A Program Logic for Tree Borrows

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References Forbid Aliasing

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fn foo(a: &mut i32) {
    let x = *a;
    *a = 42;
    bar();
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```

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Correctness: `bar()` can not access `a`,
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Unsafe Code Can Create Aliasing References

```
fn foo(a: &mut i32) { .. }

static mut GLOBAL: i32 = 0;
fn bar() {
    unsafe { println!("{}", &GLOBAL); }
}
fn main() {
    let a = unsafe { &mut GLOBAL };
    foo(a);
}
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Without optimizations:

$\leadsto 42$

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Without optimizations:

$\rightsquigarrow 42$

With optimizations:

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Why Is This Optimization Legal?

Idea: Declare that our `unsafe` code is wrong!

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Stacked Borrows: An Aliasing Model for Rust

RALF JUNG, Mozilla, USA and MPI-SWS, Germany
HOANG-HAI DANG, MPI-SWS, Germany
JEEHOON KANG, KAIST, Korea
DEREK DREYER, MPI-SWS, Germany

Type systems are useful not just for the safety guarantees they provide, but also for helping compilers generate more efficient code by simplifying important program analyses. In Rust, the type system imposes a strict

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Tree Borrows

NEVEN VILLANI*, Univ. Grenoble Alpes, CNRS, Grenoble INP (Institute of Engineering), France
JOHANNES HOSTERT*, ETH Zurich, Switzerland
DEREK DREYER, MPI-SWS, Germany
RALF JUNG†, ETH Zurich, Switzerland

The Rust programming language is well known for its ownership-based type system, which offers strong guarantees like memory safety and data race freedom. However, Rust also provides *unsafe* escape hatches, for which safety is not guaranteed automatically and must instead be manually upheld by the programmer.

What is Tree Borrows?

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Wrongly aliased references are defined to **have UB**!

change Operational Semantics

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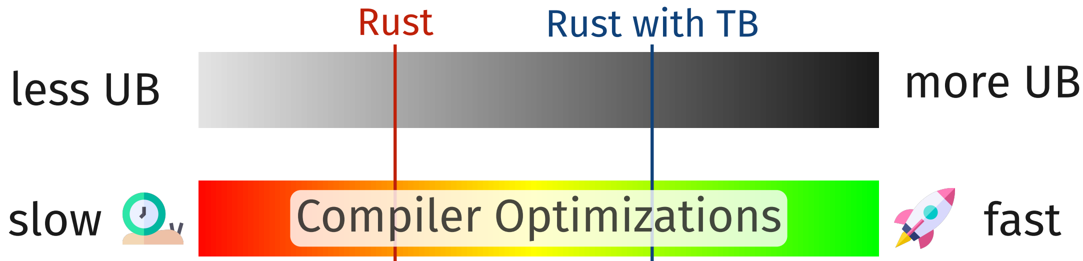

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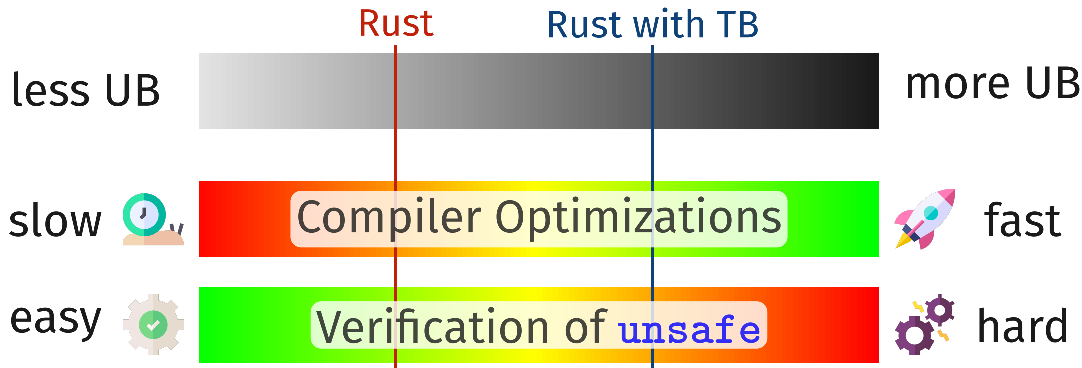

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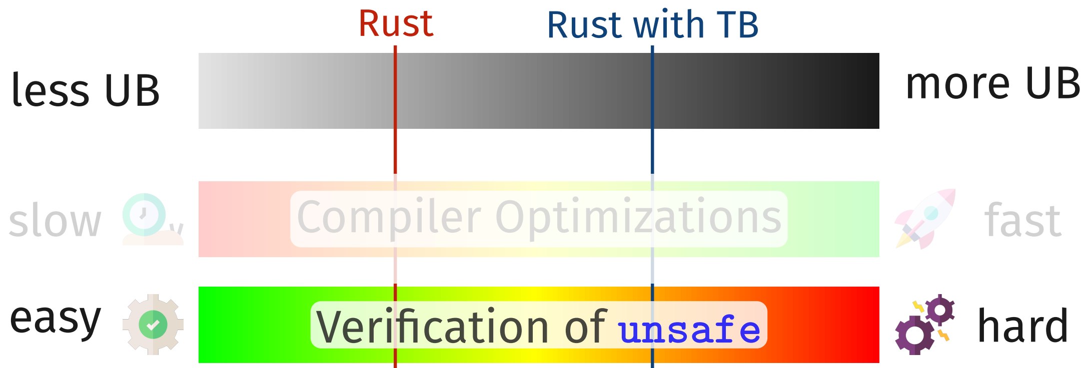

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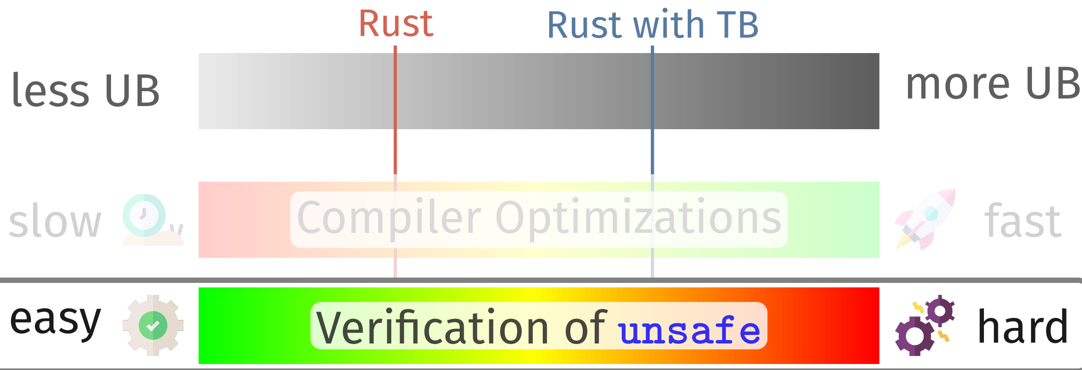

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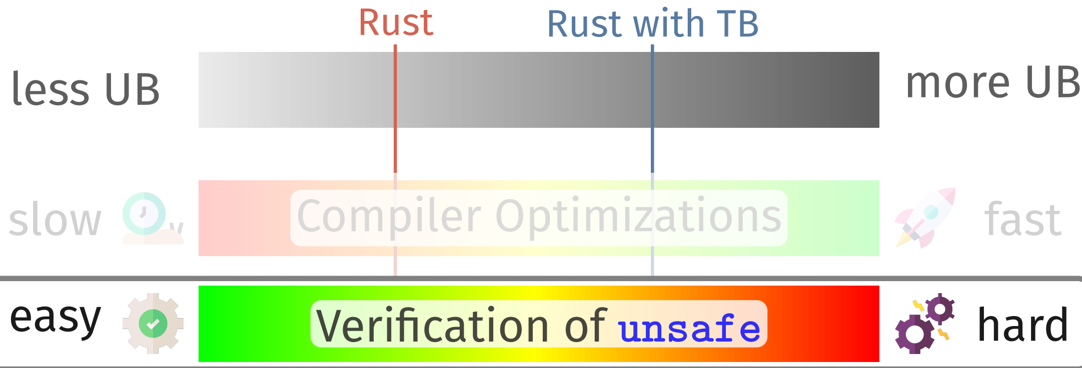

Putting The Borrows Into Trees

Tree Borrows tracks references in a tree data structure:

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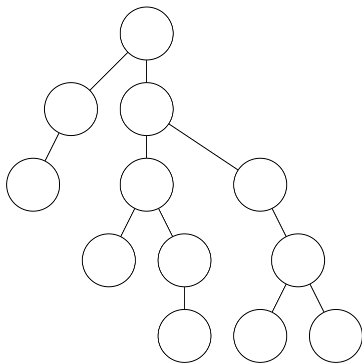

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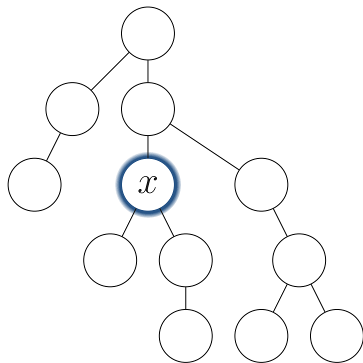

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One tree for each memory location.

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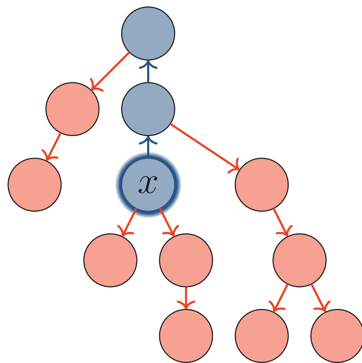

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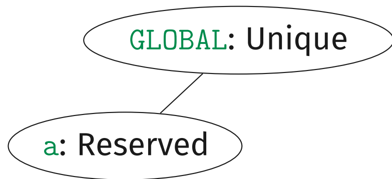

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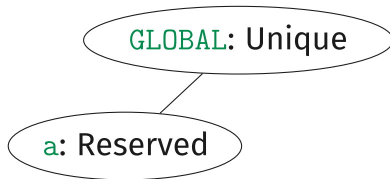

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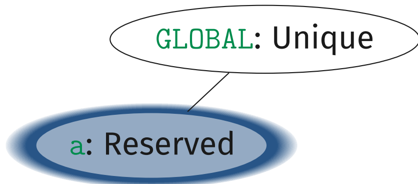

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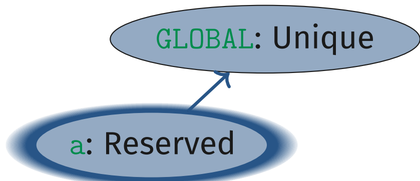

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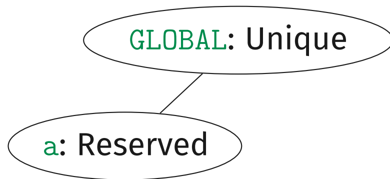

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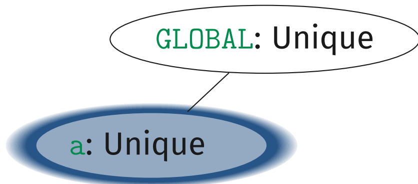

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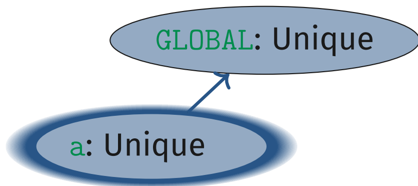

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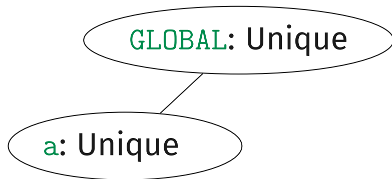

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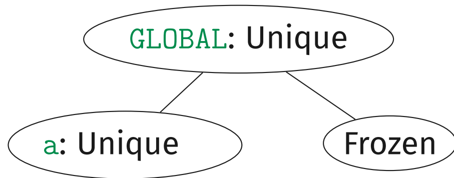

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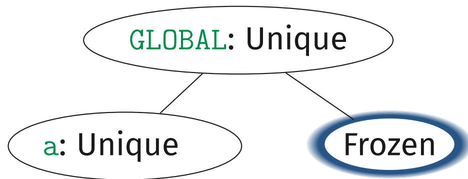

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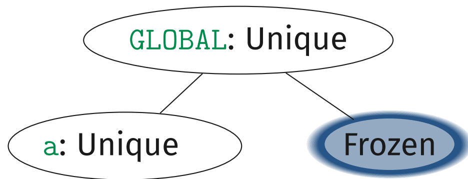

Frozen + ↑R → Frozen

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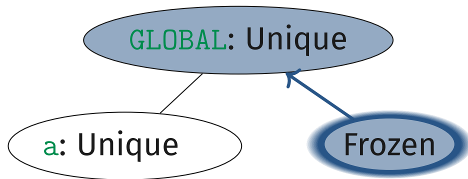

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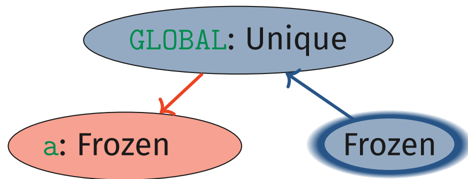

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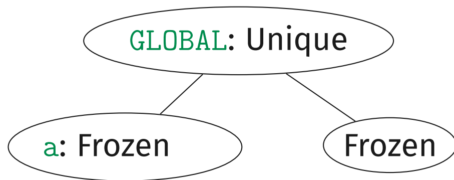

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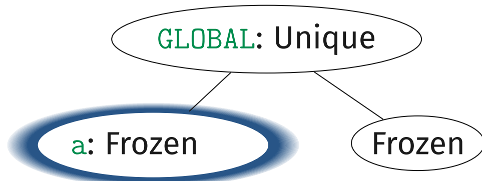

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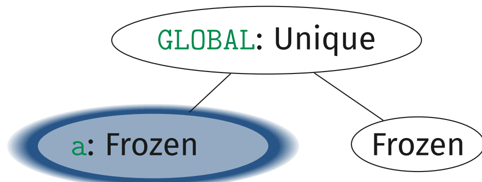

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Each Node is a State Machine

States represent permissions to read or write.

Every access causes transitions at every node, based on

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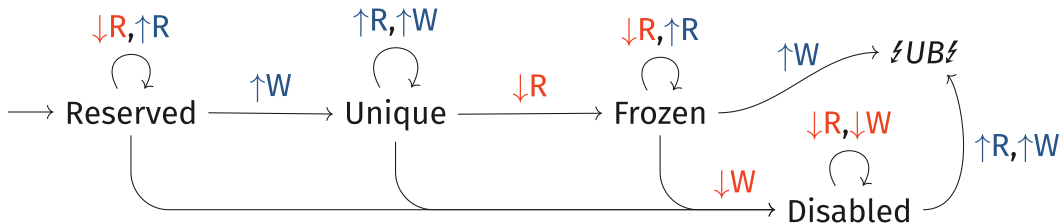

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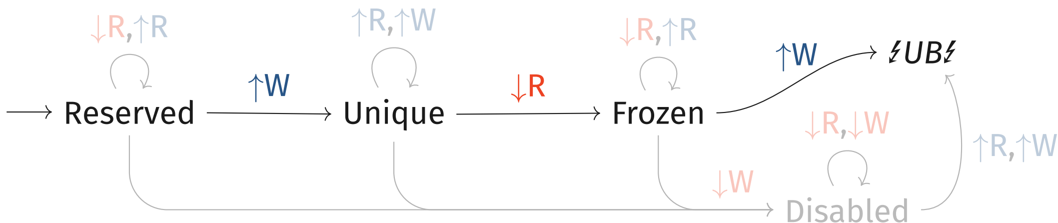

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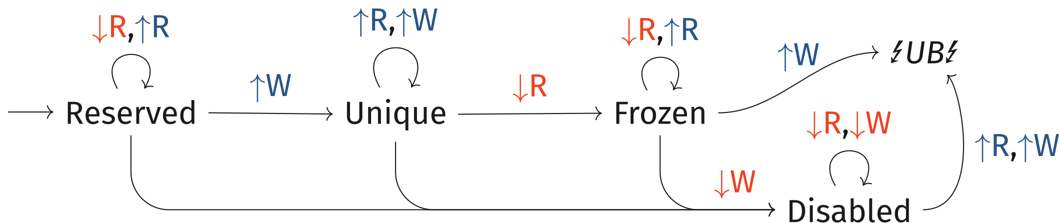

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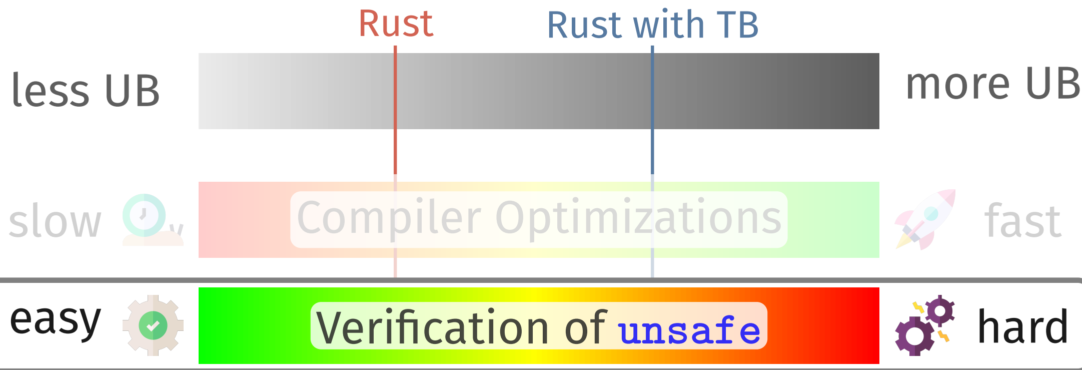

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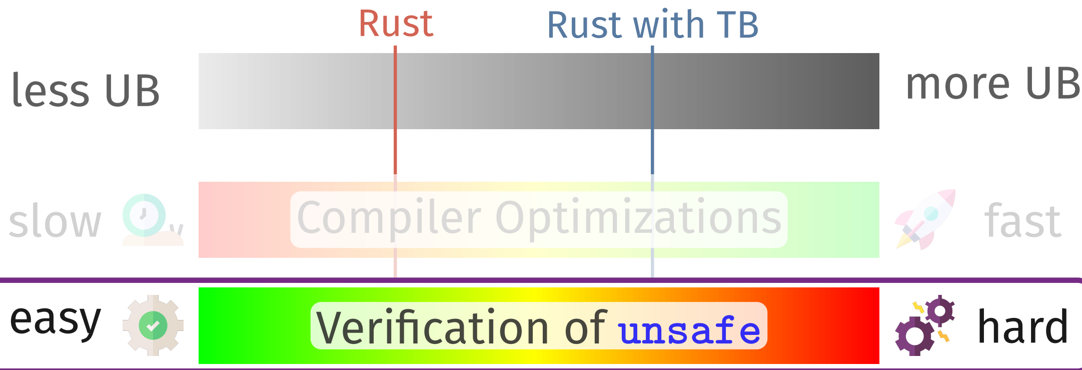

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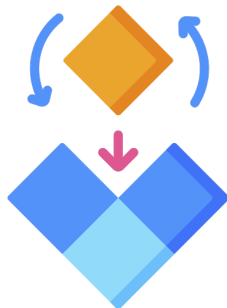


Modular Reasoning

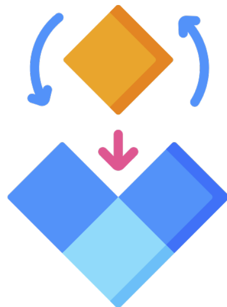
The Solution: A Program Logic for Tree Borrows

Theory at the Foundation of `unsafe` Verification Tools

Prusti, GillianRust, Verifast, Verus, ...

Separation Logic

Full Tree Details



Modular Reasoning

A (Classical) Separation Logic Refresher

$\ell \mapsto v$ Location ℓ stores value v, *exclusive ownership*

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$$\forall z_1, z_2. \{x \mapsto z_1 * y \mapsto z_2\}$$

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fn swap(x: &mut i32, y: &mut i32) {..}
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$$\{x \mapsto z_2 * y \mapsto z_1\}$$

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$$\forall z_1, z_2. \{x \mapsto z_1 * y \mapsto z_2\} \qquad \Longrightarrow x \neq y$$

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$\forall z_1, z_2. \{x \mapsto z_1 * y \mapsto z_2\}$ $\implies x \neq y$

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fn swap(x: &mut i32, y: &mut i32) {..}
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$\{x \mapsto z_2 * y \mapsto z_1\}$ $\implies$ all other state untouched

A (Classical) Separation Logic Refresher

??	Describes the Tree Borrows state
$\ell \mapsto v$	Location ℓ stores value v, *exclusive ownership*
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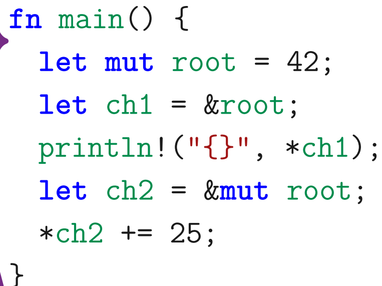
Resources in Action

```rust
fn main() {
  let mut root = 42;
  let ch1 = &root;
  println!("{}", *ch1);
  let ch2 = &mut root;
  *ch2 += 25;
}
```

Resources in Action



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$|\texttt{root}| \mapsto 42 *$ root: Unique

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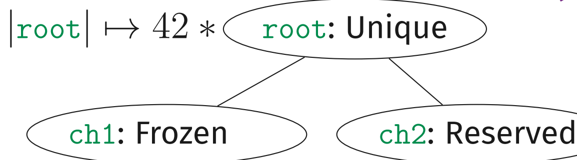

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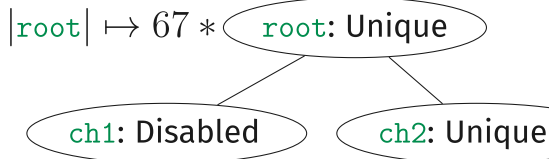

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}
```

```
fn incr(r : &mut i32) {
  *r += 25;
}
```

$|\texttt{root}| \mapsto 67 \ast$ root: Unique

ch1: Disabled

ch2: Unique

Abstraction

```
fn main() {
  let mut root = 42;
  let ch1 = &root;
  println!("{}", *ch1);
  let ch2 = &mut root;
  incr(ch2);
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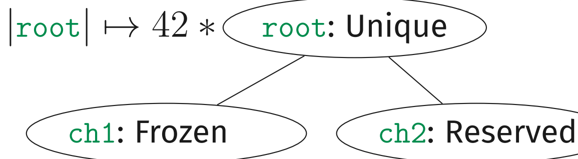

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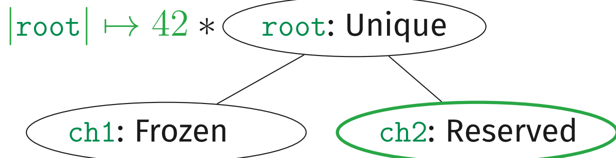

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$|\texttt{root}| \mapsto 42 *$ root: Unique

ch1: Frozen

ch2: ———

$\{|\texttt{r}| \mapsto 42 *$ ch2: Reserved $\}$

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Abstraction

```
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fn incr(r : &mut i32) {
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$\{|\texttt{r}| \mapsto 67 * (\texttt{ch2}\text{: Unique})\}$

$|\texttt{root}| \mapsto 67 * (\texttt{root}\text{: Unique})$

ch1: Frozen

ch2: Unique

Abstraction

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$\{|r| \mapsto 42 *$ (ch2: Reserved) $\}$

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$\{|r| \mapsto 67 *$ (ch2: Unique) $\}$

$|root| \mapsto 42 *$ (root: Unique)

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Abstraction

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$|\texttt{root}| \mapsto 42 *$ root: Unique

ch1: Frozen

ch2:

↑W ↓-

↑W | ↓-

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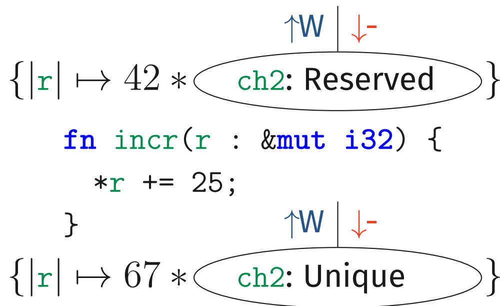

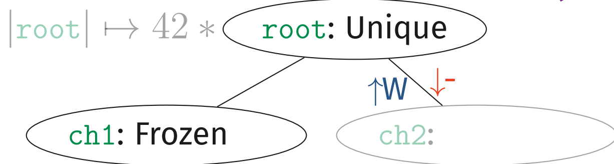

Protocol ↑W↓- imposes:

- ch2 can write
- Others may not access

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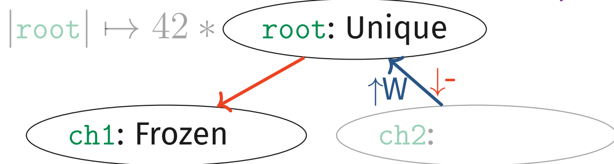

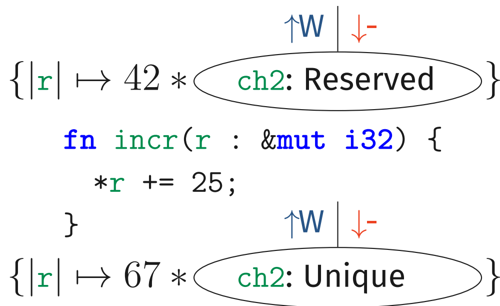

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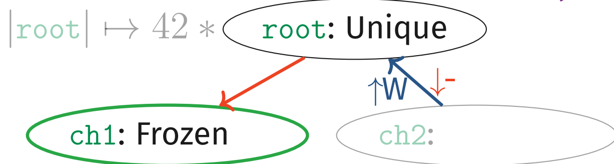

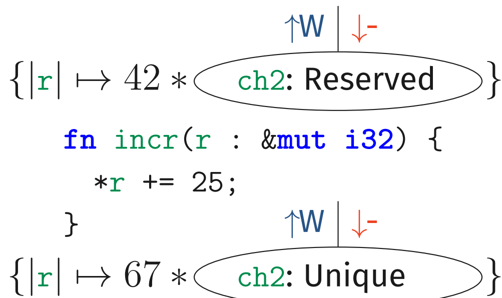

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↑W | ↓-

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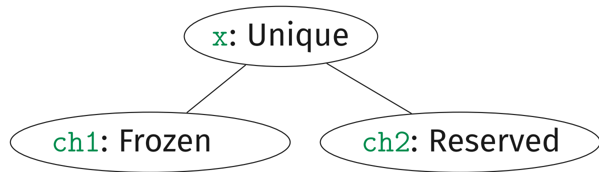

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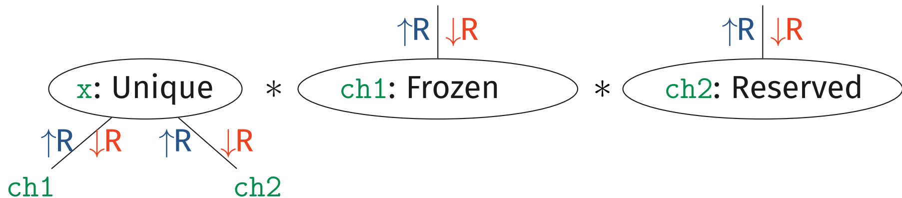

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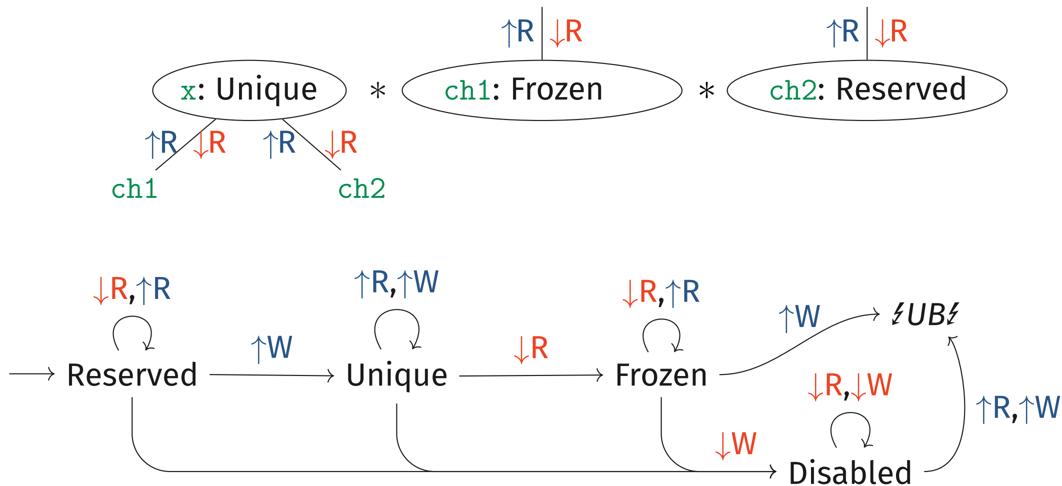

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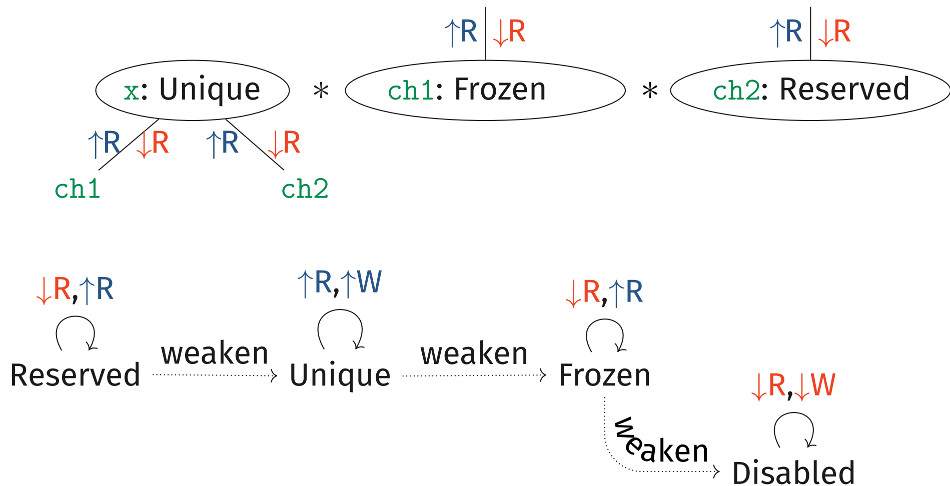

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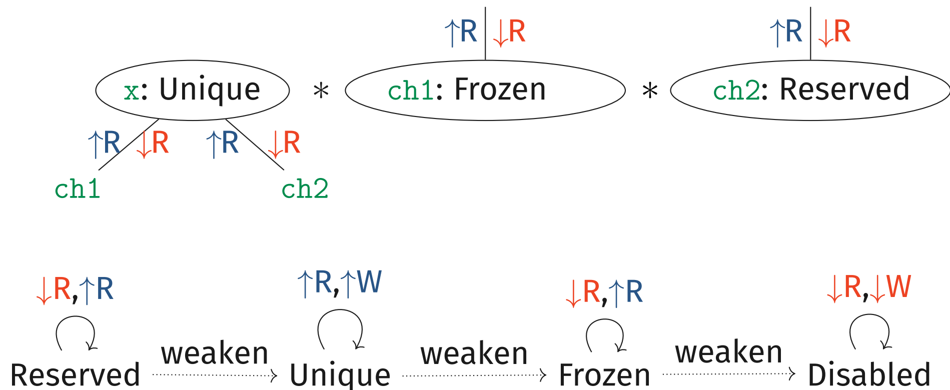

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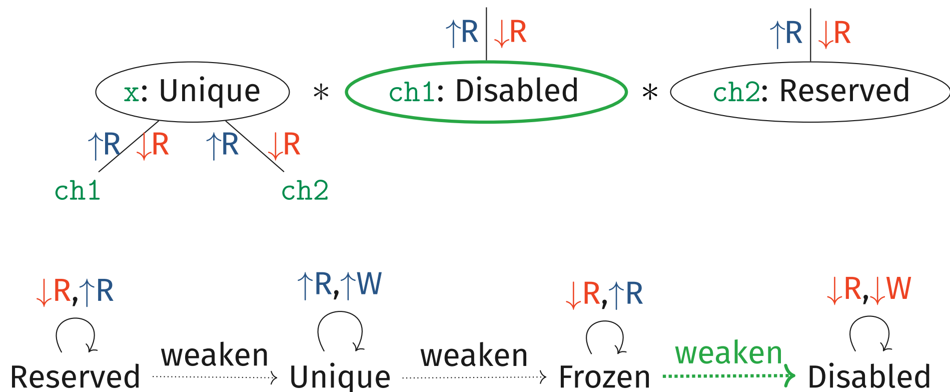

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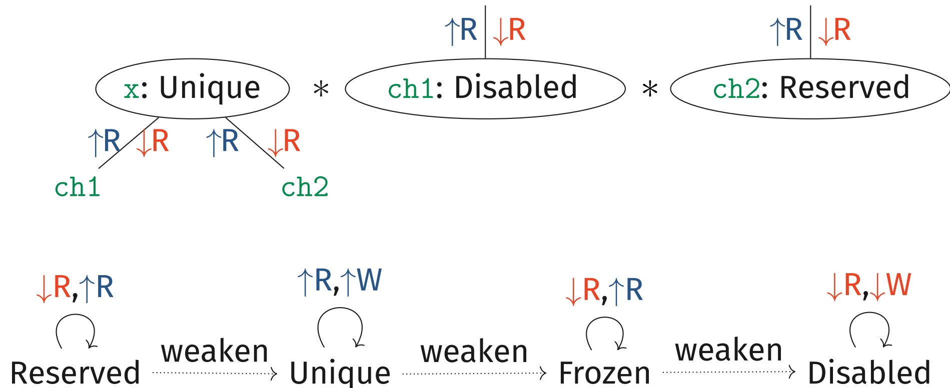
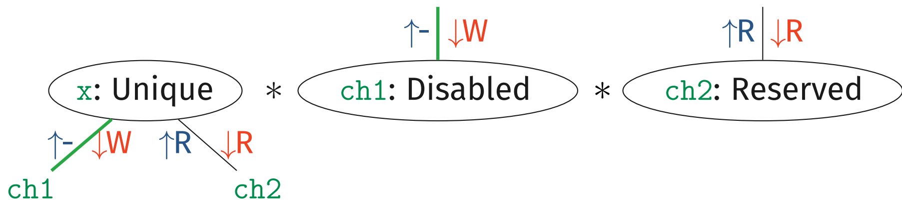
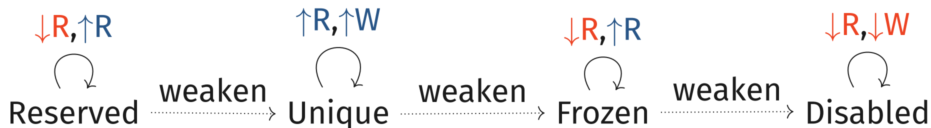


Protocol Compatibility: Nothing (-) $\leq$ Read $\leq$ Write

Protocols + Invariance = Local Reasoning





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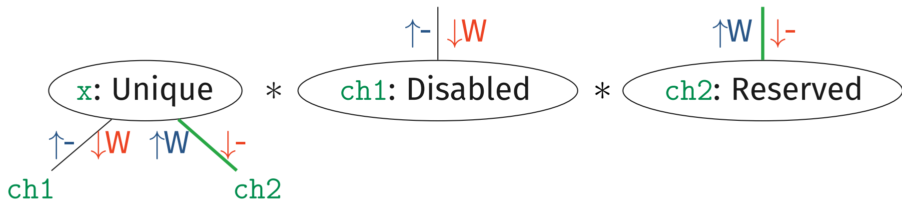

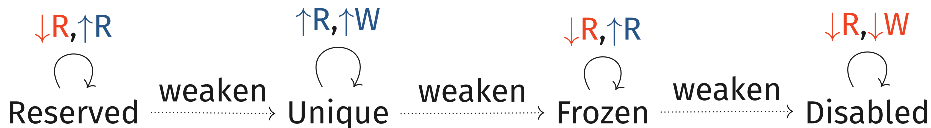

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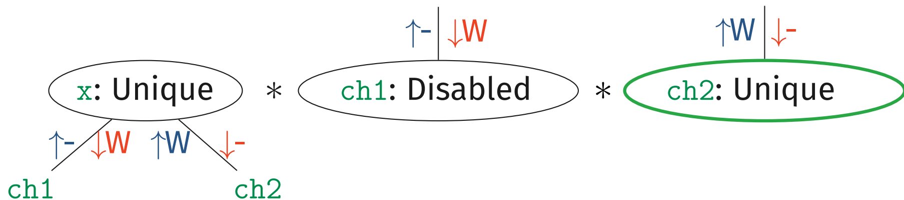

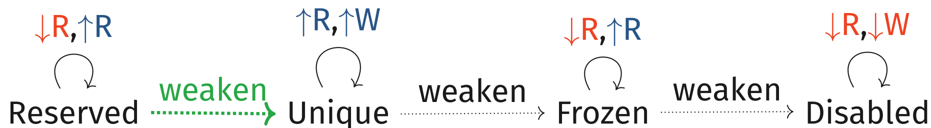

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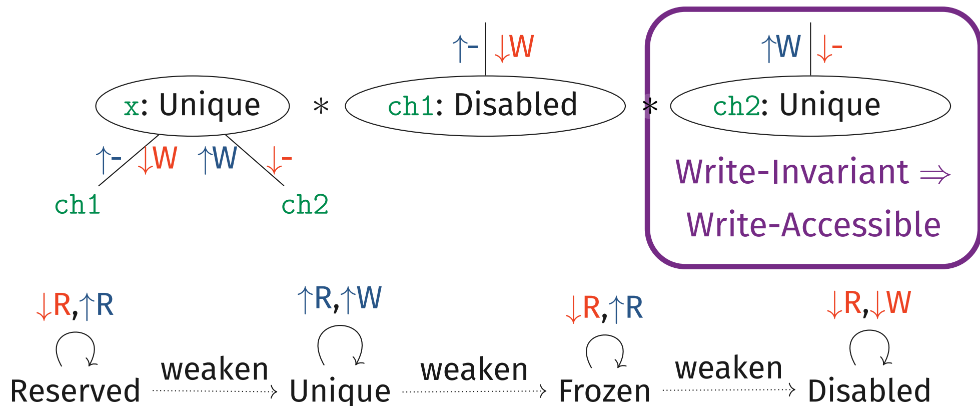

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This is Just the Beginning

Our logic can do much more:

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- Node Deletion

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- Interior Mutability, ReservedIM, ...

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- *all dark corners* of Tree Borrows

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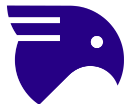

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Current Status: Iris implementation, small case-studies

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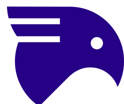

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Further plans: More examples, simplification, completeness?, verifier integration?? . . .

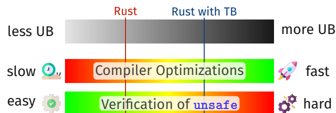
The End

Thanks for your attention!

What is Tree Borrows?

Wrongly aliased references are defined to **have UB**!

change Operational Semantics

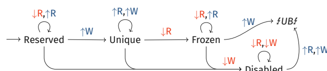


Each Node is a State Machine

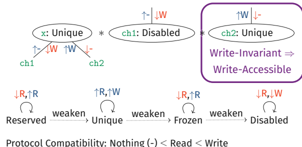
States represent permissions to read or write.

Every access causes transitions at every node, based on

- Local (↑) vs. Foreign (↓) access
- Read (R) vs. Write (W) access



Protocols + Invariance = Local Reasoning



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More info:

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