Verifying the Rope Data Structure of Xi-Editor

Anna Scholtz

26. November 2018

Outline

Motivation

Goal and Motivation

- **Motivation:** Need for good text editors
  - Xi-editor: combines newer concepts for storing text to allow very high performance
  - Core idea: modified rope data structure for storing text as well as edit history
- **Goal:** Verification of the rope data structure in xi-editor

Background

Xi-Editor

xi-editor / xi-editor

Unwatch 517 | Unstar 15,209 | Fork 560

Code | Issues 121 | Pull requests 13 | Projects 0 | Insights

A modern editor with a backend written in Rust. https://xi-editor.github.io/xi-editor

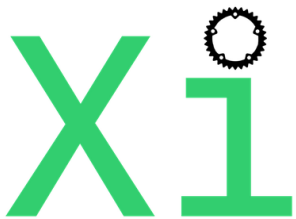
1,759 commits | 7 branches | 1 release | 1 environment | 113 contributors | Apache-2.0

Branch: master | New pull request | Create new file | Upload files | Find file | Clone or download

ThisisGurwinder and cmyr Fixing casting error from u32 to u64 (#997) ... Latest commit 96288fb 18 hours ago

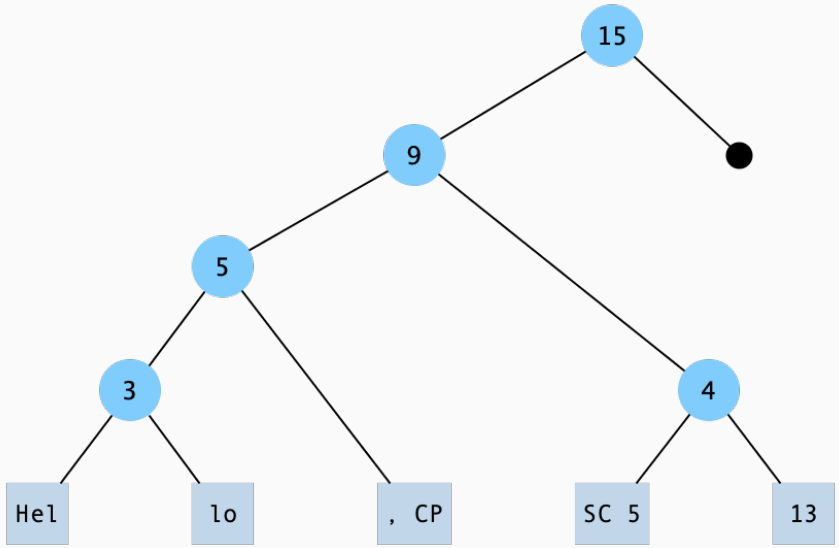
.github	Update CONTRIBUTING.MD	a day ago
doc	Update copyright messages to xi-editor	3 months ago
docs	Replace references to IRC with Zulip	9 days ago
icons	Add App Icon	3 years ago
python	Update copyright messages to xi-editor	3 months ago
rust	Fixing casting error from u32 to u64 (#997)	18 hours ago
.cirrus.yml	Update cirrusCI macOS image	16 days ago
.gitignore	Added python plugin library	2 years ago
.travis.yml	Add clippy check to CI	21 days ago
AUTHORS	Autodetect whitespace & line ending settings	2 months ago
CODE_OF_CONDUCT.md	Don't remove _all_ mentions of IRC and simplify some terminology	9 days ago
LICENSE	Rename project to xi-editor; add license info	3 years ago
README.md	Don't remove _all_ mentions of IRC and simplify some terminology	9 days ago

README.md



Rope Data Structures

- Binary Tree
- Only leaves contain text
- Operations: Index, Split, Concatenate, Report, Insert, Delete



Hello, CPSC 513

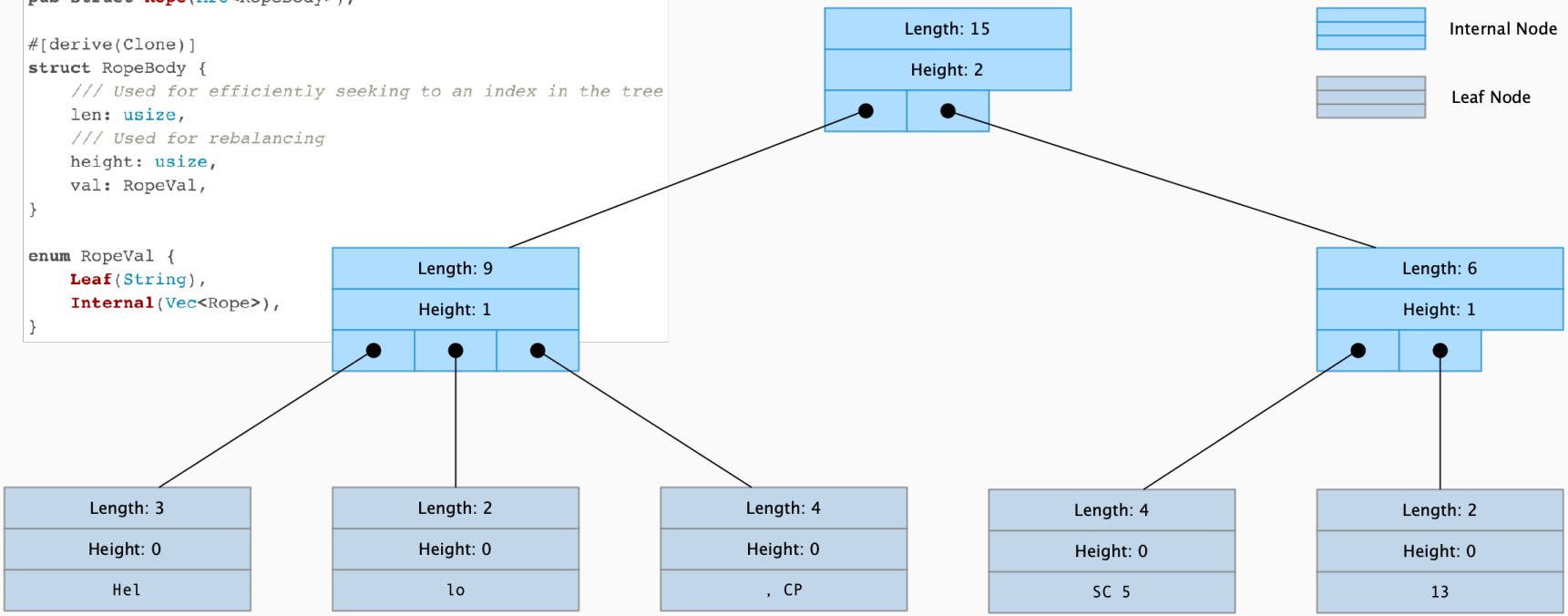
Rope Data Structure in Xi-Editor

- B-Tree
- Operations: Concatenate, Slice, Insert, SliceToString

```rust
pub struct Rope(Arc<RopeBody>);

#[derive(Clone)]
struct RopeBody {
    /// Used for efficiently seeking to an index in the tree
    len: usize,
    /// Used for rebalancing
    height: usize,
    val: RopeVal,
}

enum RopeVal {
    Leaf(String),
    Internal(Vec<Rope>),
}
```



Hello, CPSC 513

https://github.com/xi-editor/xi-editor/blob/master/rust/rope/src/tree.rs

Verifying Ropes

Verifying Ropes

- **Goal:**
  - Define properties of ropes
  - Verify that after applying operations, these properties still hold
  - Verify that this also works for distributed ropes (collaborative editing)
- Approach: first verify standard rope data structure (simpler), then verify rope data structure of xi-editor

Dafny

- Language and verifier
- Supports verification through pre-conditions, post-conditions, loop invariants, ...
- Dafny programs are translated into Boogie 2 which is used to generate first-order verification conditions that are passed to the SMT solver Z3

```
method Add(x: int, y: int) returns (r: int)
  requires 0 <= x && 0 <= y
  ensures r == 2*x + y
{
  r := x;
  var n := y;
  while n != 0
    invariant r == x+y-n && 0 <= n
  {
    r := r + 1;
    n := n - 1;
  }
}
```

Properties Standard Rope

1. Every node has at most two children
2. Only leaves contain data
3. Weight values of non-leaf nodes is the length of all children in the left subtree
4. Weight values of leaf nodes is the length of the stored text

Standard Rope Verification

Rope Data Structure:

```
datatype Node = Leaf(value: string) | InternalNode(left: Rope?, right: Rope?)

class Rope {
  ghost var Repr: set<object>   // contains all elements that are in the tree

  var len: int    // length
  var val: Node   // node value
```

Validity Conditions:

```
predicate Valid()
  reads this, Repr
{
  this in Repr &&
  (
    match this.val
    case Leaf(v) => true
    case InternalNode(left, right) =>
      (left != null ==>
        left in this.Repr && this.Repr >= left.Repr && this !in left.Repr && left.Valid()
      ) &&
      (right != null ==>
        right in this.Repr && this.Repr >= right.Repr && this !in right.Repr && right.Valid()
      )
  )
}
```

Standard Rope Verification

Validity Conditions:

```
predicate ValidLen()
  requires Valid()
  reads this, Repr
{
  match this.val
  case Leaf(v) => this.len == |v|
  case InternalNode(left, right) =>
    (left != null ==> this.len == left.Len() && left.ValidLen()) &&
    (left == null ==> this.len == 0) &&
    (right != null ==> right.ValidLen())
}
```

Standard Rope Verification

Implemented Methods:

```
method Index(i: int) returns (charAtIndex: string)
  requires Valid()
  requires ValidLen()
  ensures i >= 0 && this.Len() > i ==> charAtIndex != ""
  decreases Repr
{
```

```
method Insert(i: int, s: string) returns (newRope: Rope?)
  requires Valid()
  requires ValidLen()
  ensures Valid()
  ensures ValidLen()
  ensures newRope != null ==> newRope.Valid()
  ensures newRope != null ==> newRope.ValidLen()
  ensures i < 0 || i >= this.Len() <==> newRope == null
{
```

```
method Concat(rope: Rope) returns (concatenatedRope: Rope)
  requires Valid()
  requires ValidLen()
  requires rope.Valid()
  requires rope.ValidLen()
  ensures concatenatedRope.Valid()
  ensures concatenatedRope.ValidLen()
{
```

Properties Xi-Editor Rope

1. Every node has at most *MAX_CHILDREN* children
2. Every non-leaf node, except the root node, has at least *MIN_CHILDREN* child nodes
3. The root has at least two children if it is not a leaf node
4. Only leaves contain data
5. The length of the text stored in leaf nodes is at most *MAX_LEAF*
6. Weight values of non-leaf nodes is the sum of the children's weights
7. Weight values of leaf nodes is the length of the stored text
8. All leaves appear in the same level

Xi-Editor Rope Verification

Rope Data Structure:

```
datatype Node = Leaf(value: string) | InternalNode(children: seq<Rope>)

class Rope {
  ghost var Repr: set<Rope>
  ghost var Content: seq<string>

  var val: Node
  var len: int
  var height: int

  constructor Init()
    ensures Valid()
    ensures ValidLen()
  {
    val := Leaf("");
    len := 0;
    height := 0;
    Repr := {this};
    Content := [""];
  }
```

Xi-Editor Rope Verification

Validity Conditions:

```
predicate Valid()
  reads this, Repr
  requires MAX_LEAF_LEN >= MIN_LEAF_LEN
  requires MIN_CHILDREN <= MAX_CHILDREN && MIN_CHILDREN >= 2
{
  this in Repr &&
  (
    match this.val
    case Leaf(v) => |v| <= MAX_LEAF_LEN && Content == [v] && height == 0
    case InternalNode(children) =>
      height >= 0 &&
      |children| >= 2 &&
      |children| <= MAX_CHILDREN &&
      forall c: Rope :: c in children ==>
        c in Repr && this !in c.Repr && c.Repr < Repr &&
        c.ValidNonRoot() && c.height == height - 1 && |c.Content| <= |Content| &&
        forall cont: string :: cont in c.Content ==> cont in this.Content
  )
}
```

Xi-Editor Rope Verification

Validity Conditions:

```
predicate ValidNonRoot()
  reads this, Repr
  requires MAX_LEAF_LEN >= MIN_LEAF_LEN
  requires MIN_CHILDREN <= MAX_CHILDREN && MIN_CHILDREN >= 2
{
  this in Repr &&
  (
    match this.val
    case Leaf(v) => |v| <= MAX_LEAF_LEN && Content == [v] && height == 0
    case InternalNode(children) =>
      height >= 0 &&
      |children| >= MIN_CHILDREN &&
      |children| <= MAX_CHILDREN &&
      forall c: Rope :: c in children ==>
        c in Repr && this !in c.Repr && c.Repr < Repr && c.ValidNonRoot() &&
        c.height == height - 1 && |c.Content| <= |Content| &&
        forall cont: string :: cont in c.Content ==> cont in this.Content
  )
}
```

Xi-Editor Rope Verification

Validity Conditions:

```
predicate ValidLen()
  requires Valid()
  reads this, Repr
{
  match this.val
  case Leaf(v) =>
    this.len == |v| && ContentLen(this.Content) == |v| && |Content| == 1
  case InternalNode(children) =>
    this.len >= 0 && forall c: Rope :: c in children ==>
      c.len <= this.len && c.ValidLen()
}
```

Xi-Editor Rope Verification

Implemented Methods (work in progress):

```
method Index(i: int) returns (charAtIndex: string)
  requires Valid()
  requires ValidLen()
  ensures i < 0 || i >= this.len ==> charAtIndex == ""
  decreases Repr
{
```

```
method SliceToString(i: int, j: int) returns (slice: string)
  requires Valid()
  requires ValidLen()
  ensures i < 0 || i >= this.len || j >= this.len || i > j || j < 0 ==> slice == ""
  decreases Repr
{
```

Future Work

Future Work

- Implement remaining methods for xi-editor rope
- Implement transactions and verify that properties hold in a collaborative environment (out-of-scope)
- Verify other parts of xi-editor (very much out-of-scope)