
                var pathPosition = 0;
                path[pathPosition++] = default;
#else
                var path = new TElement[MaxPath];
                var pathPosition = 1;
#endif
                var currentNode = root;
                while (true)
                {
                    if (FirstIsToTheLeftOfSecond(node, currentNode))
                    {
                        if (GetLeftIsChild(currentNode))
                        {
                            IncrementSize(currentNode);
                            path[pathPosition++] = currentNode;
                            currentNode = GetLeft(currentNode);
                        }
                        else
                        {
                            // Threads
                            SetLeft(node, GetLeft(currentNode));
                            SetRight(node, currentNode);
                            SetLeft(currentNode, node);
                            SetLeftIsChild(currentNode, true);
                            DecrementBalance(currentNode);
                            SetSize(node, One);
                            FixSize(currentNode); // Should be incremented already
                            break;
                        }
                    }
```

```
                    else if (FirstIsToTheRightOfSecond(node, currentNode))
                    {
                        if (GetRightIsChild(currentNode))
                        {
                            IncrementSize(currentNode);
                            path[pathPosition++] = currentNode;
                            currentNode = GetRight(currentNode);
                        }
                        else
                        {
                            // Threads
                            SetRight(node, GetRight(currentNode));
                            SetLeft(node, currentNode);
                            SetRight(currentNode, node);
                            SetRightIsChild(currentNode, true);
                            IncrementBalance(currentNode);
                            SetSize(node, One);
                            FixSize(currentNode); // Should be incremented already
                            break;
                        }
                    }
                    else
                    {
                        throw new InvalidOperationException("Node with the same key already
                        ↪  attached to a tree.");
                    }
                }
                // Restore balance. This is the goodness of a non-recursive
                // implementation, when we are done with balancing we 'break'
                // the loop and we are done.
                while (true)
                {
                    var parent = path[--pathPosition];
                    var isLeftNode = !AreEqual(parent, default) && AreEqual(currentNode,
                    ↪  GetLeft(parent));
                    var currentNodeBalance = GetBalance(currentNode);
                    if (currentNodeBalance < -1 || currentNodeBalance > 1)
                    {
                        currentNode = Balance(currentNode);
                        if (AreEqual(parent, default))
                        {
                            root = currentNode;
                        }
                        else if (isLeftNode)
                        {
                            SetLeft(parent, currentNode);
                            FixSize(parent);
                        }
                        else
                        {
                            SetRight(parent, currentNode);
                            FixSize(parent);
                        }
                    }
                    currentNodeBalance = GetBalance(currentNode);
                    if (currentNodeBalance == 0 || AreEqual(parent, default))
                    {
                        break;
                    }
                    if (isLeftNode)
                    {
                        DecrementBalance(parent);
                    }
                    else
                    {
                        IncrementBalance(parent);
                    }
                    currentNode = parent;
                }
#if USEARRAYPOOL
                ArrayPool.Free(path);
#endif
            }
        }

        private TElement Balance(TElement node)
        {
            unchecked
```

```
            {
                var rootBalance = GetBalance(node);
                if (rootBalance < -1)
                {
                    var left = GetLeft(node);
                    if (GetBalance(left) > 0)
                    {
                        SetLeft(node, LeftRotateWithBalance(left));
                        FixSize(node);
                    }
                    node = RightRotateWithBalance(node);
                }
                else if (rootBalance > 1)
                {
                    var right = GetRight(node);
                    if (GetBalance(right) < 0)
                    {
                        SetRight(node, RightRotateWithBalance(right));
                        FixSize(node);
                    }
                    node = LeftRotateWithBalance(node);
                }
                return node;
            }
        }

        protected TElement LeftRotateWithBalance(TElement node)
        {
            unchecked
            {
                var right = GetRight(node);
                if (GetLeftIsChild(right))
                {
                    SetRight(node, GetLeft(right));
                }
                else
                {
                    SetRightIsChild(node, false);
                    SetLeftIsChild(right, true);
                }
                SetLeft(right, node);
                // Fix size
                SetSize(right, GetSize(node));
                FixSize(node);
                // Fix balance
                var rootBalance = GetBalance(node);
                var rightBalance = GetBalance(right);
                if (rightBalance <= 0)
                {
                    if (rootBalance >= 1)
                    {
                        SetBalance(right, (sbyte)(rightBalance - 1));
                    }
                    else
                    {
                        SetBalance(right, (sbyte)(rootBalance + rightBalance - 2));
                    }
                    SetBalance(node, (sbyte)(rootBalance - 1));
                }
                else
                {
                    if (rootBalance <= rightBalance)
                    {
                        SetBalance(right, (sbyte)(rootBalance - 2));
                    }
                    else
                    {
                        SetBalance(right, (sbyte)(rightBalance - 1));
                    }
                    SetBalance(node, (sbyte)(rootBalance - rightBalance - 1));
                }
                return right;
            }
        }

        protected TElement RightRotateWithBalance(TElement node)
        {
            unchecked
```

```
            {
                var left = GetLeft(node);
                if (GetRightIsChild(left))
                {
                    SetLeft(node, GetRight(left));
                }
                else
                {
                    SetLeftIsChild(node, false);
                    SetRightIsChild(left, true);
                }
                SetRight(left, node);
                // Fix size
                SetSize(left, GetSize(node));
                FixSize(node);
                // Fix balance
                var rootBalance = GetBalance(node);
                var leftBalance = GetBalance(left);
                if (leftBalance <= 0)
                {
                    if (leftBalance > rootBalance)
                    {
                        SetBalance(left, (sbyte)(leftBalance + 1));
                    }
                    else
                    {
                        SetBalance(left, (sbyte)(rootBalance + 2));
                    }
                    SetBalance(node, (sbyte)(rootBalance - leftBalance + 1));
                }
                else
                {
                    if (rootBalance <= -1)
                    {
                        SetBalance(left, (sbyte)(leftBalance + 1));
                    }
                    else
                    {
                        SetBalance(left, (sbyte)(rootBalance + leftBalance + 2));
                    }
                    SetBalance(node, (sbyte)(rootBalance + 1));
                }
                return left;
            }
        }

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected override TElement GetNext(TElement node)
        {
            var current = GetRight(node);
            if (GetRightIsChild(node))
            {
                return GetLeftest(current);
            }
            return current;
        }

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected override TElement GetPrevious(TElement node)
        {
            var current = GetLeft(node);
            if (GetLeftIsChild(node))
            {
                return GetRightest(current);
            }
            return current;
        }

        protected override void DetachCore(ref TElement root, TElement node)
        {
            unchecked
            {
#if USEARRAYPOOL
                var path = ArrayPool.Allocate<TElement>(MaxPath);
                var pathPosition = 0;
                path[pathPosition++] = default;
#else
                var path = new TElement[MaxPath];
                var pathPosition = 1;
```

```
#endif
                var currentNode = root;
                while (true)
                {
                    if (FirstIsToTheLeftOfSecond(node, currentNode))
                    {
                        if (!GetLeftIsChild(currentNode))
                        {
                            throw new InvalidOperationException("Cannot find a node.");
                        }
                        DecrementSize(currentNode);
                        path[pathPosition++] = currentNode;
                        currentNode = GetLeft(currentNode);
                    }
                    else if (FirstIsToTheRightOfSecond(node, currentNode))
                    {
                        if (!GetRightIsChild(currentNode))
                        {
                            throw new InvalidOperationException("Cannot find a node.");
                        }
                        DecrementSize(currentNode);
                        path[pathPosition++] = currentNode;
                        currentNode = GetRight(currentNode);
                    }
                    else
                    {
                        break;
                    }
                }
                var parent = path[--pathPosition];
                var balanceNode = parent;
                var isLeftNode = !AreEqual(parent, default) && AreEqual(currentNode,
                ↪  GetLeft(parent));
                if (!GetLeftIsChild(currentNode))
                {
                    if (!GetRightIsChild(currentNode)) // node has no children
                    {
                        if (AreEqual(parent, default))
                        {
                            root = Zero;
                        }
                        else if (isLeftNode)
                        {
                            SetLeftIsChild(parent, false);
                            SetLeft(parent, GetLeft(currentNode));
                            IncrementBalance(parent);
                        }
                        else
                        {
                            SetRightIsChild(parent, false);
                            SetRight(parent, GetRight(currentNode));
                            DecrementBalance(parent);
                        }
                    }
                    else // node has a right child
                    {
                        var successor = GetNext(currentNode);
                        SetLeft(successor, GetLeft(currentNode));
                        var right = GetRight(currentNode);
                        if (AreEqual(parent, default))
                        {
                            root = right;
                        }
                        else if (isLeftNode)
                        {
                            SetLeft(parent, right);
                            IncrementBalance(parent);
                        }
                        else
                        {
                            SetRight(parent, right);
                            DecrementBalance(parent);
                        }
                    }
                }
                else // node has a left child
                {
                    if (!GetRightIsChild(currentNode))
```

```
                {
                    var predecessor = GetPrevious(currentNode);
                    SetRight(predecessor, GetRight(currentNode));
                    var leftValue = GetLeft(currentNode);
                    if (AreEqual(parent, default))
                    {
                        root = leftValue;
                    }
                    else if (isLeftNode)
                    {
                        SetLeft(parent, leftValue);
                        IncrementBalance(parent);
                    }
                    else
                    {
                        SetRight(parent, leftValue);
                        DecrementBalance(parent);
                    }
                }
                else // node has a both children (left and right)
                {
                    var predecessor = GetLeft(currentNode);
                    var successor = GetRight(currentNode);
                    var successorParent = currentNode;
                    int previousPathPosition = ++pathPosition;
                    // find the immediately next node (and its parent)
                    while (GetLeftIsChild(successor))
                    {
                        path[++pathPosition] = successorParent = successor;
                        successor = GetLeft(successor);
                        if (!AreEqual(successorParent, currentNode))
                        {
                            DecrementSize(successorParent);
                        }
                    }
                    path[previousPathPosition] = successor;
                    balanceNode = path[pathPosition];
                    // remove 'successor' from the tree
                    if (!AreEqual(successorParent, currentNode))
                    {
                        if (!GetRightIsChild(successor))
                        {
                            SetLeftIsChild(successorParent, false);
                        }
                        else
                        {
                            SetLeft(successorParent, GetRight(successor));
                        }
                        IncrementBalance(successorParent);
                        SetRightIsChild(successor, true);
                        SetRight(successor, GetRight(currentNode));
                    }
                    else
                    {
                        DecrementBalance(currentNode);
                    }
                    // set the predecessor's successor link to point to the right place
                    while (GetRightIsChild(predecessor))
                    {
                        predecessor = GetRight(predecessor);
                    }
                    SetRight(predecessor, successor);
                    // prepare 'successor' to replace 'node'
                    var left = GetLeft(currentNode);
                    SetLeftIsChild(successor, true);
                    SetLeft(successor, left);
                    SetBalance(successor, GetBalance(currentNode));
                    FixSize(successor);
                    if (AreEqual(parent, default))
                    {
                        root = successor;
                    }
                    else if (isLeftNode)
                    {
                        SetLeft(parent, successor);
                    }
                    else
                    {
```

```
                                SetRight(parent, successor);
                            }
                        }
                    }
                    // restore balance
                    if (!AreEqual(balanceNode, default))
                    {
                        while (true)
                        {
                            var balanceParent = path[--pathPosition];
                            isLeftNode = !AreEqual(balanceParent, default) && AreEqual(balanceNode,
                            ↪  GetLeft(balanceParent));
                            var currentNodeBalance = GetBalance(balanceNode);
                            if (currentNodeBalance < -1 || currentNodeBalance > 1)
                            {
                                balanceNode = Balance(balanceNode);
                                if (AreEqual(balanceParent, default))
                                {
                                    root = balanceNode;
                                }
                                else if (isLeftNode)
                                {
                                    SetLeft(balanceParent, balanceNode);
                                }
                                else
                                {
                                    SetRight(balanceParent, balanceNode);
                                }
                            }
                            currentNodeBalance = GetBalance(balanceNode);
                            if (currentNodeBalance != 0 || AreEqual(balanceParent, default))
                            {
                                break;
                            }
                            if (isLeftNode)
                            {
                                IncrementBalance(balanceParent);
                            }
                            else
                            {
                                DecrementBalance(balanceParent);
                            }
                            balanceNode = balanceParent;
                        }
                    }
                    ClearNode(node);
#if USEARRAYPOOL
                    ArrayPool.Free(path);
#endif
                }
            }

            [MethodImpl(MethodImplOptions.AggressiveInlining)]
            protected override void ClearNode(TElement node)
            {
                SetLeft(node, Zero);
                SetRight(node, Zero);
                SetSize(node, Zero);
                SetLeftIsChild(node, false);
                SetRightIsChild(node, false);
                SetBalance(node, 0);
            }
        }
    }
```

./Platform.Collections.Methods/Trees/SizedBinaryTreeMethodsBase.cs

```
using System;
using System.Runtime.CompilerServices;
using System.Text;
using Platform.Numbers;

//#define ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
#pragma warning disable CS1591 // Missing XML comment for publicly visible type or member

namespace Platform.Collections.Methods.Trees
{
    public abstract class SizedBinaryTreeMethodsBase<TElement> :
    ↪  GenericCollectionMethodsBase<TElement>
    {
```

```
13          [MethodImpl(MethodImplOptions.AggressiveInlining)]
14          protected abstract ref TElement GetLeftReference(TElement node);
15
16          [MethodImpl(MethodImplOptions.AggressiveInlining)]
17          protected abstract ref TElement GetRightReference(TElement node);
18
19          [MethodImpl(MethodImplOptions.AggressiveInlining)]
20          protected abstract TElement GetLeft(TElement node);
21
22          [MethodImpl(MethodImplOptions.AggressiveInlining)]
23          protected abstract TElement GetRight(TElement node);
24
25          [MethodImpl(MethodImplOptions.AggressiveInlining)]
26          protected abstract TElement GetSize(TElement node);
27
28          [MethodImpl(MethodImplOptions.AggressiveInlining)]
29          protected abstract void SetLeft(TElement node, TElement left);
30
31          [MethodImpl(MethodImplOptions.AggressiveInlining)]
32          protected abstract void SetRight(TElement node, TElement right);
33
34          [MethodImpl(MethodImplOptions.AggressiveInlining)]
35          protected abstract void SetSize(TElement node, TElement size);
36
37          [MethodImpl(MethodImplOptions.AggressiveInlining)]
38          protected abstract bool FirstIsToTheLeftOfSecond(TElement first, TElement second);
39
40          [MethodImpl(MethodImplOptions.AggressiveInlining)]
41          protected abstract bool FirstIsToTheRightOfSecond(TElement first, TElement second);
42
43          [MethodImpl(MethodImplOptions.AggressiveInlining)]
44          protected virtual TElement GetLeftOrDefault(TElement node) => AreEqual(node, default) ?
            ↪  default : GetLeft(node);
45
46          [MethodImpl(MethodImplOptions.AggressiveInlining)]
47          protected virtual TElement GetRightOrDefault(TElement node) => AreEqual(node, default) ?
            ↪  default : GetRight(node);
48
49          [MethodImpl(MethodImplOptions.AggressiveInlining)]
50          protected void IncrementSize(TElement node) => SetSize(node, Increment(GetSize(node)));
51
52          [MethodImpl(MethodImplOptions.AggressiveInlining)]
53          protected void DecrementSize(TElement node) => SetSize(node, Decrement(GetSize(node)));
54
55          [MethodImpl(MethodImplOptions.AggressiveInlining)]
56          protected TElement GetLeftSize(TElement node) => GetSizeOrZero(GetLeftOrDefault(node));
57
58          [MethodImpl(MethodImplOptions.AggressiveInlining)]
59          protected TElement GetRightSize(TElement node) => GetSizeOrZero(GetRightOrDefault(node));
60
61          [MethodImpl(MethodImplOptions.AggressiveInlining)]
62          protected TElement GetSizeOrZero(TElement node) => EqualToZero(node) ? Zero :
            ↪  GetSize(node);
63
64          [MethodImpl(MethodImplOptions.AggressiveInlining)]
65          protected void FixSize(TElement node) => SetSize(node, Increment(Add(GetLeftSize(node),
            ↪  GetRightSize(node))));
66
67          [MethodImpl(MethodImplOptions.AggressiveInlining)]
68          protected void LeftRotate(ref TElement root) => root = LeftRotate(root);
69
70          [MethodImpl(MethodImplOptions.AggressiveInlining)]
71          protected TElement LeftRotate(TElement root)
72          {
73              var right = GetRight(root);
74  #if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
75              if (EqualToZero(right))
76              {
77                  throw new Exception("Right is null.");
78              }
79  #endif
80              SetRight(root, GetLeft(right));
81              SetLeft(right, root);
82              SetSize(right, GetSize(root));
83              FixSize(root);
84              return right;
85          }
86
87          [MethodImpl(MethodImplOptions.AggressiveInlining)]
```

```
        protected void RightRotate(ref TElement root) => root = RightRotate(root);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected TElement RightRotate(TElement root)
        {
            var left = GetLeft(root);
#if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
            if (EqualToZero(left))
            {
                throw new Exception("Left is null.");
            }
#endif
            SetLeft(root, GetRight(left));
            SetRight(left, root);
            SetSize(left, GetSize(root));
            FixSize(root);
            return left;
        }

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual TElement GetRightest(TElement current)
        {
            var currentRight = GetRight(current);
            while (!EqualToZero(currentRight))
            {
                current = currentRight;
                currentRight = GetRight(current);
            }
            return current;
        }

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual TElement GetLeftest(TElement current)
        {
            var currentLeft = GetLeft(current);
            while (!EqualToZero(currentLeft))
            {
                current = currentLeft;
                currentLeft = GetLeft(current);
            }
            return current;
        }

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual TElement GetNext(TElement node) => GetLeftest(GetRight(node));

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual TElement GetPrevious(TElement node) => GetRightest(GetLeft(node));

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        public virtual bool Contains(TElement node, TElement root)
        {
            while (!EqualToZero(root))
            {
                if (FirstIsToTheLeftOfSecond(node, root)) // node.Key < root.Key
                {
                    root = GetLeft(root);
                }
                else if (FirstIsToTheRightOfSecond(node, root)) // node.Key > root.Key
                {
                    root = GetRight(root);
                }
                else // node.Key == root.Key
                {
                    return true;
                }
            }
            return false;
        }

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected virtual void ClearNode(TElement node)
        {
            SetLeft(node, Zero);
            SetRight(node, Zero);
            SetSize(node, Zero);
        }

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
```

```
        public void Attach(ref TElement root, TElement node)
        {
#if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
            ValidateSizes(root);
            Debug.WriteLine("--BeforeAttach--");
            Debug.WriteLine(PrintNodes(root));
            Debug.WriteLine("----------------");
            var sizeBefore = GetSize(root);
#endif
            if (EqualToZero(root))
            {
                SetSize(node, One);
                root = node;
                return;
            }
            AttachCore(ref root, node);
#if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
            Debug.WriteLine("--AfterAttach--");
            Debug.WriteLine(PrintNodes(root));
            Debug.WriteLine("----------------");
            ValidateSizes(root);
            var sizeAfter = GetSize(root);
            if (!IsEquals(MathHelpers.Increment(sizeBefore), sizeAfter))
            {
                throw new Exception("Tree was broken after attach.");
            }
#endif
        }

        protected abstract void AttachCore(ref TElement root, TElement node);

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        public void Detach(ref TElement root, TElement node)
        {
#if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
            ValidateSizes(root);
            Debug.WriteLine("--BeforeDetach--");
            Debug.WriteLine(PrintNodes(root));
            Debug.WriteLine("----------------");
            var sizeBefore = GetSize(root);
            if (ValueEqualToZero(root))
            {
                throw new Exception($"Элемент с {node} не содержится в дереве.");
            }
#endif
            DetachCore(ref root, node);
#if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
            Debug.WriteLine("--AfterDetach--");
            Debug.WriteLine(PrintNodes(root));
            Debug.WriteLine("----------------");
            ValidateSizes(root);
            var sizeAfter = GetSize(root);
            if (!IsEquals(MathHelpers.Decrement(sizeBefore), sizeAfter))
            {
                throw new Exception("Tree was broken after detach.");
            }
#endif
        }

        protected abstract void DetachCore(ref TElement root, TElement node);

        public void FixSizes(TElement node)
        {
            if (AreEqual(node, default))
            {
                return;
            }
            FixSizes(GetLeft(node));
            FixSizes(GetRight(node));
            FixSize(node);
        }

        public void ValidateSizes(TElement node)
        {
            if (AreEqual(node, default))
            {
                return;
            }
            var size = GetSize(node);
```

```
            var leftSize = GetLeftSize(node);
            var rightSize = GetRightSize(node);
            var expectedSize = Arithmetic.Increment(Arithmetic.Add(leftSize, rightSize));
            if (!AreEqual(size, expectedSize))
            {
                throw new InvalidOperationException($"Size of {node} is not valid. Expected size: {expectedSize}, actual size: {size}.");
            }
            ValidateSizes(GetLeft(node));
            ValidateSizes(GetRight(node));
        }

        public void ValidateSize(TElement node)
        {
            var size = GetSize(node);
            var leftSize = GetLeftSize(node);
            var rightSize = GetRightSize(node);
            var expectedSize = Arithmetic.Increment(Arithmetic.Add(leftSize, rightSize));
            if (!AreEqual(size, expectedSize))
            {
                throw new InvalidOperationException($"Size of {node} is not valid. Expected size: {expectedSize}, actual size: {size}.");
            }
        }

        public string PrintNodes(TElement node)
        {
            var sb = new StringBuilder();
            PrintNodes(node, sb);
            return sb.ToString();
        }

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        public void PrintNodes(TElement node, StringBuilder sb) => PrintNodes(node, sb, 0);

        public void PrintNodes(TElement node, StringBuilder sb, int level)
        {
            if (AreEqual(node, default))
            {
                return;
            }
            PrintNodes(GetLeft(node), sb, level + 1);
            PrintNode(node, sb, level);
            sb.AppendLine();
            PrintNodes(GetRight(node), sb, level + 1);
        }

        public string PrintNode(TElement node)
        {
            var sb = new StringBuilder();
            PrintNode(node, sb);
            return sb.ToString();
        }

        [MethodImpl(MethodImplOptions.AggressiveInlining)]
        protected void PrintNode(TElement node, StringBuilder sb) => PrintNode(node, sb, 0);

        protected virtual void PrintNode(TElement node, StringBuilder sb, int level)
        {
            sb.Append('\t', level);
            sb.Append(node);
            PrintNodeValue(node, sb);
            sb.Append(' ');
            sb.Append('s');
            sb.Append(GetSize(node));
        }

        protected abstract void PrintNodeValue(TElement node, StringBuilder sb);
    }
}
```

./Platform.Collections.Methods.Tests/RecursionlessSizeBalancedTree.cs

```
using System;
using System.Collections.Generic;
using System.Text;
using Platform.Numbers;
using Platform.Collections.Methods.Trees;

namespace Platform.Collections.Methods.Tests
```

```
{
    public class RecursionlessSizeBalancedTree<TElement> :
    ↪ RecursionlessSizeBalancedTreeMethods<TElement>
    {
        private struct TreeElement
        {
            public TElement Size;
            public TElement Left;
            public TElement Right;
        }

        private readonly TreeElement[] _elements;
        private TElement _allocated;

        public TElement Root;

        public TElement Count => GetSizeOrZero(Root);

        public RecursionlessSizeBalancedTree(int capacity) => (_elements, _allocated) = (new
        ↪ TreeElement[capacity], Integer<TElement>.One);

        public TElement Allocate()
        {
            var newNode = _allocated;
            if (IsEmpty(newNode))
            {
                _allocated = Arithmetic.Increment(_allocated);
                return newNode;
            }
            else
            {
                throw new InvalidOperationException("Allocated tree element is not empty.");
            }
        }

        public void Free(TElement node)
        {
            while (!EqualityComparer.Equals(_allocated, Integer<TElement>.One) && IsEmpty(node))
            {
                var lastNode = Arithmetic.Decrement(_allocated);
                if (EqualityComparer.Equals(lastNode, node))
                {
                    _allocated = lastNode;
                    node = Arithmetic.Decrement(node);
                }
                else
                {
                    return;
                }
            }
        }

        public bool IsEmpty(TElement node) =>
        ↪ EqualityComparer<TreeElement>.Default.Equals(GetElement(node), default);

        protected override bool FirstIsToTheLeftOfSecond(TElement first, TElement second) =>
        ↪ Comparer.Compare(first, second) < 0;

        protected override bool FirstIsToTheRightOfSecond(TElement first, TElement second) =>
        ↪ Comparer.Compare(first, second) > 0;

        protected override ref TElement GetLeftReference(TElement node) => ref
        ↪ GetElement(node).Left;

        protected override TElement GetLeft(TElement node) => GetElement(node).Left;

        protected override ref TElement GetRightReference(TElement node) => ref
        ↪ GetElement(node).Right;

        protected override TElement GetRight(TElement node) => GetElement(node).Right;

        protected override TElement GetSize(TElement node) => GetElement(node).Size;

        protected override void PrintNodeValue(TElement node, StringBuilder sb) =>
        ↪ sb.Append(node);

        protected override void SetLeft(TElement node, TElement left) => GetElement(node).Left =
        ↪ left;

```

```
        protected override void SetRight(TElement node, TElement right) =>
        ↪ GetElement(node).Right = right;

        protected override void SetSize(TElement node, TElement size) => GetElement(node).Size =
        ↪ size;

        private ref TreeElement GetElement(TElement node) => ref
        ↪ _elements[(Integer<TElement>)node];
    }
}
```

./Platform.Collections.Methods.Tests/SizeBalancedTree.cs

```
using System;
using System.Collections.Generic;
using System.Text;
using Platform.Numbers;
using Platform.Collections.Methods.Trees;

namespace Platform.Collections.Methods.Tests
{
    public class SizeBalancedTree<TElement> : SizeBalancedTreeMethods<TElement>
    {
        private struct TreeElement
        {
            public TElement Size;
            public TElement Left;
            public TElement Right;
        }

        private readonly TreeElement[] _elements;
        private TElement _allocated;

        public TElement Root;

        public TElement Count => GetSizeOrZero(Root);

        public SizeBalancedTree(int capacity) => (_elements, _allocated) = (new
        ↪ TreeElement[capacity], Integer<TElement>.One);

        public TElement Allocate()
        {
            var newNode = _allocated;
            if (IsEmpty(newNode))
            {
                _allocated = Arithmetic.Increment(_allocated);
                return newNode;
            }
            else
            {
                throw new InvalidOperationException("Allocated tree element is not empty.");
            }
        }

        public void Free(TElement node)
        {
            while (!EqualityComparer.Equals(_allocated, Integer<TElement>.One) && IsEmpty(node))
            {
                var lastNode = Arithmetic.Decrement(_allocated);
                if (EqualityComparer.Equals(lastNode, node))
                {
                    _allocated = lastNode;
                    node = Arithmetic.Decrement(node);
                }
                else
                {
                    return;
                }
            }
        }

        public bool IsEmpty(TElement node) =>
        ↪ EqualityComparer<TreeElement>.Default.Equals(GetElement(node), default);

        protected override bool FirstIsToTheLeftOfSecond(TElement first, TElement second) =>
        ↪ Comparer.Compare(first, second) < 0;

        protected override bool FirstIsToTheRightOfSecond(TElement first, TElement second) =>
        ↪ Comparer.Compare(first, second) > 0;

```

```
64          protected override ref TElement GetLeftReference(TElement node) => ref
            ↪ GetElement(node).Left;
65
66          protected override TElement GetLeft(TElement node) => GetElement(node).Left;
67
68          protected override ref TElement GetRightReference(TElement node) => ref
            ↪ GetElement(node).Right;
69
70          protected override TElement GetRight(TElement node) => GetElement(node).Right;
71
72          protected override TElement GetSize(TElement node) => GetElement(node).Size;
73
74          protected override void PrintNodeValue(TElement node, StringBuilder sb) =>
            ↪ sb.Append(node);
75
76          protected override void SetLeft(TElement node, TElement left) => GetElement(node).Left =
            ↪ left;
77
78          protected override void SetRight(TElement node, TElement right) =>
            ↪ GetElement(node).Right = right;
79
80          protected override void SetSize(TElement node, TElement size) => GetElement(node).Size =
            ↪ size;
81
82          private ref TreeElement GetElement(TElement node) => ref
            ↪ _elements[(Integer<TElement>)node];
83      }
84  }
```

./Platform.Collections.Methods.Tests/SizedAndThreadedAVLBalancedTree.cs

```
1   using System;
2   using System.Collections.Generic;
3   using System.Text;
4   using Platform.Numbers;
5   using Platform.Collections.Methods.Trees;
6
7   namespace Platform.Collections.Methods.Tests
8   {
9       public class SizedAndThreadedAVLBalancedTree<TElement> :
        ↪ SizedAndThreadedAVLBalancedTreeMethods<TElement>
10      {
11          private struct TreeElement
12          {
13              public TElement Size;
14              public TElement Left;
15              public TElement Right;
16              public sbyte Balance;
17              public bool LeftIsChild;
18              public bool RightIsChild;
19          }
20
21          private readonly TreeElement[] _elements;
22          private TElement _allocated;
23
24          public TElement Root;
25
26          public TElement Count => GetSizeOrZero(Root);
27
28          public SizedAndThreadedAVLBalancedTree(int capacity) => (_elements, _allocated) = (new
            ↪ TreeElement[capacity], Integer<TElement>.One);
29
30          public TElement Allocate()
31          {
32              var newNode = _allocated;
33              if (IsEmpty(newNode))
34              {
35                  _allocated = Arithmetic.Increment(_allocated);
36                  return newNode;
37              }
38              else
39              {
40                  throw new InvalidOperationException("Allocated tree element is not empty.");
41              }
42          }
43
44          public void Free(TElement node)
45          {
46              while (!EqualityComparer.Equals(_allocated, Integer<TElement>.One) && IsEmpty(node))
47              {
48                  var lastNode = Arithmetic.Decrement(_allocated);
```

```
                if (EqualityComparer.Equals(lastNode, node))
                {
                    _allocated = lastNode;
                    node = Arithmetic.Decrement(node);
                }
                else
                {
                    return;
                }
            }
        }

        public bool IsEmpty(TElement node) =>
        ↪  EqualityComparer<TreeElement>.Default.Equals(GetElement(node), default);

        protected override bool FirstIsToTheLeftOfSecond(TElement first, TElement second) =>
        ↪  Comparer.Compare(first, second) < 0;

        protected override bool FirstIsToTheRightOfSecond(TElement first, TElement second) =>
        ↪  Comparer.Compare(first, second) > 0;

        protected override sbyte GetBalance(TElement node) => GetElement(node).Balance;

        protected override bool GetLeftIsChild(TElement node) => GetElement(node).LeftIsChild;

        protected override ref TElement GetLeftReference(TElement node) => ref
        ↪  GetElement(node).Left;

        protected override TElement GetLeft(TElement node) => GetElement(node).Left;

        protected override bool GetRightIsChild(TElement node) => GetElement(node).RightIsChild;

        protected override ref TElement GetRightReference(TElement node) => ref
        ↪  GetElement(node).Right;

        protected override TElement GetRight(TElement node) => GetElement(node).Right;

        protected override TElement GetSize(TElement node) => GetElement(node).Size;

        protected override void PrintNodeValue(TElement node, StringBuilder sb) =>
        ↪  sb.Append(node);

        protected override void SetBalance(TElement node, sbyte value) =>
        ↪  GetElement(node).Balance = value;

        protected override void SetLeft(TElement node, TElement left) => GetElement(node).Left =
        ↪  left;

        protected override void SetLeftIsChild(TElement node, bool value) =>
        ↪  GetElement(node).LeftIsChild = value;

        protected override void SetRight(TElement node, TElement right) =>
        ↪  GetElement(node).Right = right;

        protected override void SetRightIsChild(TElement node, bool value) =>
        ↪  GetElement(node).RightIsChild = value;

        protected override void SetSize(TElement node, TElement size) => GetElement(node).Size =
        ↪  size;

        private ref TreeElement GetElement(TElement node) => ref
        ↪  _elements[(Integer<TElement>)node];
    }
}
```

./Platform.Collections.Methods.Tests/TestExtensions.cs

```
using System;
using System.Collections.Generic;
using Xunit;
using Platform.Numbers;
using Platform.Collections.Methods.Trees;

namespace Platform.Collections.Methods.Tests
{
    public static class TestExtensions
    {
        public static void TestMultipleCreationsAndDeletions<TElement>(this
        ↪  SizedBinaryTreeMethodsBase<TElement> tree, Func<TElement> allocate, Action<TElement>
        ↪  free, ref TElement root, Func<TElement> treeCount, int maximumOperationsPerCycle)
```

```
        {
            for (var N = 1; N < maximumOperationsPerCycle; N++)
            {
                var currentCount = 0;
                for (var i = 0; i < N; i++)
                {
                    var node = allocate();
                    tree.Attach(ref root, node);
                    currentCount++;
                    Assert.Equal(currentCount, (int)(Integer<TElement>)treeCount());
                }
                for (var i = 1; i <= N; i++)
                {
                    TElement node = (Integer<TElement>)i;
                    if (tree.Contains(node, root))
                    {
                        tree.Detach(ref root, node);
                        free(node);
                        currentCount--;
                        Assert.Equal(currentCount, (int)(Integer<TElement>)treeCount());
                    }
                }
            }
        }

        public static void TestMultipleRandomCreationsAndDeletions<TElement>(this
        ↪  SizedBinaryTreeMethodsBase<TElement> tree, ref TElement root, Func<TElement>
        ↪  treeCount, int maximumOperationsPerCycle)
        {
            var random = new System.Random(0);
            var added = new HashSet<TElement>();
            var currentCount = 0;
            for (var N = 1; N < maximumOperationsPerCycle; N++)
            {
                for (var i = 0; i < N; i++)
                {
                    var node = (Integer<TElement>)random.Next(1, N);
                    if (added.Add(node))
                    {
                        tree.Attach(ref root, node);
                        currentCount++;
                        Assert.Equal(currentCount, (int)(Integer<TElement>)treeCount());
                    }
                }
                for (var i = 1; i <= N; i++)
                {
                    TElement node = (Integer<TElement>)random.Next(1, N);
                    if (tree.Contains(node, root))
                    {
                        tree.Detach(ref root, node);
                        currentCount--;
                        Assert.Equal(currentCount, (int)(Integer<TElement>)treeCount());
                        added.Remove(node);
                    }
                }
            }
        }
    }
}
```

./Platform.Collections.Methods.Tests/TreesTests.cs

```
using Xunit;

namespace Platform.Collections.Methods.Tests
{
    public static class TreesTests
    {
        private const int _n = 500;

        [Fact]
        public static void RecursionlessSizeBalancedTreeMultipleAttachAndDetachTest()
        {
            var recursionlessSizeBalancedTree = new RecursionlessSizeBalancedTree<uint>(10000);
            recursionlessSizeBalancedTree.TestMultipleCreationsAndDeletions(recursionlessSizeBal
            ↪  ancedTree.Allocate, recursionlessSizeBalancedTree.Free, ref
            ↪  recursionlessSizeBalancedTree.Root, () => recursionlessSizeBalancedTree.Count,
            ↪  _n);
        }

```

```
16          [Fact]
17          public static void SizeBalancedTreeMultipleAttachAndDetachTest()
18          {
19              var sizeBalancedTree = new SizeBalancedTree<uint>(10000);
20              sizeBalancedTree.TestMultipleCreationsAndDeletions(sizeBalancedTree.Allocate,
                    ↪  sizeBalancedTree.Free, ref sizeBalancedTree.Root, () => sizeBalancedTree.Count,
                    ↪  _n);
21          }
22
23          [Fact]
24          public static void SizedAndThreadedAVLBalancedTreeMultipleAttachAndDetachTest()
25          {
26              var avlTree = new SizedAndThreadedAVLBalancedTree<uint>(10000);
27              avlTree.TestMultipleCreationsAndDeletions(avlTree.Allocate, avlTree.Free, ref
                    ↪  avlTree.Root, () => avlTree.Count, _n);
28          }
29
30          [Fact]
31          public static void RecursionlessSizeBalancedTreeMultipleRandomAttachAndDetachTest()
32          {
33              var recursionlessSizeBalancedTree = new RecursionlessSizeBalancedTree<uint>(10000);
34              recursionlessSizeBalancedTree.TestMultipleRandomCreationsAndDeletions(ref
                    ↪  recursionlessSizeBalancedTree.Root, () => recursionlessSizeBalancedTree.Count,
                    ↪  _n);
35          }
36
37          [Fact]
38          public static void SizeBalancedTreeMultipleRandomAttachAndDetachTest()
39          {
40              var sizeBalancedTree = new SizeBalancedTree<uint>(10000);
41              sizeBalancedTree.TestMultipleRandomCreationsAndDeletions(ref sizeBalancedTree.Root,
                    ↪  () => sizeBalancedTree.Count, _n);
42          }
43
44          [Fact]
45          public static void SizedAndThreadedAVLBalancedTreeMultipleRandomAttachAndDetachTest()
46          {
47              var avlTree = new SizedAndThreadedAVLBalancedTree<uint>(10000);
48              avlTree.TestMultipleRandomCreationsAndDeletions(ref avlTree.Root, () =>
                    ↪  avlTree.Count, _n);
49          }
50      }
51  }
```

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