

# LinksPlatform's Platform.Collections.Methods Class Library

## 1.1 ./csharp/Platform.Collections.Methods/GenericCollectionMethodsBase.cs

```
1  using System.Collections.Generic;
2  using System.Runtime.CompilerServices;
3  using Platform.Numbers;
4
5  #pragma warning disable CS1591 // Missing XML comment for publicly visible type or member
6
7  namespace Platform.Collections.Methods
8  {
9      public abstract class GenericCollectionMethodsBase<TElement>
10     {
11         [MethodImpl(MethodImplOptions.AggressiveInlining)]
12         protected virtual TElement GetZero() => default;
13
14         [MethodImpl(MethodImplOptions.AggressiveInlining)]
15         protected virtual bool EqualToZero(TElement value) => EqualityComparer.Equals(value,
16             ↪ Zero);
17
18         [MethodImpl(MethodImplOptions.AggressiveInlining)]
19         protected virtual bool AreEqual(TElement first, TElement second) =>
20             ↪ EqualityComparer.Equals(first, second);
21
22         [MethodImpl(MethodImplOptions.AggressiveInlining)]
23         protected virtual bool GreaterThanZero(TElement value) => Comparer.Compare(value, Zero)
24             ↪ > 0;
25
26         [MethodImpl(MethodImplOptions.AggressiveInlining)]
27         protected virtual bool GreaterThan(TElement first, TElement second) =>
28             ↪ Comparer.Compare(first, second) > 0;
29
30         [MethodImpl(MethodImplOptions.AggressiveInlining)]
31         protected virtual bool GreaterOrEqualThanZero(TElement value) => Comparer.Compare(value,
32             ↪ Zero) >= 0;
33
34         [MethodImpl(MethodImplOptions.AggressiveInlining)]
35         protected virtual bool GreaterOrEqualThan(TElement first, TElement second) =>
36             ↪ Comparer.Compare(first, second) >= 0;
37
38         [MethodImpl(MethodImplOptions.AggressiveInlining)]
39         protected virtual bool LessOrEqualThanZero(TElement value) => Comparer.Compare(value,
40             ↪ Zero) <= 0;
41
42         [MethodImpl(MethodImplOptions.AggressiveInlining)]
43         protected virtual bool LessOrEqualThan(TElement first, TElement second) =>
44             ↪ Comparer.Compare(first, second) <= 0;
45
46         [MethodImpl(MethodImplOptions.AggressiveInlining)]
47         protected virtual bool LessThanZero(TElement value) => Comparer.Compare(value, Zero) < 0;
48
49         [MethodImpl(MethodImplOptions.AggressiveInlining)]
50         protected virtual bool LessThan(TElement first, TElement second) =>
51             ↪ Comparer.Compare(first, second) < 0;
52
53         [MethodImpl(MethodImplOptions.AggressiveInlining)]
54         protected virtual TElement Increment(TElement value) =>
55             ↪ Arithmetic<TElement>.Increment(value);
56
57         [MethodImpl(MethodImplOptions.AggressiveInlining)]
58         protected virtual TElement Decrement(TElement value) =>
59             ↪ Arithmetic<TElement>.Decrement(value);
60
61         [MethodImpl(MethodImplOptions.AggressiveInlining)]
62         protected virtual TElement Add(TElement first, TElement second) =>
63             ↪ Arithmetic<TElement>.Add(first, second);
64
65         [MethodImpl(MethodImplOptions.AggressiveInlining)]
66         protected virtual TElement Subtract(TElement first, TElement second) =>
67             ↪ Arithmetic<TElement>.Subtract(first, second);
68
69         protected readonly TElement Zero;
70         protected readonly TElement One;
71         protected readonly TElement Two;
72         protected readonly EqualityComparer<TElement> EqualityComparer;
73         protected readonly Comparer<TElement> Comparer;
74
75         protected GenericCollectionMethodsBase()
76         {
77             EqualityComparer = EqualityComparer<TElement>.Default;
78         }
79     }
80 }
```

```

65         Comparer = Comparer<TElement>.Default;
66         Zero = GetZero(); //-V3068
67         One = Increment(Zero); //-V3068
68         Two = Increment(One); //-V3068
69     }
70 }
71 }

```

## 1.2 ./csharp/Platform.Collections.Methods/Lists/CircularDoublyLinkedListMethods.cs

```

1  #pragma warning disable CS1591 // Missing XML comment for publicly visible type or member
2
3  namespace Platform.Collections.Methods.Lists
4  {
5      public abstract class CircularDoublyLinkedListMethods<TElement> :
6          ↳ DoublyLinkedListMethodsBase<TElement>
7      {
8          public void AttachBefore(TElement baseElement, TElement newElement)
9          {
10             var baseElementPrevious = GetPrevious(baseElement);
11             SetPrevious(newElement, baseElementPrevious);
12             SetNext(newElement, baseElement);
13             if (AreEqual(baseElement, GetFirst()))
14             {
15                 SetFirst(newElement);
16             }
17             SetNext(baseElementPrevious, newElement);
18             SetPrevious(baseElement, newElement);
19             IncrementSize();
20         }
21
22         public void AttachAfter(TElement baseElement, TElement newElement)
23         {
24             var baseElementNext = GetNext(baseElement);
25             SetPrevious(newElement, baseElement);
26             SetNext(newElement, baseElementNext);
27             if (AreEqual(baseElement, GetLast()))
28             {
29                 SetLast(newElement);
30             }
31             SetPrevious(baseElementNext, newElement);
32             SetNext(baseElement, newElement);
33             IncrementSize();
34         }
35
36         public void AttachAsFirst(TElement element)
37         {
38             var first = GetFirst();
39             if (EqualToZero(first))
40             {
41                 SetFirst(element);
42                 SetLast(element);
43                 SetPrevious(element, element);
44                 SetNext(element, element);
45                 IncrementSize();
46             }
47             else
48             {
49                 AttachBefore(first, element);
50             }
51         }
52
53         public void AttachAsLast(TElement element)
54         {
55             var last = GetLast();
56             if (EqualToZero(last))
57             {
58                 AttachAsFirst(element);
59             }
60             else
61             {
62                 AttachAfter(last, element);
63             }
64         }
65
66         public void Detach(TElement element)
67         {
68             var elementPrevious = GetPrevious(element);
69             var elementNext = GetNext(element);

```

```

69         if (AreEqual(elementNext, element))
70         {
71             SetFirst(Zero);
72             SetLast(Zero);
73         }
74         else
75         {
76             SetNext(elementPrevious, elementNext);
77             SetPrevious(elementNext, elementPrevious);
78             if (AreEqual(element, GetFirst()))
79             {
80                 SetFirst(elementNext);
81             }
82             if (AreEqual(element, GetLast()))
83             {
84                 SetLast(elementPrevious);
85             }
86         }
87         SetPrevious(element, Zero);
88         SetNext(element, Zero);
89         DecrementSize();
90     }
91 }
92 }

```

### 1.3 ./csharp/Platform.Collections.Methods/Lists/DoublyLinkedListMethodsBase.cs

```

1  using System.Runtime.CompilerServices;
2
3  #pragma warning disable CS1591 // Missing XML comment for publicly visible type or member
4
5  namespace Platform.Collections.Methods.Lists
6  {
7      /// <remarks>
8      /// Based on <a href="https://en.wikipedia.org/wiki/Doubly_linked_list">doubly linked
9      /// list</a> implementation.
10     /// </remarks>
11     public abstract class DoublyLinkedListMethodsBase<TElement> :
12         GenericCollectionMethodsBase<TElement>
13     {
14         [MethodImpl(MethodImplOptions.AggressiveInlining)]
15         protected abstract TElement GetFirst();
16
17         [MethodImpl(MethodImplOptions.AggressiveInlining)]
18         protected abstract TElement GetLast();
19
20         [MethodImpl(MethodImplOptions.AggressiveInlining)]
21         protected abstract TElement GetPrevious(TElement element);
22
23         [MethodImpl(MethodImplOptions.AggressiveInlining)]
24         protected abstract TElement GetNext(TElement element);
25
26         [MethodImpl(MethodImplOptions.AggressiveInlining)]
27         protected abstract TElement GetSize();
28
29         [MethodImpl(MethodImplOptions.AggressiveInlining)]
30         protected abstract void SetFirst(TElement element);
31
32         [MethodImpl(MethodImplOptions.AggressiveInlining)]
33         protected abstract void SetLast(TElement element);
34
35         [MethodImpl(MethodImplOptions.AggressiveInlining)]
36         protected abstract void SetPrevious(TElement element, TElement previous);
37
38         [MethodImpl(MethodImplOptions.AggressiveInlining)]
39         protected abstract void SetNext(TElement element, TElement next);
40
41         [MethodImpl(MethodImplOptions.AggressiveInlining)]
42         protected abstract void SetSize(TElement size);
43
44         [MethodImpl(MethodImplOptions.AggressiveInlining)]
45         protected void IncrementSize() => SetSize(Increment(GetSize()));
46
47         [MethodImpl(MethodImplOptions.AggressiveInlining)]
48         protected void DecrementSize() => SetSize(Decrement(GetSize()));
49     }
50 }

```

#### 1.4 ./csharp/Platform.Collections.Methods/Lists/OpenDoublyLinkedListMethods.cs

```
#pragma warning disable CS1591 // Missing XML comment for publicly visible type or member
2
3 namespace Platform.Collections.Methods.Lists
4 {
5     public abstract class OpenDoublyLinkedListMethods<TElement> :
        ↳ DoublyLinkedListMethodsBase<TElement>
6     {
7         public void AttachBefore(TElement baseElement, TElement newElement)
8         {
9             var baseElementPrevious = GetPrevious(baseElement);
10            SetPrevious(newElement, baseElementPrevious);
11            SetNext(newElement, baseElement);
12            if (EqualToZero(baseElementPrevious))
13            {
14                SetFirst(newElement);
15            }
16            else
17            {
18                SetNext(baseElementPrevious, newElement);
19            }
20            SetPrevious(baseElement, newElement);
21            IncrementSize();
22        }
23
24        public void AttachAfter(TElement baseElement, TElement newElement)
25        {
26            var baseElementNext = GetNext(baseElement);
27            SetPrevious(newElement, baseElement);
28            SetNext(newElement, baseElementNext);
29            if (EqualToZero(baseElementNext))
30            {
31                SetLast(newElement);
32            }
33            else
34            {
35                SetPrevious(baseElementNext, newElement);
36            }
37            SetNext(baseElement, newElement);
38            IncrementSize();
39        }
40
41        public void AttachAsFirst(TElement element)
42        {
43            var first = GetFirst();
44            if (EqualToZero(first))
45            {
46                SetFirst(element);
47                SetLast(element);
48                SetPrevious(element, Zero);
49                SetNext(element, Zero);
50                IncrementSize();
51            }
52            else
53            {
54                AttachBefore(first, element);
55            }
56        }
57
58        public void AttachAsLast(TElement element)
59        {
60            var last = GetLast();
61            if (EqualToZero(last))
62            {
63                AttachAsFirst(element);
64            }
65            else
66            {
67                AttachAfter(last, element);
68            }
69        }
70
71        public void Detach(TElement element)
72        {
73            var elementPrevious = GetPrevious(element);
74            var elementNext = GetNext(element);
75            if (EqualToZero(elementPrevious))
76            {
77                SetFirst(elementNext);
78            }
79            else
80            {
81                SetNext(elementPrevious, elementNext);
82            }
83            if (EqualToZero(elementNext))
84            {
85                SetLast(elementPrevious);
86            }
87            else
88            {
89                SetPrevious(elementNext, elementPrevious);
90            }
91            DecrementSize();
92        }
93    }
94 }
```

```

77         SetFirst(elementNext);
78     }
79     else
80     {
81         SetNext(elementPrevious, elementNext);
82     }
83     if (EqualToZero(elementNext))
84     {
85         SetLast(elementPrevious);
86     }
87     else
88     {
89         SetPrevious(elementNext, elementPrevious);
90     }
91     SetPrevious(element, Zero);
92     SetNext(element, Zero);
93     DecrementSize();
94 }
95 }
96 }

```

## 1.5 ./csharp/Platform.Collections.Methods/Trees/RecursionlessSizeBalancedTreeMethods.cs

```

1  #pragma warning disable CS1591 // Missing XML comment for publicly visible type or member
2
3  namespace Platform.Collections.Methods.Trees
4  {
5      public abstract class RecursionlessSizeBalancedTreeMethods<TElement> :
6          ↳ SizedBinaryTreeMethodsBase<TElement>
7      {
8          protected override void AttachCore(ref TElement root, TElement node)
9          {
10              while (true)
11              {
12                  ref var left = ref GetLeftReference(root);
13                  var leftSize = GetSizeOrZero(left);
14                  ref var right = ref GetRightReference(root);
15                  var rightSize = GetSizeOrZero(right);
16                  if (FirstIsToTheLeftOfSecond(node, root)) // node.Key less than root.Key
17                  {
18                      if (EqualToZero(left))
19                      {
20                          IncrementSize(root);
21                          SetSize(node, One);
22                          left = node;
23                          return;
24                      }
25                      if (FirstIsToTheLeftOfSecond(node, left)) // node.Key less than left.Key
26                      {
27                          if (GreaterThan(Increment(leftSize), rightSize))
28                          {
29                              RightRotate(ref root);
30                          }
31                          else
32                          {
33                              IncrementSize(root);
34                              root = ref left;
35                          }
36                      }
37                      else // node.Key greater than left.Key
38                      {
39                          var leftRightSize = GetSizeOrZero(GetRight(left));
40                          if (GreaterThan(Increment(leftRightSize), rightSize))
41                          {
42                              if (EqualToZero(leftRightSize) && EqualToZero(rightSize))
43                              {
44                                  SetLeft(node, left);
45                                  SetRight(node, root);
46                                  SetSize(node, Add(leftSize, Two)); // Two (2) - node the size of
47                                  ↳ root and a node itself
48                                  SetLeft(root, Zero);
49                                  SetSize(root, One);
50                                  root = node;
51                                  return;
52                              }
53                              LeftRotate(ref left);
54                              RightRotate(ref root);
55                          }
56                      }
57                  }
58              }
59          }
60      }
61  }

```

```

56         IncrementSize(root);
57         root = ref left;
58     }
59 }
60 }
61 else // node.Key greater than root.Key
62 {
63     if (EqualToZero(right))
64     {
65         IncrementSize(root);
66         SetSize(node, One);
67         right = node;
68         return;
69     }
70     if (FirstIsToTheRightOfSecond(node, right)) // node.Key greater than
        ↪ right.Key
71     {
72         if (GreaterThan(Increment(rightSize), leftSize))
73         {
74             LeftRotate(ref root);
75         }
76         else
77         {
78             IncrementSize(root);
79             root = ref right;
80         }
81     }
82     else // node.Key less than right.Key
83     {
84         var rightLeftSize = GetSizeOrZero(GetLeft(right));
85         if (GreaterThan(Increment(rightLeftSize), leftSize))
86         {
87             if (EqualToZero(rightLeftSize) && EqualToZero(leftSize))
88             {
89                 SetLeft(node, root);
90                 SetRight(node, right);
91                 SetSize(node, Add(rightSize, Two)); // Two (2) - node the size
                    ↪ of root and a node itself
92                 SetRight(root, Zero);
93                 SetSize(root, One);
94                 root = node;
95                 return;
96             }
97             RightRotate(ref right);
98             LeftRotate(ref root);
99         }
100         else
101         {
102             IncrementSize(root);
103             root = ref right;
104         }
105     }
106 }
107 }
108 }
109
110 protected override void DetachCore(ref TElement root, TElement node)
111 {
112     while (true)
113     {
114         ref var left = ref GetLeftReference(root);
115         var leftSize = GetSizeOrZero(left);
116         ref var right = ref GetRightReference(root);
117         var rightSize = GetSizeOrZero(right);
118         if (FirstIsToTheLeftOfSecond(node, root)) // node.Key less than root.Key
119         {
120             var decrementedLeftSize = Decrement(leftSize);
121             if (GreaterThan(GetSizeOrZero(GetRightOrDefault(right)),
                ↪ decrementedLeftSize))
122             {
123                 LeftRotate(ref root);
124             }
125             else if (GreaterThan(GetSizeOrZero(GetLeftOrDefault(right)),
                ↪ decrementedLeftSize))
126             {
127                 RightRotate(ref right);
128                 LeftRotate(ref root);
129             }

```

```

130         else
131         {
132             DecrementSize(root);
133             root = ref left;
134         }
135     }
136     else if (FirstIsToTheRightOfSecond(node, root)) // node.Key greater than root.Key
137     {
138         var decrementedRightSize = Decrement(rightSize);
139         if (GreaterThan(GetSizeOrZero(GetLeftOrDefault(left)), decrementedRightSize))
140         {
141             RightRotate(ref root);
142         }
143         else if (GreaterThan(GetSizeOrZero(GetRightOrDefault(left)),
144             ↪ decrementedRightSize))
145         {
146             LeftRotate(ref left);
147             RightRotate(ref root);
148         }
149         else
150         {
151             DecrementSize(root);
152             root = ref right;
153         }
154     }
155     else // key equals to root.Key
156     {
157         if (GreaterThanZero(leftSize) && GreaterThanZero(rightSize))
158         {
159             TElement replacement;
160             if (GreaterThan(leftSize, rightSize))
161             {
162                 replacement = GetRighttest(left);
163                 DetachCore(ref left, replacement);
164             }
165             else
166             {
167                 replacement = GetLefttest(right);
168                 DetachCore(ref right, replacement);
169             }
170             SetLeft(replacement, left);
171             SetRight(replacement, right);
172             SetSize(replacement, Add(leftSize, rightSize));
173             root = replacement;
174         }
175         else if (GreaterThanZero(leftSize))
176         {
177             root = left;
178         }
179         else if (GreaterThanZero(rightSize))
180         {
181             root = right;
182         }
183         else
184         {
185             root = Zero;
186         }
187         ClearNode(node);
188         return;
189     }
190 }
191 }
192 }

```

## 1.6 ./csharp/Platform.Collections.Methods/Trees/SizeBalancedTreeMethods.cs

```

1 using System;
2
3 #pragma warning disable CS1591 // Missing XML comment for publicly visible type or member
4
5 namespace Platform.Collections.Methods.Trees
6 {
7     public abstract class SizeBalancedTreeMethods<TElement> :
8     ↪ SizedBinaryTreeMethodsBase<TElement>
9     {
10         protected override void AttachCore(ref TElement root, TElement node)
11         {
12             if (EqualToZero(root))
13             {

```

```

13         root = node;
14         IncrementSize(root);
15     }
16     else
17     {
18         IncrementSize(root);
19         if (FirstIsToTheLeftOfSecond(node, root))
20         {
21             AttachCore(ref GetLeftReference(root), node);
22             LeftMaintain(ref root);
23         }
24         else
25         {
26             AttachCore(ref GetRightReference(root), node);
27             RightMaintain(ref root);
28         }
29     }
30 }
31
32 protected override void DetachCore(ref TElement root, TElement nodeToDetach)
33 {
34     ref var currentNode = ref root;
35     ref var parent = ref root;
36     var replacementNode = Zero;
37     while (!AreEqual(currentNode, nodeToDetach))
38     {
39         DecrementSize(currentNode);
40         if (FirstIsToTheLeftOfSecond(nodeToDetach, currentNode))
41         {
42             parent = ref currentNode;
43             currentNode = ref GetLeftReference(currentNode);
44         }
45         else if (FirstIsToTheRightOfSecond(nodeToDetach, currentNode))
46         {
47             parent = ref currentNode;
48             currentNode = ref GetRightReference(currentNode);
49         }
50         else
51         {
52             throw new InvalidOperationException("Duplicate link found in the tree.");
53         }
54     }
55     var nodeToDetachLeft = GetLeft(nodeToDetach);
56     var node = GetRight(nodeToDetach);
57     if (!EqualToZero(nodeToDetachLeft) && !EqualToZero(node))
58     {
59         var lefttestNode = GetLefttest(node);
60         DetachCore(ref GetRightReference(nodeToDetach), lefttestNode);
61         SetLeft(lefttestNode, nodeToDetachLeft);
62         node = GetRight(nodeToDetach);
63         if (!EqualToZero(node))
64         {
65             SetRight(lefttestNode, node);
66             SetSize(lefttestNode, Increment(Add(GetSize(nodeToDetachLeft),
67                 ↪ GetSize(node))));
68         }
69         else
70         {
71             SetSize(lefttestNode, Increment(GetSize(nodeToDetachLeft)));
72         }
73         replacementNode = lefttestNode;
74     }
75     else if (!EqualToZero(nodeToDetachLeft))
76     {
77         replacementNode = nodeToDetachLeft;
78     }
79     else if (!EqualToZero(node))
80     {
81         replacementNode = node;
82     }
83     if (AreEqual(root, nodeToDetach)
84     {
85         root = replacementNode;
86     }
87     else if (AreEqual(GetLeft(parent), nodeToDetach))
88     {
89         SetLeft(parent, replacementNode);
90     }
91     else if (AreEqual(GetRight(parent), nodeToDetach))

```



```

91     {
92         SetRight(parent, replacementNode);
93     }
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) ||
109                  → GreaterThan(GetSize(rootLeftNodeLeftNode), rootRightNodeSize)))
110             {
111                 RightRotate(ref root);
112             }
113             else
114             {
115                 var rootLeftNodeRightNode = GetRight(rootLeftNode);
116                 if (!EqualToZero(rootLeftNodeRightNode) &&
117                     (EqualToZero(rootRightNode) ||
118                      → GreaterThan(GetSize(rootLeftNodeRightNode), rootRightNodeSize)))
119                 {
120                     LeftRotate(ref GetLeftReference(root));
121                     RightRotate(ref root);
122                 }
123                 else
124                 {
125                     return;
126                 }
127             }
128             LeftMaintain(ref GetLeftReference(root));
129             RightMaintain(ref GetRightReference(root));
130             LeftMaintain(ref root);
131             RightMaintain(ref root);
132         }
133     }
134 }
135
136 private void RightMaintain(ref TElement root)
137 {
138     if (!EqualToZero(root))
139     {
140         var rootRightNode = GetRight(root);
141         if (!EqualToZero(rootRightNode))
142         {
143             var rootLeftNode = GetLeft(root);
144             var rootLeftNodeSize = GetSize(rootLeftNode);
145             var rootRightNodeRightNode = GetRight(rootRightNode);
146             if (!EqualToZero(rootRightNodeRightNode) &&
147                 (EqualToZero(rootLeftNode) ||
148                  → GreaterThan(GetSize(rootRightNodeRightNode), rootLeftNodeSize)))
149             {
150                 LeftRotate(ref root);
151             }
152             else
153             {
154                 var rootRightNodeLeftNode = GetLeft(rootRightNode);
155                 if (!EqualToZero(rootRightNodeLeftNode) &&
156                     (EqualToZero(rootLeftNode) ||
157                      → GreaterThan(GetSize(rootRightNodeLeftNode), rootLeftNodeSize)))
158                 {
159                     RightRotate(ref GetRightReference(root));
160                     LeftRotate(ref root);
161                 }
162                 else
163                 {
164                     return;
165                 }
166             }
167             LeftMaintain(ref GetLeftReference(root));
168             RightMaintain(ref GetRightReference(root));

```

```

165         LeftMaintain(ref root);
166         RightMaintain(ref root);
167     }
168 }
169 }
170 }
171 }

```

## 1.7 ./csharp/Platform.Collections.Methods/Trees/SizedAndThreadedAVLBalancedTreeMethods.cs

```

1  using System;
2  using System.Runtime.CompilerServices;
3  using System.Text;
4  #if USEARRAYPOOL
5  using Platform.Collections;
6  #endif
7  using Platform.Reflection;
8
9  #pragma warning disable CS1591 // Missing XML comment for publicly visible type or member
10
11 namespace Platform.Collections.Methods.Trees
12 {
13     /// <summary>
14     /// Combination of Size, Height (AVL), and threads.
15     /// </summary>
16     /// <remarks>
17     /// Based on: <a href="https://github.com/programatom/TreeLib/blob/master/TreeLib/TreeLib/G_
18     ↪ enerated/AVLTreeList.cs">TreeLib.AVLTreeList</a>.
19     /// Which itself based on: <a
20     ↪ href="https://github.com/GNOME/glib/blob/master/glib/gtree.c">GNOME/glib/gtree</a>.
21     /// </remarks>
22     public abstract class SizedAndThreadedAVLBalancedTreeMethods<TElement> :
23     ↪ SizedBinaryTreeMethodsBase<TElement>
24     {
25         private static readonly int _maxPath = 11 * NumericType<TElement>.BytesSize + 4;
26
27         [MethodImpl(MethodImplOptions.AggressiveInlining)]
28         protected override TElement GetRighttest(TElement current)
29         {
30             var currentRight = GetRightOrDefault(current);
31             while (!EqualToZero(currentRight))
32             {
33                 current = currentRight;
34                 currentRight = GetRightOrDefault(current);
35             }
36             return current;
37         }
38
39         [MethodImpl(MethodImplOptions.AggressiveInlining)]
40         protected override TElement GetLefttest(TElement current)
41         {
42             var currentLeft = GetLeftOrDefault(current);
43             while (!EqualToZero(currentLeft))
44             {
45                 current = currentLeft;
46                 currentLeft = GetLeftOrDefault(current);
47             }
48             return current;
49         }
50
51         public override bool Contains(TElement node, TElement root)
52         {
53             while (!EqualToZero(root))
54             {
55                 if (FirstIsToTheLeftOfSecond(node, root)) // node.Key < root.Key
56                 {
57                     root = GetLeftOrDefault(root);
58                 }
59                 else if (FirstIsToTheRightOfSecond(node, root)) // node.Key > root.Key
60                 {
61                     root = GetRightOrDefault(root);
62                 }
63                 else // node.Key == root.Key
64                 {
65                     return true;
66                 }
67             }
68             return false;
69         }
70     }
71 }

```

```

68     protected override void PrintNode(TElement node, StringBuilder sb, int level)
69     {
70         base.PrintNode(node, sb, level);
71         sb.Append(' ');
72         sb.Append(GetLeftIsChild(node) ? 'l' : 'L');
73         sb.Append(GetRightIsChild(node) ? 'r' : 'R');
74         sb.Append(' ');
75         sb.Append(GetBalance(node));
76     }
77
78     [MethodImpl(MethodImplOptions.AggressiveInlining)]
79     protected void IncrementBalance(TElement node) => SetBalance(node,
80         ↪ (sbyte)(GetBalance(node) + 1));
81
82     [MethodImpl(MethodImplOptions.AggressiveInlining)]
83     protected void DecrementBalance(TElement node) => SetBalance(node,
84         ↪ (sbyte)(GetBalance(node) - 1));
85
86     [MethodImpl(MethodImplOptions.AggressiveInlining)]
87     protected override TElement GetLeftOrDefault(TElement node) => GetLeftIsChild(node) ?
88         ↪ GetLeft(node) : default;
89
90     [MethodImpl(MethodImplOptions.AggressiveInlining)]
91     protected override TElement GetRightOrDefault(TElement node) => GetRightIsChild(node) ?
92         ↪ GetRight(node) : default;
93
94     [MethodImpl(MethodImplOptions.AggressiveInlining)]
95     protected abstract bool GetLeftIsChild(TElement node);
96
97     [MethodImpl(MethodImplOptions.AggressiveInlining)]
98     protected abstract void SetLeftIsChild(TElement node, bool value);
99
100    [MethodImpl(MethodImplOptions.AggressiveInlining)]
101    protected abstract bool GetRightIsChild(TElement node);
102
103    [MethodImpl(MethodImplOptions.AggressiveInlining)]
104    protected abstract void SetRightIsChild(TElement node, bool value);
105
106    [MethodImpl(MethodImplOptions.AggressiveInlining)]
107    protected abstract sbyte GetBalance(TElement node);
108
109    [MethodImpl(MethodImplOptions.AggressiveInlining)]
110    protected abstract void SetBalance(TElement node, sbyte value);
111
112    protected override void AttachCore(ref TElement root, TElement node)
113    {
114        unchecked
115        {
116            // TODO: Check what is faster to use simple array or array from array pool
117            // TODO: Try to use stackalloc as an optimization (requires code generation,
118            ↪ because of generics)
119
120            #if USEARRAYPOOL
121                var path = ArrayPool.Allocate<TElement>(MaxPath);
122                var pathPosition = 0;
123                path[pathPosition++] = default;
124            #else
125                var path = new TElement[_maxPath];
126                var pathPosition = 1;
127            #endif
128
129            var currentNode = root;
130            while (true)
131            {
132                if (FirstIsToTheLeftOfSecond(node, currentNode))
133                {
134                    if (GetLeftIsChild(currentNode))
135                    {
136                        IncrementSize(currentNode);
137                        path[pathPosition++] = currentNode;
138                        currentNode = GetLeft(currentNode);
139                    }
140                    else
141                    {
142                        // Threads
143                        SetLeft(node, GetLeft(currentNode));
144                        SetRight(node, currentNode);
145                        SetLeft(currentNode, node);
146                        SetLeftIsChild(currentNode, true);
147                        DecrementBalance(currentNode);
148                        SetSize(node, One);
149                    }
150                }
151            }
152        }
153    }

```

```

142         FixSize(currentNode); // Should be incremented already
143         break;
144     }
145 }
146 else if (FirstIsToTheRightOfSecond(node, currentNode))
147 {
148     if (GetRightIsChild(currentNode))
149     {
150         IncrementSize(currentNode);
151         path[pathPosition++] = currentNode;
152         currentNode = GetRight(currentNode);
153     }
154     else
155     {
156         // Threads
157         SetRight(node, GetRight(currentNode));
158         SetLeft(node, currentNode);
159         SetRight(currentNode, node);
160         SetRightIsChild(currentNode, true);
161         IncrementBalance(currentNode);
162         SetSize(node, One);
163         FixSize(currentNode); // Should be incremented already
164         break;
165     }
166 }
167 else
168 {
169     throw new InvalidOperationException("Node with the same key already
170     ↳ attached to a tree.");
171 }
172 // Restore balance. This is the goodness of a non-recursive
173 // implementation, when we are done with balancing we 'break'
174 // the loop and we are done.
175 while (true)
176 {
177     var parent = path[--pathPosition];
178     var isLeftNode = !AreEqual(parent, default) && AreEqual(currentNode,
179     ↳ GetLeft(parent));
180     var currentNodeBalance = GetBalance(currentNode);
181     if (currentNodeBalance < -1 || currentNodeBalance > 1)
182     {
183         currentNode = Balance(currentNode);
184         if (AreEqual(parent, default))
185         {
186             root = currentNode;
187         }
188         else if (isLeftNode)
189         {
190             SetLeft(parent, currentNode);
191             FixSize(parent);
192         }
193         else
194         {
195             SetRight(parent, currentNode);
196             FixSize(parent);
197         }
198     }
199     currentNodeBalance = GetBalance(currentNode);
200     if (currentNodeBalance == 0 || AreEqual(parent, default))
201     {
202         break;
203     }
204     if (isLeftNode)
205     {
206         DecrementBalance(parent);
207     }
208     else
209     {
210         IncrementBalance(parent);
211     }
212     currentNode = parent;
213 }
214 #if USEARRAYPOOL
215     ArrayPool.Free(path);
216 #endif
217 }

```

```

218
219 private TElement Balance(TElement node)
220 {
221     unchecked
222     {
223         var rootBalance = GetBalance(node);
224         if (rootBalance < -1)
225         {
226             var left = GetLeft(node);
227             if (GetBalance(left) > 0)
228             {
229                 SetLeft(node, LeftRotateWithBalance(left));
230                 FixSize(node);
231             }
232             node = RightRotateWithBalance(node);
233         }
234         else if (rootBalance > 1)
235         {
236             var right = GetRight(node);
237             if (GetBalance(right) < 0)
238             {
239                 SetRight(node, RightRotateWithBalance(right));
240                 FixSize(node);
241             }
242             node = LeftRotateWithBalance(node);
243         }
244         return node;
245     }
246 }
247
248 protected TElement LeftRotateWithBalance(TElement node)
249 {
250     unchecked
251     {
252         var right = GetRight(node);
253         if (GetLeftIsChild(right))
254         {
255             SetRight(node, GetLeft(right));
256         }
257         else
258         {
259             SetRightIsChild(node, false);
260             SetLeftIsChild(right, true);
261         }
262         SetLeft(right, node);
263         // Fix size
264         SetSize(right, GetSize(node));
265         FixSize(node);
266         // Fix balance
267         var rootBalance = GetBalance(node);
268         var rightBalance = GetBalance(right);
269         if (rightBalance <= 0)
270         {
271             if (rootBalance >= 1)
272             {
273                 SetBalance(right, (sbyte)(rightBalance - 1));
274             }
275             else
276             {
277                 SetBalance(right, (sbyte)(rootBalance + rightBalance - 2));
278             }
279             SetBalance(node, (sbyte)(rootBalance - 1));
280         }
281         else
282         {
283             if (rootBalance <= rightBalance)
284             {
285                 SetBalance(right, (sbyte)(rootBalance - 2));
286             }
287             else
288             {
289                 SetBalance(right, (sbyte)(rightBalance - 1));
290             }
291             SetBalance(node, (sbyte)(rootBalance - rightBalance - 1));
292         }
293         return right;
294     }
295 }

```

```

296
297 protected TElement RightRotateWithBalance(TElement node)
298 {
299     unchecked
300     {
301         var left = GetLeft(node);
302         if (GetRightIsChild(left))
303         {
304             SetLeft(node, GetRight(left));
305         }
306         else
307         {
308             SetLeftIsChild(node, false);
309             SetRightIsChild(left, true);
310         }
311         SetRight(left, node);
312         // Fix size
313         SetSize(left, GetSize(node));
314         FixSize(node);
315         // Fix balance
316         var rootBalance = GetBalance(node);
317         var leftBalance = GetBalance(left);
318         if (leftBalance <= 0)
319         {
320             if (leftBalance > rootBalance)
321             {
322                 SetBalance(left, (sbyte)(leftBalance + 1));
323             }
324             else
325             {
326                 SetBalance(left, (sbyte)(rootBalance + 2));
327             }
328             SetBalance(node, (sbyte)(rootBalance - leftBalance + 1));
329         }
330         else
331         {
332             if (rootBalance <= -1)
333             {
334                 SetBalance(left, (sbyte)(leftBalance + 1));
335             }
336             else
337             {
338                 SetBalance(left, (sbyte)(rootBalance + leftBalance + 2));
339             }
340             SetBalance(node, (sbyte)(rootBalance + 1));
341         }
342         return left;
343     }
344 }
345
346 [MethodImpl(MethodImplOptions.AggressiveInlining)]
347 protected override TElement GetNext(TElement node)
348 {
349     var current = GetRight(node);
350     if (GetRightIsChild(node))
351     {
352         return GetLefttest(current);
353     }
354     return current;
355 }
356
357 [MethodImpl(MethodImplOptions.AggressiveInlining)]
358 protected override TElement GetPrevious(TElement node)
359 {
360     var current = GetLeft(node);
361     if (GetLeftIsChild(node))
362     {
363         return GetRighttest(current);
364     }
365     return current;
366 }
367
368 protected override void DetachCore(ref TElement root, TElement node)
369 {
370     unchecked
371     {
372 #if USEARRAYPOOL
373         var path = ArrayPool.Allocate<TElement>(MaxPath);
374         var pathPosition = 0;

```

```

375     path[pathPosition++] = default;
376 #else
377     var path = new TElement[_maxPath];
378     var pathPosition = 1;
379 #endif
380     var currentNode = root;
381     while (true)
382     {
383         if (FirstIsToTheLeftOfSecond(node, currentNode))
384         {
385             if (!GetLeftIsChild(currentNode))
386             {
387                 throw new InvalidOperationException("Cannot find a node.");
388             }
389             DecrementSize(currentNode);
390             path[pathPosition++] = currentNode;
391             currentNode = GetLeft(currentNode);
392         }
393         else if (FirstIsToTheRightOfSecond(node, currentNode))
394         {
395             if (!GetRightIsChild(currentNode))
396             {
397                 throw new InvalidOperationException("Cannot find a node.");
398             }
399             DecrementSize(currentNode);
400             path[pathPosition++] = currentNode;
401             currentNode = GetRight(currentNode);
402         }
403         else
404         {
405             break;
406         }
407     }
408     var parent = path[--pathPosition];
409     var balanceNode = parent;
410     var isLeftNode = !AreEqual(parent, default) && AreEqual(currentNode,
411     ↪ GetLeft(parent));
412     if (!GetLeftIsChild(currentNode))
413     {
414         if (!GetRightIsChild(currentNode)) // node has no children
415         {
416             if (AreEqual(parent, default))
417             {
418                 root = Zero;
419             }
420             else if (isLeftNode)
421             {
422                 SetLeftIsChild(parent, false);
423                 SetLeft(parent, GetLeft(currentNode));
424                 IncrementBalance(parent);
425             }
426             else
427             {
428                 SetRightIsChild(parent, false);
429                 SetRight(parent, GetRight(currentNode));
430                 DecrementBalance(parent);
431             }
432         }
433         else // node has a right child
434         {
435             var successor = GetNext(currentNode);
436             SetLeft(successor, GetLeft(currentNode));
437             var right = GetRight(currentNode);
438             if (AreEqual(parent, default))
439             {
440                 root = right;
441             }
442             else if (isLeftNode)
443             {
444                 SetLeft(parent, right);
445                 IncrementBalance(parent);
446             }
447             else
448             {
449                 SetRight(parent, right);
450                 DecrementBalance(parent);
451             }
452         }
453     }

```

```

452 }
453 else // node has a left child
454 {
455     if (!GetRightIsChild(currentNode))
456     {
457         var predecessor = GetPrevious(currentNode);
458         SetRight(predecessor, GetRight(currentNode));
459         var leftValue = GetLeft(currentNode);
460         if (AreEqual(parent, default))
461         {
462             root = leftValue;
463         }
464         else if (isLeftNode)
465         {
466             SetLeft(parent, leftValue);
467             IncrementBalance(parent);
468         }
469         else
470         {
471             SetRight(parent, leftValue);
472             DecrementBalance(parent);
473         }
474     }
475     else // node has a both children (left and right)
476     {
477         var predecessor = GetLeft(currentNode);
478         var successor = GetRight(currentNode);
479         var successorParent = currentNode;
480         int previousPathPosition = ++pathPosition;
481         // find the immediately next node (and its parent)
482         while (GetLeftIsChild(successor))
483         {
484             path[++pathPosition] = successorParent = successor;
485             successor = GetLeft(successor);
486             if (!AreEqual(successorParent, currentNode))
487             {
488                 DecrementSize(successorParent);
489             }
490         }
491         path[previousPathPosition] = successor;
492         balanceNode = path[pathPosition];
493         // remove 'successor' from the tree
494         if (!AreEqual(successorParent, currentNode))
495         {
496             if (!GetRightIsChild(successor))
497             {
498                 SetLeftIsChild(successorParent, false);
499             }
500             else
501             {
502                 SetLeft(successorParent, GetRight(successor));
503             }
504             IncrementBalance(successorParent);
505             SetRightIsChild(successor, true);
506             SetRight(successor, GetRight(currentNode));
507         }
508         else
509         {
510             DecrementBalance(currentNode);
511         }
512         // set the predecessor's successor link to point to the right place
513         while (GetRightIsChild(predecessor))
514         {
515             predecessor = GetRight(predecessor);
516         }
517         SetRight(predecessor, successor);
518         // prepare 'successor' to replace 'node'
519         var left = GetLeft(currentNode);
520         SetLeftIsChild(successor, true);
521         SetLeft(successor, left);
522         SetBalance(successor, GetBalance(currentNode));
523         FixSize(successor);
524         if (AreEqual(parent, default))
525         {
526             root = successor;
527         }
528         else if (isLeftNode)
529         {

```



```

530         SetLeft(parent, successor);
531     }
532     else
533     {
534         SetRight(parent, successor);
535     }
536 }
537 }
538 // restore balance
539 if (!AreEqual(balanceNode, default))
540 {
541     while (true)
542     {
543         var balanceParent = path[--pathPosition];
544         isLeftNode = !AreEqual(balanceParent, default) && AreEqual(balanceNode,
545             ↪ GetLeft(balanceParent));
546         var currentNodeBalance = GetBalance(balanceNode);
547         if (currentNodeBalance < -1 || currentNodeBalance > 1)
548         {
549             balanceNode = Balance(balanceNode);
550             if (AreEqual(balanceParent, default))
551             {
552                 root = balanceNode;
553             }
554             else if (isLeftNode)
555             {
556                 SetLeft(balanceParent, balanceNode);
557             }
558             else
559             {
560                 SetRight(balanceParent, balanceNode);
561             }
562             currentNodeBalance = GetBalance(balanceNode);
563             if (currentNodeBalance != 0 || AreEqual(balanceParent, default))
564             {
565                 break;
566             }
567             if (isLeftNode)
568             {
569                 IncrementBalance(balanceParent);
570             }
571             else
572             {
573                 DecrementBalance(balanceParent);
574             }
575             balanceNode = balanceParent;
576         }
577     }
578     ClearNode(node);
579 #if USEARRAYPOOL
580     ArrayPool.Free(path);
581 #endif
582 }
583 }
584
585 [MethodImpl(MethodImplOptions.AggressiveInlining)]
586 protected override void ClearNode(TElement node)
587 {
588     SetLeft(node, Zero);
589     SetRight(node, Zero);
590     SetSize(node, Zero);
591     SetLeftIsChild(node, false);
592     SetRightIsChild(node, false);
593     SetBalance(node, 0);
594 }
595 }
596 }

```

## 1.8 ./csharp/Platform.Collections.Methods/Trees/SizedBinaryTreeMethodsBase.cs

```

1  // #define ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
2
3  using System;
4  using System.Diagnostics;
5  using System.Runtime.CompilerServices;
6  using System.Text;
7  using Platform.Numbers;
8
9  #pragma warning disable CS1591 // Missing XML comment for publicly visible type or member

```

```

10
11 namespace Platform.Collections.Methods.Trees
12 {
13     public abstract class SizedBinaryTreeMethodsBase<TElement> :
14         ↳ GenericCollectionMethodsBase<TElement>
15     {
16         [MethodImpl(MethodImplOptions.AggressiveInlining)]
17         protected abstract ref TElement GetLeftReference(TElement node);
18
19         [MethodImpl(MethodImplOptions.AggressiveInlining)]
20         protected abstract ref TElement GetRightReference(TElement node);
21
22         [MethodImpl(MethodImplOptions.AggressiveInlining)]
23         protected abstract TElement GetLeft(TElement node);
24
25         [MethodImpl(MethodImplOptions.AggressiveInlining)]
26         protected abstract TElement GetRight(TElement node);
27
28         [MethodImpl(MethodImplOptions.AggressiveInlining)]
29         protected abstract TElement GetSize(TElement node);
30
31         [MethodImpl(MethodImplOptions.AggressiveInlining)]
32         protected abstract void SetLeft(TElement node, TElement left);
33
34         [MethodImpl(MethodImplOptions.AggressiveInlining)]
35         protected abstract void SetRight(TElement node, TElement right);
36
37         [MethodImpl(MethodImplOptions.AggressiveInlining)]
38         protected abstract void SetSize(TElement node, TElement size);
39
40         [MethodImpl(MethodImplOptions.AggressiveInlining)]
41         protected abstract bool FirstIsToLeftOfSecond(TElement first, TElement second);
42
43         [MethodImpl(MethodImplOptions.AggressiveInlining)]
44         protected abstract bool FirstIsToTheRightOfSecond(TElement first, TElement second);
45
46         [MethodImpl(MethodImplOptions.AggressiveInlining)]
47         protected virtual TElement GetLeftOrDefault(TElement node) => AreEqual(node, default) ?
48             ↳ default : GetLeft(node);
49
50         [MethodImpl(MethodImplOptions.AggressiveInlining)]
51         protected virtual TElement GetRightOrDefault(TElement node) => AreEqual(node, default) ?
52             ↳ default : GetRight(node);
53
54         [MethodImpl(MethodImplOptions.AggressiveInlining)]
55         protected void IncrementSize(TElement node) => SetSize(node, Increment(GetSize(node)));
56
57         [MethodImpl(MethodImplOptions.AggressiveInlining)]
58         protected void DecrementSize(TElement node) => SetSize(node, Decrement(GetSize(node)));
59
60         [MethodImpl(MethodImplOptions.AggressiveInlining)]
61         protected TElement GetLeftSize(TElement node) => GetSizeOrZero(GetLeftOrDefault(node));
62
63         [MethodImpl(MethodImplOptions.AggressiveInlining)]
64         protected TElement GetRightSize(TElement node) => GetSizeOrZero(GetRightOrDefault(node));
65
66         [MethodImpl(MethodImplOptions.AggressiveInlining)]
67         protected TElement GetSizeOrZero(TElement node) => EqualToZero(node) ? Zero :
68             ↳ GetSize(node);
69
70         [MethodImpl(MethodImplOptions.AggressiveInlining)]
71         protected void FixSize(TElement node) => SetSize(node, Increment(Add(GetLeftSize(node),
72             ↳ GetRightSize(node))));
73
74         [MethodImpl(MethodImplOptions.AggressiveInlining)]
75         protected void LeftRotate(ref TElement root) => root = LeftRotate(root);
76
77         [MethodImpl(MethodImplOptions.AggressiveInlining)]
78         protected TElement LeftRotate(TElement root)
79         {
80             var right = GetRight(root);
81             #if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
82                 if (EqualToZero(right))
83                 {
84                     throw new InvalidOperationException("Right is null.");
85                 }
86             #endif
87             SetRight(root, GetLeft(right));
88             SetLeft(right, root);
89         }
90     }
91 }

```

```

84         SetSize(right, GetSize(root));
85         FixSize(root);
86         return right;
87     }
88
89     [MethodImpl(MethodImplOptions.AggressiveInlining)]
90     protected void RightRotate(ref TElement root) => root = RightRotate(root);
91
92     [MethodImpl(MethodImplOptions.AggressiveInlining)]
93     protected TElement RightRotate(TElement root)
94     {
95         var left = GetLeft(root);
96         #if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
97         if (EqualToZero(left))
98         {
99             throw new InvalidOperationException("Left is null.");
100         }
101         #endif
102         SetLeft(root, GetRight(left));
103         SetRight(left, root);
104         SetSize(left, GetSize(root));
105         FixSize(root);
106         return left;
107     }
108
109     [MethodImpl(MethodImplOptions.AggressiveInlining)]
110     protected virtual TElement GetRightest(TElement current)
111     {
112         var currentRight = GetRight(current);
113         while (!EqualToZero(currentRight))
114         {
115             current = currentRight;
116             currentRight = GetRight(current);
117         }
118         return current;
119     }
120
121     [MethodImpl(MethodImplOptions.AggressiveInlining)]
122     protected virtual TElement GetLeftest(TElement current)
123     {
124         var currentLeft = GetLeft(current);
125         while (!EqualToZero(currentLeft))
126         {
127             current = currentLeft;
128             currentLeft = GetLeft(current);
129         }
130         return current;
131     }
132
133     [MethodImpl(MethodImplOptions.AggressiveInlining)]
134     protected virtual TElement GetNext(TElement node) => GetLeftest(GetRight(node));
135
136     [MethodImpl(MethodImplOptions.AggressiveInlining)]
137     protected virtual TElement GetPrevious(TElement node) => GetRightest(GetLeft(node));
138
139     [MethodImpl(MethodImplOptions.AggressiveInlining)]
140     public virtual bool Contains(TElement node, TElement root)
141     {
142         while (!EqualToZero(root))
143         {
144             if (FirstIsToTheLeftOfSecond(node, root)) // node.Key < root.Key
145             {
146                 root = GetLeft(root);
147             }
148             else if (FirstIsToTheRightOfSecond(node, root)) // node.Key > root.Key
149             {
150                 root = GetRight(root);
151             }
152             else // node.Key == root.Key
153             {
154                 return true;
155             }
156         }
157         return false;
158     }
159
160     [MethodImpl(MethodImplOptions.AggressiveInlining)]
161     protected virtual void ClearNode(TElement node)
162     {

```

```

163         SetLeft(node, Zero);
164         SetRight(node, Zero);
165         SetSize(node, Zero);
166     }
167
168     [MethodImpl(MethodImplOptions.AggressiveInlining)]
169     public void Attach(ref TElement root, TElement node)
170     {
171         #if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
172             ValidateSizes(root);
173             Debug.WriteLine("--BeforeAttach--");
174             Debug.WriteLine(PrintNodes(root));
175             Debug.WriteLine("-----");
176             var sizeBefore = GetSize(root);
177         #endif
178         if (EqualToZero(root))
179         {
180             SetSize(node, One);
181             root = node;
182             return;
183         }
184         AttachCore(ref root, node);
185         #if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
186             Debug.WriteLine("--AfterAttach--");
187             Debug.WriteLine(PrintNodes(root));
188             Debug.WriteLine("-----");
189             ValidateSizes(root);
190             var sizeAfter = GetSize(root);
191             if (!AreEqual(Arithmetic.Increment(sizeBefore), sizeAfter))
192             {
193                 throw new InvalidOperationException("Tree was broken after attach.");
194             }
195         #endif
196     }
197
198     protected abstract void AttachCore(ref TElement root, TElement node);
199
200     [MethodImpl(MethodImplOptions.AggressiveInlining)]
201     public void Detach(ref TElement root, TElement node)
202     {
203         #if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
204             ValidateSizes(root);
205             Debug.WriteLine("--BeforeDetach--");
206             Debug.WriteLine(PrintNodes(root));
207             Debug.WriteLine("-----");
208             var sizeBefore = GetSize(root);
209             if (EqualToZero(root))
210             {
211                 throw new InvalidOperationException($"Элемент с {node} не содержится в
212                 ↳ дереве.");
213             }
214         #endif
215         DetachCore(ref root, node);
216         #if ENABLE_TREE_AUTO_DEBUG_AND_VALIDATION
217             Debug.WriteLine("--AfterDetach--");
218             Debug.WriteLine(PrintNodes(root));
219             Debug.WriteLine("-----");
220             ValidateSizes(root);
221             var sizeAfter = GetSize(root);
222             if (!AreEqual(Arithmetic.Decrement(sizeBefore), sizeAfter))
223             {
224                 throw new InvalidOperationException("Tree was broken after detach.");
225             }
226         #endif
227     }
228
229     protected abstract void DetachCore(ref TElement root, TElement node);
230
231     public void FixSizes(TElement node)
232     {
233         if (AreEqual(node, default))
234         {
235             return;
236         }
237         FixSizes(GetLeft(node));
238         FixSizes(GetRight(node));
239         FixSize(node);
240     }

```

```

241 public void ValidateSizes(TElement node)
242 {
243     if (AreEqual(node, default))
244     {
245         return;
246     }
247     var size = GetSize(node);
248     var leftSize = GetLeftSize(node);
249     var rightSize = GetRightSize(node);
250     var expectedSize = Arithmetic.Increment(Arithmetic.Add(leftSize, rightSize));
251     if (!AreEqual(size, expectedSize))
252     {
253         throw new InvalidOperationException($"Size of {node} is not valid. Expected
        ↳ size: {expectedSize}, actual size: {size}.");
254     }
255     ValidateSizes(GetLeft(node));
256     ValidateSizes(GetRight(node));
257 }
258
259 public void ValidateSize(TElement node)
260 {
261     var size = GetSize(node);
262     var leftSize = GetLeftSize(node);
263     var rightSize = GetRightSize(node);
264     var expectedSize = Arithmetic.Increment(Arithmetic.Add(leftSize, rightSize));
265     if (!AreEqual(size, expectedSize))
266     {
267         throw new InvalidOperationException($"Size of {node} is not valid. Expected
        ↳ size: {expectedSize}, actual size: {size}.");
268     }
269 }
270
271 public string PrintNodes(TElement node)
272 {
273     var sb = new StringBuilder();
274     PrintNodes(node, sb);
275     return sb.ToString();
276 }
277
278 [MethodImpl(MethodImplOptions.AggressiveInlining)]
279 public void PrintNodes(TElement node, StringBuilder sb) => PrintNodes(node, sb, 0);
280
281 public void PrintNodes(TElement node, StringBuilder sb, int level)
282 {
283     if (AreEqual(node, default))
284     {
285         return;
286     }
287     PrintNodes(GetLeft(node), sb, level + 1);
288     PrintNode(node, sb, level);
289     sb.AppendLine();
290     PrintNodes(GetRight(node), sb, level + 1);
291 }
292
293 public string PrintNode(TElement node)
294 {
295     var sb = new StringBuilder();
296     PrintNode(node, sb);
297     return sb.ToString();
298 }
299
300 [MethodImpl(MethodImplOptions.AggressiveInlining)]
301 protected void PrintNode(TElement node, StringBuilder sb) => PrintNode(node, sb, 0);
302
303 protected virtual void PrintNode(TElement node, StringBuilder sb, int level)
304 {
305     sb.Append('\t', level);
306     sb.Append(node);
307     PrintNodeValue(node, sb);
308     sb.Append(' ');
309     sb.Append('s');
310     sb.Append(GetSize(node));
311 }
312
313 protected abstract void PrintNodeValue(TElement node, StringBuilder sb);
314 }
315 }

```

## 1.9 ./csharp/Platform.Collections.Methods.Tests/RecursionlessSizeBalancedTree.cs

```

1  using System;
2  using System.Collections.Generic;
3  using System.Text;
4  using Platform.Numbers;
5  using Platform.Collections.Methods.Trees;
6  using Platform.Converters;
7
8  namespace Platform.Collections.Methods.Tests
9  {
10     public class RecursionlessSizeBalancedTree<TElement> :
        ↳ RecursionlessSizeBalancedTreeMethods<TElement>
11     {
12         private struct TreeElement
13         {
14             public TElement Size;
15             public TElement Left;
16             public TElement Right;
17         }
18
19         private readonly TreeElement[] _elements;
20         private TElement _allocated;
21
22         public TElement Root;
23
24         public TElement Count => GetSizeOrZero(Root);
25
26         public RecursionlessSizeBalancedTree(int capacity) => (_elements, _allocated) = (new
        ↳ TreeElement[capacity], One);
27
28         public TElement Allocate()
29         {
30             var newNode = _allocated;
31             if (IsEmpty(newNode))
32             {
33                 _allocated = Arithmetic.Increment(_allocated);
34                 return newNode;
35             }
36             else
37             {
38                 throw new InvalidOperationException("Allocated tree element is not empty.");
39             }
40         }
41
42         public void Free(TElement node)
43         {
44             while (!EqualityComparer.Equals(_allocated, One) && IsEmpty(node))
45             {
46                 var lastNode = Arithmetic.Decrement(_allocated);
47                 if (EqualityComparer.Equals(lastNode, node))
48                 {
49                     _allocated = lastNode;
50                     node = Arithmetic.Decrement(node);
51                 }
52                 else
53                 {
54                     return;
55                 }
56             }
57         }
58
59         public bool IsEmpty(TElement node) =>
        ↳ EqualityComparer<TreeElement>.Default.Equals(GetElement(node), default);
60
61         protected override bool FirstIsToTheLeftOfSecond(TElement first, TElement second) =>
        ↳ Comparer.Compare(first, second) < 0;
62
63         protected override bool FirstIsToTheRightOfSecond(TElement first, TElement second) =>
        ↳ Comparer.Compare(first, second) > 0;
64
65         protected override ref TElement GetLeftReference(TElement node) => ref
        ↳ GetElement(node).Left;
66
67         protected override TElement GetLeft(TElement node) => GetElement(node).Left;
68
69         protected override ref TElement GetRightReference(TElement node) => ref
        ↳ GetElement(node).Right;
70
71         protected override TElement GetRight(TElement node) => GetElement(node).Right;
72

```

```

73     protected override TElement GetSize(TElement node) => GetElement(node).Size;
74
75     protected override void PrintNodeValue(TElement node, StringBuilder sb) =>
76         ↳ sb.Append(node);
77
78     protected override void SetLeft(TElement node, TElement left) => GetElement(node).Left =
79         ↳ left;
80
81     protected override void SetRight(TElement node, TElement right) =>
82         ↳ GetElement(node).Right = right;
83
84     protected override void SetSize(TElement node, TElement size) => GetElement(node).Size =
85         ↳ size;
86
87     private ref TreeElement GetElement(TElement node) => ref
88         ↳ _elements[UncheckedConverter<TElement, long>.Default.Convert(node)];
89 }
90
91 }

```

## 1.10 ./csharp/Platform.Collections.Methods.Tests/SizeBalancedTree.cs

```

1  using System;
2  using System.Collections.Generic;
3  using System.Text;
4  using Platform.Numbers;
5  using Platform.Collections.Methods.Trees;
6  using Platform.Converters;
7
8  namespace Platform.Collections.Methods.Tests
9  {
10     public class SizeBalancedTree<TElement> : SizeBalancedTreeMethods<TElement>
11     {
12         private struct TreeElement
13         {
14             public TElement Size;
15             public TElement Left;
16             public TElement Right;
17         }
18
19         private readonly TreeElement[] _elements;
20         private TElement _allocated;
21
22         public TElement Root;
23
24         public TElement Count => GetSizeOrZero(Root);
25
26         public SizeBalancedTree(int capacity) => (_elements, _allocated) = (new
27             ↳ TreeElement[capacity], One);
28
29         public TElement Allocate()
30         {
31             var newNode = _allocated;
32             if (IsEmpty(newNode))
33             {
34                 _allocated = Arithmetic.Increment(_allocated);
35                 return newNode;
36             }
37             else
38             {
39                 throw new InvalidOperationException("Allocated tree element is not empty.");
40             }
41         }
42
43         public void Free(TElement node)
44         {
45             while (!EqualityComparer.Equals(_allocated, One) && IsEmpty(node))
46             {
47                 var lastNode = Arithmetic.Decrement(_allocated);
48                 if (EqualityComparer.Equals(lastNode, node))
49                 {
50                     _allocated = lastNode;
51                     node = Arithmetic.Decrement(node);
52                 }
53                 else
54                 {
55                     return;
56                 }
57             }
58         }
59     }
60 }

```

```

59     public bool IsEmpty(TElement node) =>
        ↳ EqualityComparer<TreeElement>.Default.Equals(GetElement(node), default);
60
61     protected override bool FirstIsToTheLeftOfSecond(TElement first, TElement second) =>
        ↳ Comparer.Compare(first, second) < 0;
62
63     protected override bool FirstIsToTheRightOfSecond(TElement first, TElement second) =>
        ↳ Comparer.Compare(first, second) > 0;
64
65     protected override ref TElement GetLeftReference(TElement node) => ref
        ↳ GetElement(node).Left;
66
67     protected override TElement GetLeft(TElement node) => GetElement(node).Left;
68
69     protected override ref TElement GetRightReference(TElement node) => ref
        ↳ GetElement(node).Right;
70
71     protected override TElement GetRight(TElement node) => GetElement(node).Right;
72
73     protected override TElement GetSize(TElement node) => GetElement(node).Size;
74
75     protected override void PrintNodeValue(TElement node, StringBuilder sb) =>
        ↳ sb.Append(node);
76
77     protected override void SetLeft(TElement node, TElement left) => GetElement(node).Left =
        ↳ left;
78
79     protected override void SetRight(TElement node, TElement right) =>
        ↳ GetElement(node).Right = right;
80
81     protected override void SetSize(TElement node, TElement size) => GetElement(node).Size =
        ↳ size;
82
83     private ref TreeElement GetElement(TElement node) => ref
        ↳ _elements[UncheckedConverter<TElement, long>.Default.Convert(node)];
84 }
85 }

```

### 1.11 ./csharp/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  using Platform.Converters;
7
8  namespace Platform.Collections.Methods.Tests
9  {
10     public class SizedAndThreadedAVLBalancedTree<TElement> :
        ↳ SizedAndThreadedAVLBalancedTreeMethods<TElement>
11     {
12         private struct TreeElement
13         {
14             public TElement Size;
15             public TElement Left;
16             public TElement Right;
17             public sbyte Balance;
18             public bool LeftIsChild;
19             public bool RightIsChild;
20         }
21
22         private readonly TreeElement[] _elements;
23         private TElement _allocated;
24
25         public TElement Root;
26
27         public TElement Count => GetSizeOrZero(Root);
28
29         public SizedAndThreadedAVLBalancedTree(int capacity) => (_elements, _allocated) = (new
        ↳ TreeElement[capacity], One);
30
31         public TElement Allocate()
32         {
33             var newNode = _allocated;
34             if (IsEmpty(newNode))
35             {
36                 _allocated = Arithmetic.Increment(_allocated);
37                 return newNode;
38             }
39             else

```



```

40     {
41         throw new InvalidOperationException("Allocated tree element is not empty.");
42     }
43 }
44
45 public void Free(TElement node)
46 {
47     while (!EqualityComparer.Equals(_allocated, One) && IsEmpty(node))
48     {
49         var lastNode = Arithmetic.Decrement(_allocated);
50         if (EqualityComparer.Equals(lastNode, node))
51         {
52             _allocated = lastNode;
53             node = Arithmetic.Decrement(node);
54         }
55         else
56         {
57             return;
58         }
59     }
60 }
61
62 public bool IsEmpty(TElement node) =>
63     ↳ EqualityComparer<TreeElement>.Default.Equals(GetElement(node), default);
64
65 protected override bool FirstIsToLeftOfSecond(TElement first, TElement second) =>
66     ↳ Comparer.Compare(first, second) < 0;
67
68 protected override bool FirstIsToTheRightOfSecond(TElement first, TElement second) =>
69     ↳ Comparer.Compare(first, second) > 0;
70
71 protected override sbyte GetBalance(TElement node) => GetElement(node).Balance;
72
73 protected override bool GetLeftIsChild(TElement node) => GetElement(node).LeftIsChild;
74
75 protected override ref TElement GetLeftReference(TElement node) => ref
76     ↳ GetElement(node).Left;
77
78 protected override TElement GetLeft(TElement node) => GetElement(node).Left;
79
80 protected override bool GetRightIsChild(TElement node) => GetElement(node).RightIsChild;
81
82 protected override ref TElement GetRightReference(TElement node) => ref
83     ↳ GetElement(node).Right;
84
85 protected override TElement GetRight(TElement node) => GetElement(node).Right;
86
87 protected override TElement GetSize(TElement node) => GetElement(node).Size;
88
89 protected override void PrintNodeValue(TElement node, StringBuilder sb) =>
90     ↳ sb.Append(node);
91
92 protected override void SetBalance(TElement node, sbyte value) =>
93     ↳ GetElement(node).Balance = value;
94
95 protected override void SetLeft(TElement node, TElement left) => GetElement(node).Left =
96     ↳ left;
97
98 protected override void SetLeftIsChild(TElement node, bool value) =>
99     ↳ GetElement(node).LeftIsChild = value;
100
101 protected override void SetRight(TElement node, TElement right) =>
102     ↳ GetElement(node).Right = right;
103
104 protected override void SetRightIsChild(TElement node, bool value) =>
105     ↳ GetElement(node).RightIsChild = value;
106
107 protected override void SetSize(TElement node, TElement size) => GetElement(node).Size =
108     ↳ size;
109
110 private ref TreeElement GetElement(TElement node) => ref
111     ↳ _elements[UncheckedConverter<TElement, long>.Default.Convert(node)];
112
113 }

```

## 1.12 ./csharp/Platform.Collections.Methods.Tests/TestExtensions.cs

```

1 using System;
2 using System.Collections.Generic;
3 using Xunit;

```

```

4 using Platform.Collections.Methods.Trees;
5 using Platform.Converters;
6
7 namespace Platform.Collections.Methods.Tests
8 {
9     public static class TestExtensions
10    {
11        public static void TestMultipleCreationsAndDeletions<TElement>(this
12            ↪ SizedBinaryTreeMethodsBase<TElement> tree, Func<TElement> allocate, Action<TElement>
13            ↪ free, ref TElement root, Func<TElement> treeCount, int maximumOperationsPerCycle)
14        {
15            for (var N = 1; N < maximumOperationsPerCycle; N++)
16            {
17                var currentCount = 0;
18                for (var i = 0; i < N; i++)
19                {
20                    var node = allocate();
21                    tree.Attach(ref root, node);
22                    currentCount++;
23                    Assert.Equal(currentCount, (int)UncheckedConverter<TElement,
24                        ↪ int>.Default.Convert(treeCount()));
25                }
26                for (var i = 1; i <= N; i++)
27                {
28                    TElement node = UncheckedConverter<int, TElement>.Default.Convert(i);
29                    if (tree.Contains(node, root))
30                    {
31                        tree.Detach(ref root, node);
32                        free(node);
33                        currentCount--;
34                        Assert.Equal(currentCount, (int)UncheckedConverter<TElement,
35                            ↪ int>.Default.Convert(treeCount()));
36                    }
37                }
38            }
39        }
40
41        public static void TestMultipleRandomCreationsAndDeletions<TElement>(this
42            ↪ SizedBinaryTreeMethodsBase<TElement> tree, ref TElement root, Func<TElement>
43            ↪ treeCount, int maximumOperationsPerCycle)
44        {
45            var random = new System.Random(0);
46            var added = new HashSet<TElement>();
47            var currentCount = 0;
48            for (var N = 1; N < maximumOperationsPerCycle; N++)
49            {
50                for (var i = 0; i < N; i++)
51                {
52                    var node = UncheckedConverter<int, TElement>.Default.Convert(random.Next(1,
53                        ↪ N));
54                    if (added.Add(node))
55                    {
56                        tree.Attach(ref root, node);
57                        currentCount++;
58                        Assert.Equal(currentCount, (int)UncheckedConverter<TElement,
59                            ↪ int>.Default.Convert(treeCount()));
60                    }
61                }
62                for (var i = 1; i <= N; i++)
63                {
64                    TElement node = UncheckedConverter<int,
65                        ↪ TElement>.Default.Convert(random.Next(1, N));
66                    if (tree.Contains(node, root))
67                    {
68                        tree.Detach(ref root, node);
69                        currentCount--;
70                        Assert.Equal(currentCount, (int)UncheckedConverter<TElement,
71                            ↪ int>.Default.Convert(treeCount()));
72                        added.Remove(node);
73                    }
74                }
75            }
76        }
77    }
78 }

```

## 1.13 ./csharp/Platform.Collections.Methods.Tests/TreesTests.cs

```

1  using Xunit;
2
3  namespace Platform.Collections.Methods.Tests
4  {
5      public static class TreesTests
6      {
7          private const int _n = 500;
8
9          [Fact]
10         public static void RecursionlessSizeBalancedTreeMultipleAttachAndDetachTest()
11         {
12             var recursionlessSizeBalancedTree = new RecursionlessSizeBalancedTree<uint>(10000);
13             recursionlessSizeBalancedTree.TestMultipleCreationsAndDeletions(recursionlessSizeBal
14             ↪ ancedTree.Allocate, recursionlessSizeBalancedTree.Free, ref
15             ↪ recursionlessSizeBalancedTree.Root, () => recursionlessSizeBalancedTree.Count,
16             ↪ _n);
17         }
18
19         [Fact]
20         public static void SizeBalancedTreeMultipleAttachAndDetachTest()
21         {
22             var sizeBalancedTree = new SizeBalancedTree<uint>(10000);
23             sizeBalancedTree.TestMultipleCreationsAndDeletions(sizeBalancedTree.Allocate,
24             ↪ sizeBalancedTree.Free, ref sizeBalancedTree.Root, () => sizeBalancedTree.Count,
25             ↪ _n);
26         }
27
28         [Fact]
29         public static void SizedAndThreadedAVLBalancedTreeMultipleAttachAndDetachTest()
30         {
31             var avlTree = new SizedAndThreadedAVLBalancedTree<uint>(10000);
32             avlTree.TestMultipleCreationsAndDeletions(avlTree.Allocate, avlTree.Free, ref
33             ↪ avlTree.Root, () => avlTree.Count, _n);
34         }
35
36         [Fact]
37         public static void RecursionlessSizeBalancedTreeMultipleRandomAttachAndDetachTest()
38         {
39             var recursionlessSizeBalancedTree = new RecursionlessSizeBalancedTree<uint>(10000);
40             recursionlessSizeBalancedTree.TestMultipleRandomCreationsAndDeletions(ref
41             ↪ recursionlessSizeBalancedTree.Root, () => recursionlessSizeBalancedTree.Count,
42             ↪ _n);
43         }
44
45         [Fact]
46         public static void SizeBalancedTreeMultipleRandomAttachAndDetachTest()
47         {
48             var sizeBalancedTree = new SizeBalancedTree<uint>(10000);
49             sizeBalancedTree.TestMultipleRandomCreationsAndDeletions(ref sizeBalancedTree.Root,
50             ↪ () => sizeBalancedTree.Count, _n);
51         }
52
53         [Fact]
54         public static void SizedAndThreadedAVLBalancedTreeMultipleRandomAttachAndDetachTest()
55         {
56             var avlTree = new SizedAndThreadedAVLBalancedTree<uint>(10000);
57             avlTree.TestMultipleRandomCreationsAndDeletions(ref avlTree.Root, () =>
58             ↪ avlTree.Count, _n);
59         }
60     }
61 }

```

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