Dynamic Symbolic Data Structure Repair

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Why Data Structure Repair is important

- All software use some sort of data structure underneath.
- Data structure corruption might result into software crash
- User intervention might not be an option for corruption repair, e.g., real time systems.

Goal:

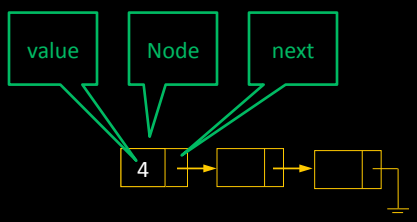
- Automatically repair data structures to prevent software crash.
- Perform such repair actions effectively and in a time efficient manner. Cannot wait forever!

Example: Single linked list

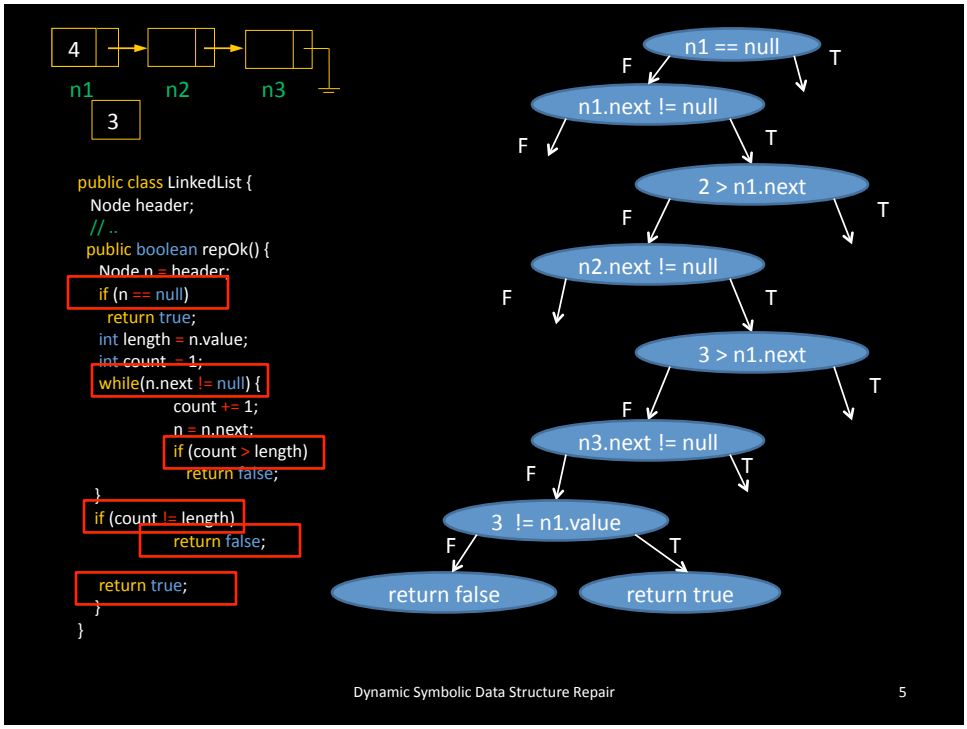
```
public class LinkedList {
  Node header;
  // ..
  public boolean repOk() {
    Node n = header;
    if (n == null)
      return true;
    int length = n.value;
    int count  = 1;
    while(n.next != null) {
            count += 1;
            n = n.next;
            if (count > length)
              return false;
    }
    if (count != length)
            return false;

    return true;
    }
}
```

```
public class Node {
   int value;
   Node next;
   // ..
}
```



First node has a value that is equal to the number of nodes in the list.



Our approach to the problem:

```
public class LinkedList {
  Node header;
  // ..
 public boolean repOk() {
   Node n = header;
   if (n == null)
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   int length = n.value;
   int count  = 1;
   while(n.next != null) {
            count += 1;
            n = n.next;
            if (count > length)
              return false;
   }
   if (count != length)
            return false;

   return true;
  }
}
```
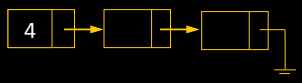

```
public class Node {
  int value;
  Node next;
  // ..
}
```

n1 n2 n3



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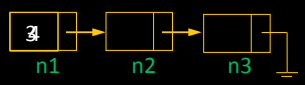
   int count  = 1;
   while(n.next != null) {
            count += 1;
            n = n.next;
            if (count > length)
              return false;
   }
   if (count != length)
            return false;

   return true;
   }
}
```

```
public class Node {
   int value;
   Node next;
   // ..
}
```



First node has a value that is equal to the number of nodes in the list.

Constraints:

```
n1 != null
n1.next != null
2 <= n1.value
n2.next != null
3 <= n1.value
n3.next == null
3!= n1.value    3 == n1.value
```

Solve

3 = n1.value

Existing state of the art tool: Juzi

Few facts about Juzi:

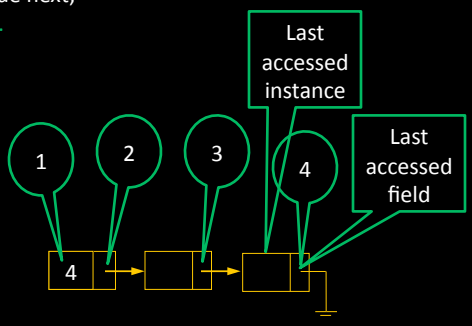
- Developed by Bassem Elkarablieh and Sarfaraz Khurshid of University of Texas at Austin.
  - http://users.ece.utexas.edu/~elkarabl/Juzi/index.html
- Assumes last instance and field accessed before returning are corrupt.
- Uses constraint solving techniques for primitive fields.
- Uses exhaustive search technique for reference fields.
- Does not suggest new instances of classes.

Juzi's approach in solving our example problem:

```
public class LinkedList {
  Node header;
  // ..
 public boolean repOk() {
   Node n = header;
   if (n == null)
     return true;
   int length = n.value;
   int count  = 1;
   while(n.next != null) {
            count += 1;
            n = n.next;
            if (count > length)
              return false;
   }
   if (count != length)
            return false;

   return true;
   }
}
```

```
public class Node {
   int value;
   Node next;
   // ..
}
```



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   while(n.next != null) {
            count += 1;
            n = n.next;
            if (count > length)
              return false;
   }
   if (count != length)
            return false;

   return true;
   }
}
```
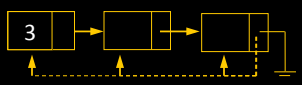
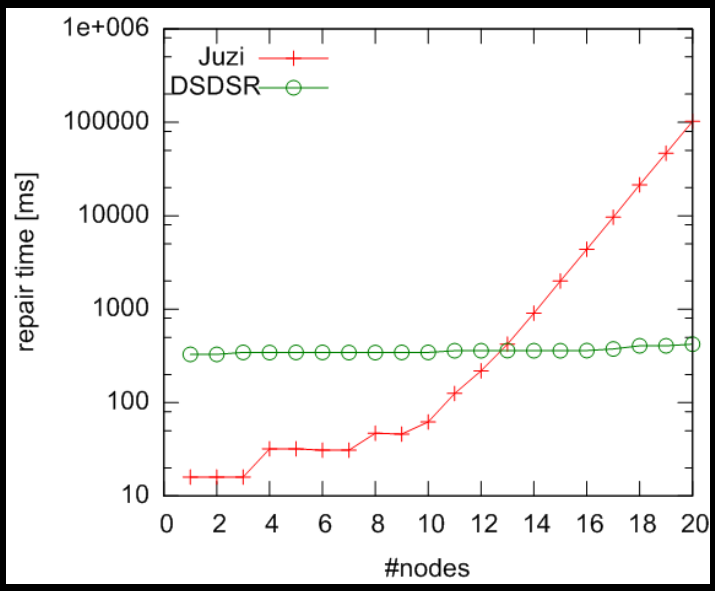

```
public class Node {
   int value;
   Node next;
   // ..
}
```



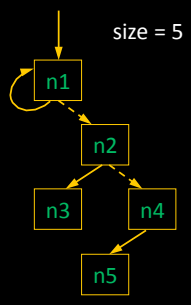
First node has a value that is equal to the number of nodes in the list.

Performance of Juzi and DSDSR for linkedlist



Another example: Binary tree

```
public boolean repOk() {
    boolean result = true;  // An empty tree == zero in size
   if (root == null){
      if (size  != 0)
          result = false;
       return result;
   }
   // ...
    while (!workList.isEmpty()) {
       Node current = workList.removeFirst();
       if (current.left != null) {     // no cycles along left
           if (!visited.add(current.left)) {
               result =  false;
           } else
               workList.add(current.left);
       }
       if (current.right != null) {  // no cycles along right
           if (!visited.add(current.right)) {
               result =  false;
           } else
               workList.add(current.right);
       }
    }
      if (visited.size() != size)  // size == #visited nodes
         result = false;

     return result;
   }
}
```



- Acyclic along left and right pointers.
- Cannot share nodes.
- #nodes reachable from root along left and right fields is stored in the size field.

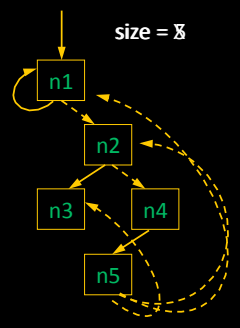
Another example: Binary tree

Observations:

- Defining correctness properties are hard.
- Writing a correctness condition that checks correctly, easy to read and meets repair specific style – is even harder.
- Juzi requires specific style in correctness condition, namely, last accessed field and instance should be the actual corrupt ones.

Binary tree: modified repOk - Juzi

```
public boolean repOk() {
   boolean result = true; // An empty tree == zero in size
   if (root == null){
      if (size  != 0)
         result = false;
      return result;
   }
   // ...
    while (!workList.isEmpty()) {
        Node current = workList.removeFirst();
        if (current.left != null) {     // no cycles along left
            if (!visited.add(current.left)) {
                result =  false;
            } else
                workList.add(current.left);
        }
        if (current.right != null) {  // no cycles along right
            if (!visited.add(current.right)) {
                result =  false;
            } else
                workList.add(current.right);
        }
    }
      if (visited.size() != size)  // size == #visited nodes
         result = false;

    return result;
   }
}
```



- Acyclic along left and right pointers.
- Cannot share nodes.
- #nodes reachable from root along left and right fields is stored in the size field.

Binary tree: modified repOk - DSDSR

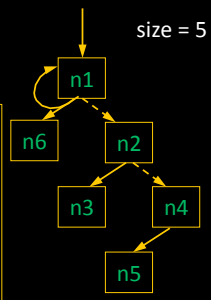
```
public boolean repOk() {
    boolean result = true;   // An empty tree == zero in size
   if (root == null){
     if (size  != 0)
        result = false;
      return result;
   }
   // ...
    while (!workList.isEmpty()) {
       Node current = workList.removeFirst();
       if (current.left != null) {     // no cycles along left
           if (!visited.add(current.left)) {
               result =  false;
           } else
               workList.add(current.left);
       }
       if (current.right != null) {  // no cycles along right
           if (!visited.add(current.right)) {
               result =  false;
           } else
               workList.add(current.right);
       }
    }
     if (visited.size() != size)  // size == #visited nodes
        result = false;

    return result;
   }
}
```

Constraints:

n1 != null
n1.left != null
~~n1.left == n1~~ n1.left != n1
n1.right != null
~~n1.right != n1~~
n2.left != null
n2.left != n1
n2.left != n2
...
5 == size

Solve

n1.left = new_Node



Binary tree: modified repOk

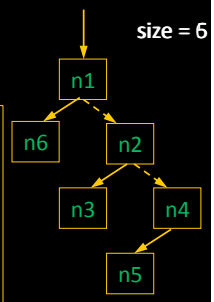
```
public boolean repOk() {
    boolean result = true;   // An empty tree == zero in size
   if (root == null){
     if (size  != 0)
        result = false;
      return result;
   }
   // ...
    while (!workList.isEmpty()) {
       Node current = workList.removeFirst();
       if (current.left != null) {     // no cycles along left
           if (!visited.add(current.left)) {
               result =  false;
           } else
               workList.add(current.left);
       }
       if (current.right != null) {  // no cycles along right
           if (!visited.add(current.right)) {
               result =  false;
           } else
               workList.add(current.right);
       }
    }
     if (visited.size() != size)  // size == #visited nodes
        result = false;

    return result;
   }
}
```

Constraints:

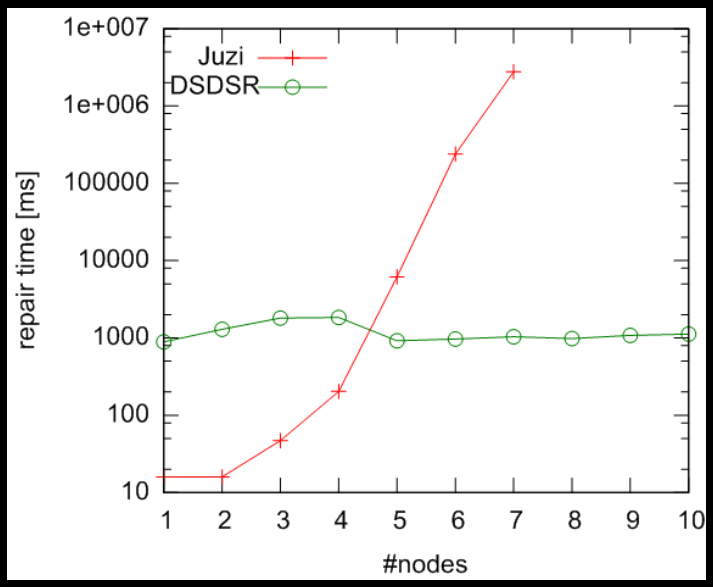
n1 != null
n1.left != null
n1.left != n1
n1.right != null
n1.right != n1
n1.right != n6
...
~~6 != size~~
6 == size

Solve

size = 6



Results (1): Juzi Vs. DSDSR, return late



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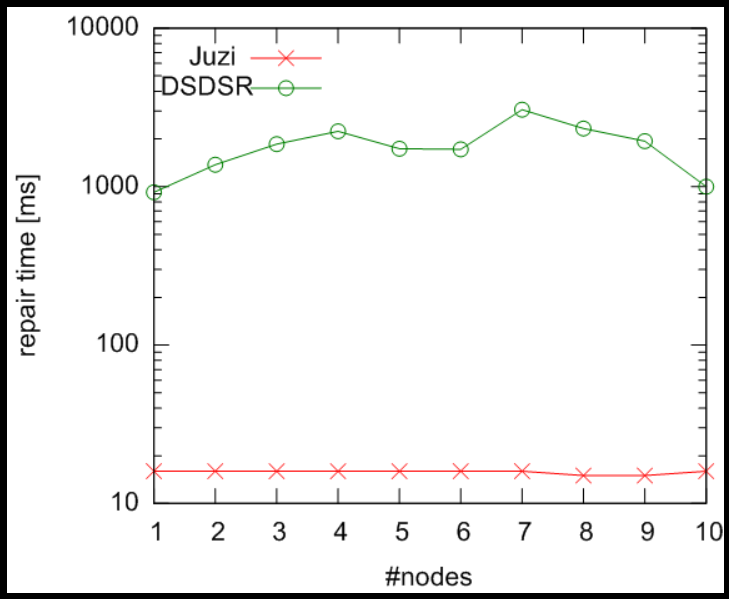
Results (2): Juzi Vs. DSDSR, return immediate



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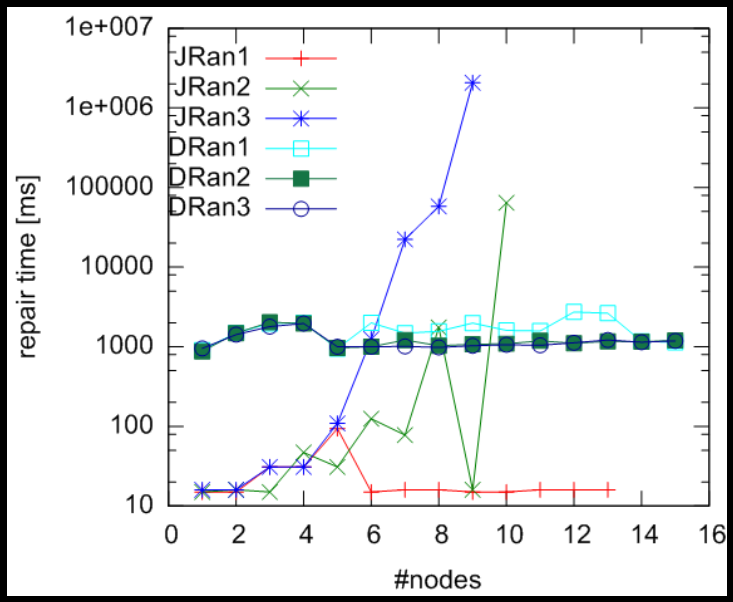
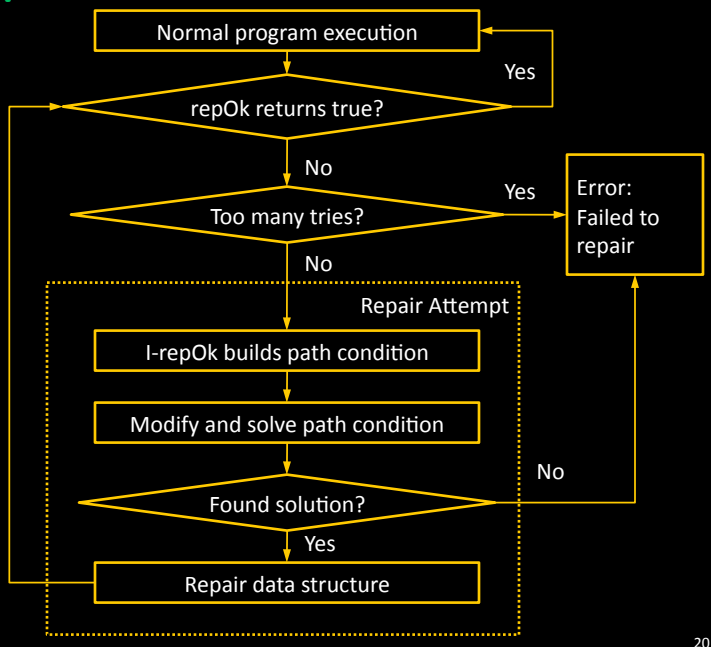
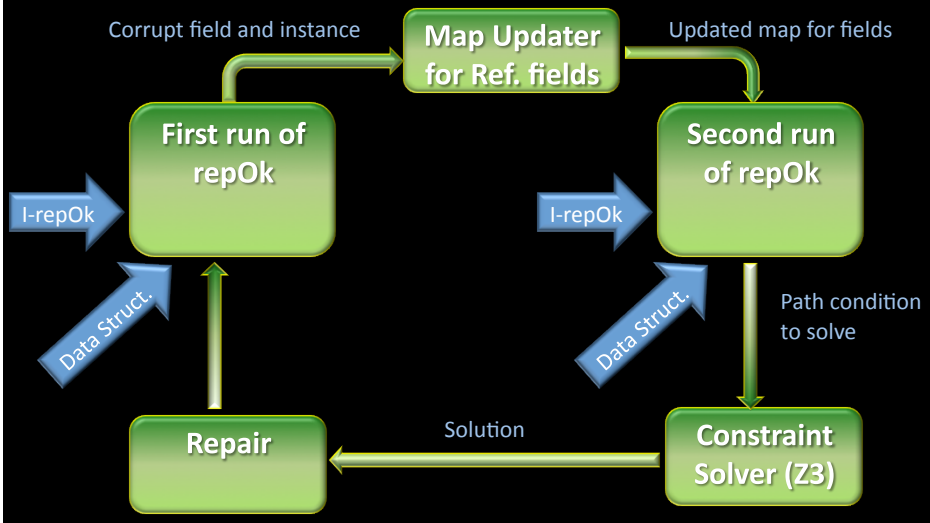
Results (3): Random



Algorithm:



Implementation:



Thank you!

We specially thank **Bassem Elkarablieh** and Sarfaraz Khurshid for helping us with Juzi.