A Program Logic for Tree Borrows

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Rust type system

1-slide summary

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Aliasing: two pointers pointing to the same object

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This system ensures safety!

Can it do more?

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    let x = *a;
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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 };
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Why Is This Optimization Legal?

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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

Why Is This Optimization Legal?

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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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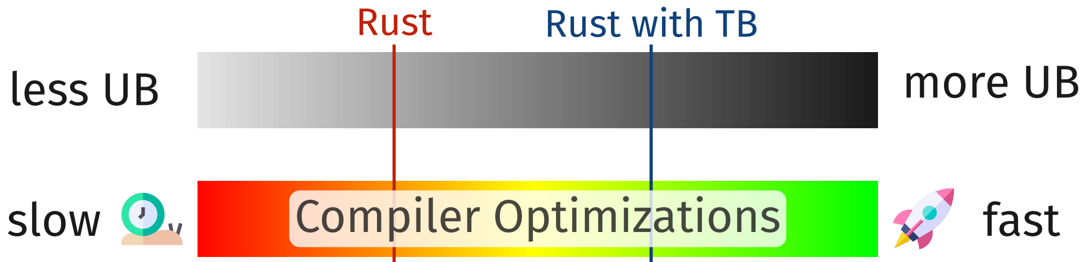

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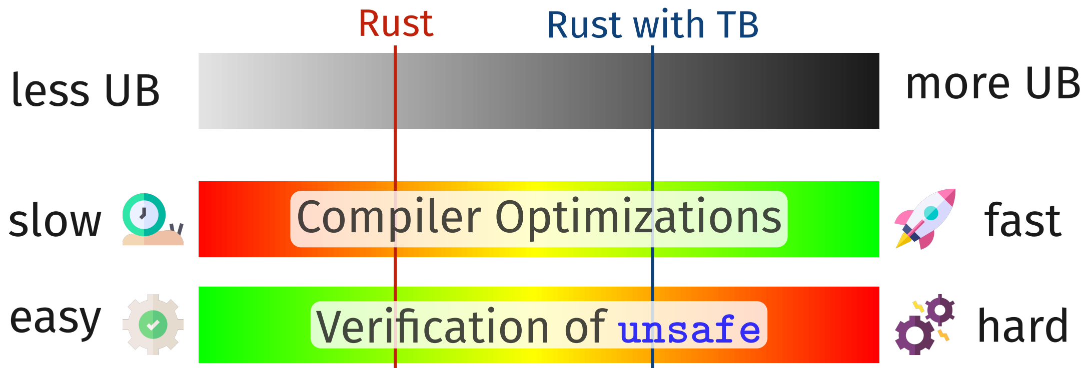

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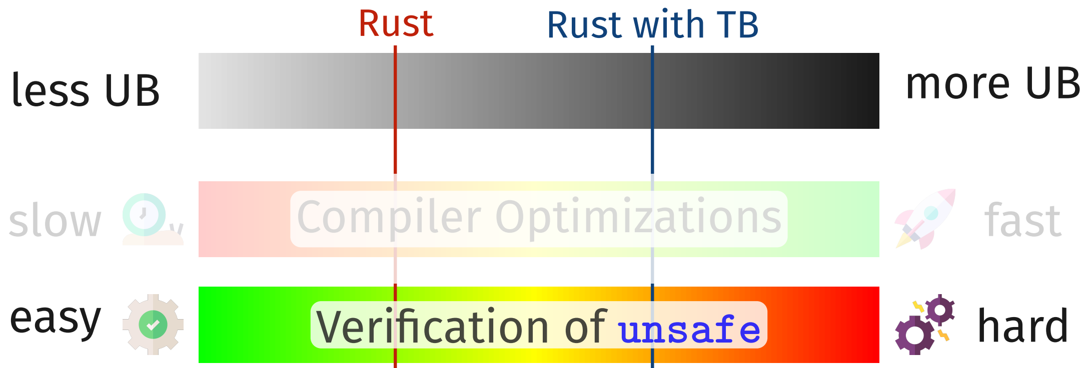

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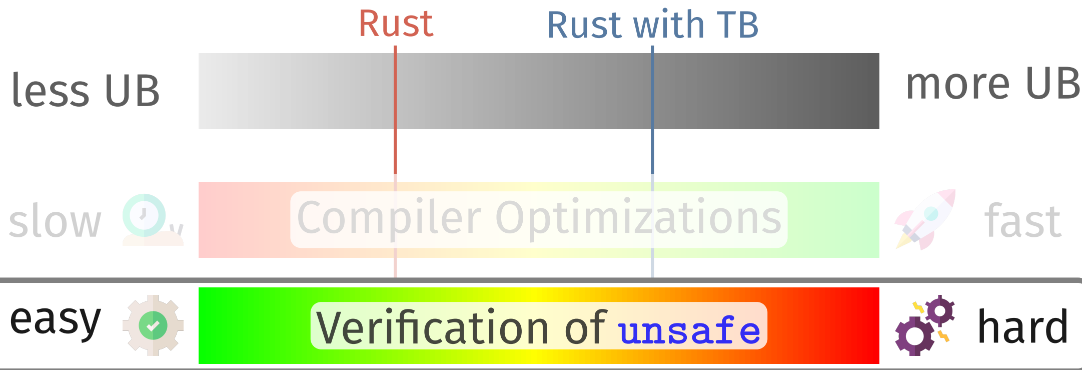

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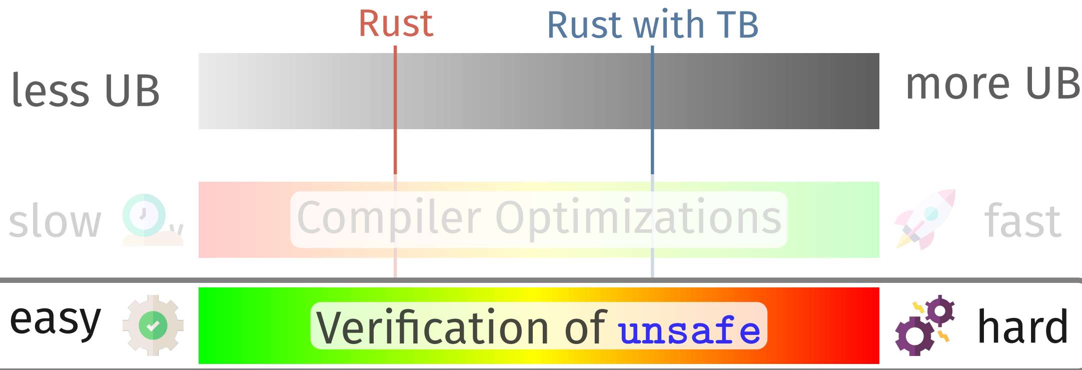

Putting The Borrows Into Trees

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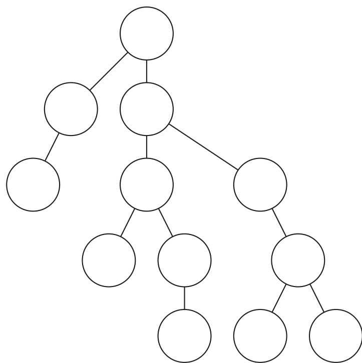

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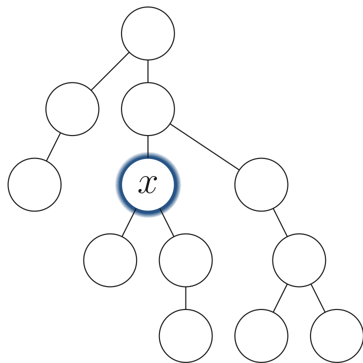

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One tree for each memory location.

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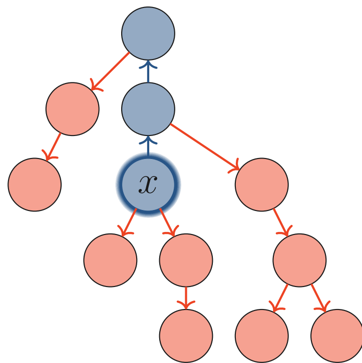

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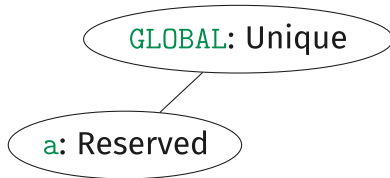

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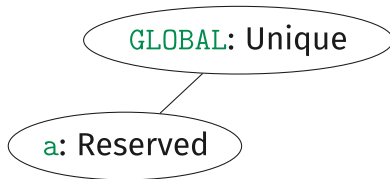

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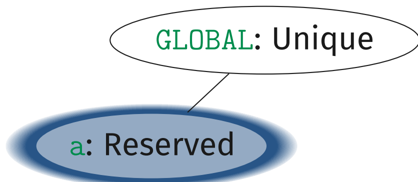

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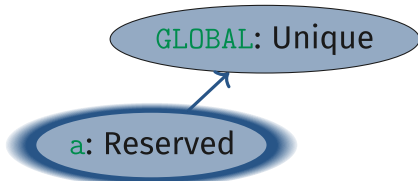

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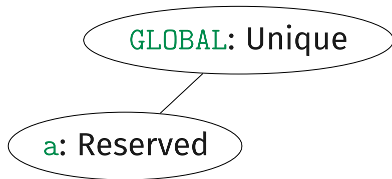

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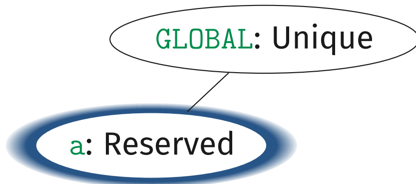

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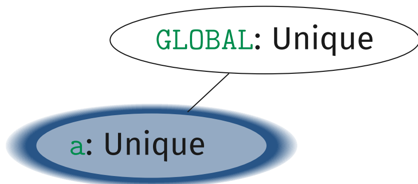

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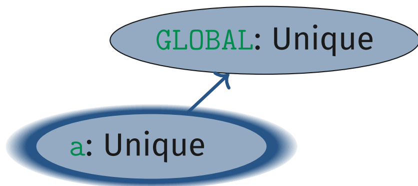

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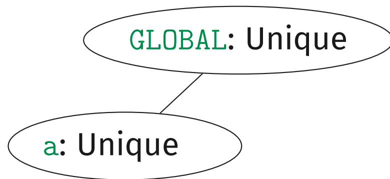

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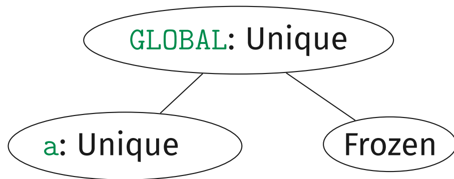

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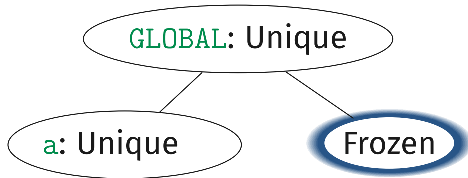

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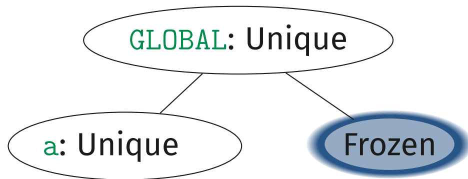

Frozen + ↑R → Frozen

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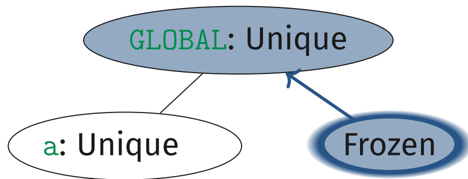

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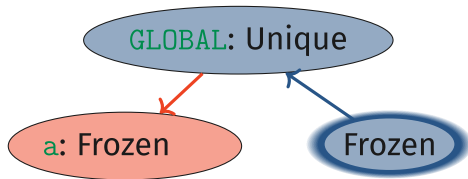

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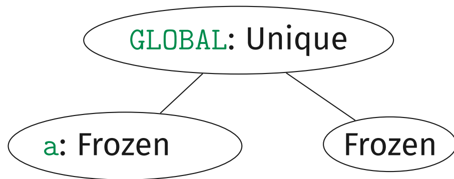

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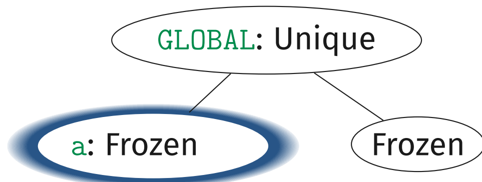

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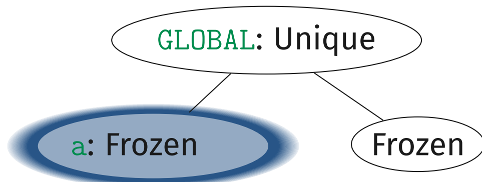

Frozen + ↑W → ⚡UB⚡

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States represent permissions to read or write.

Every access causes transitions at every node, based on

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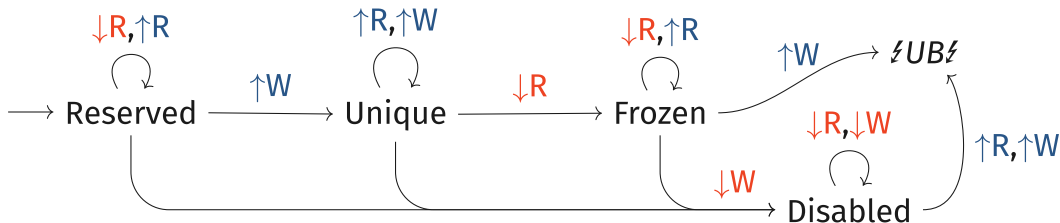

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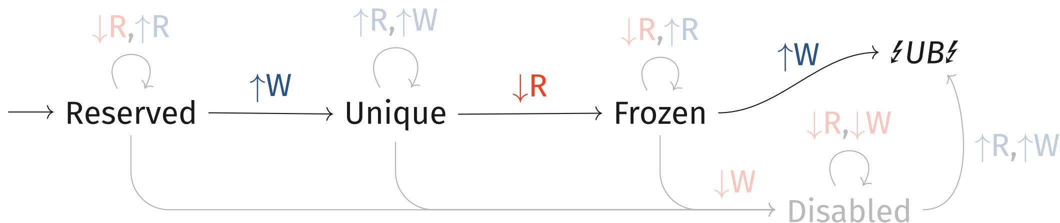

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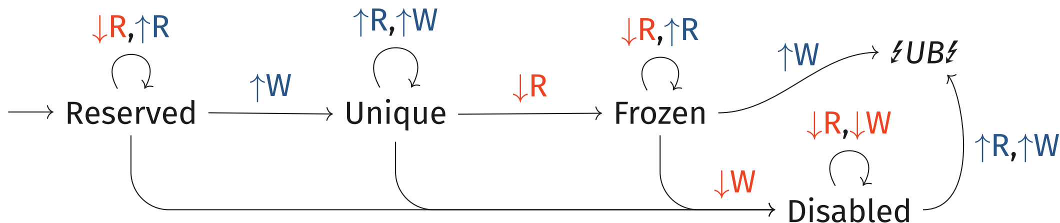

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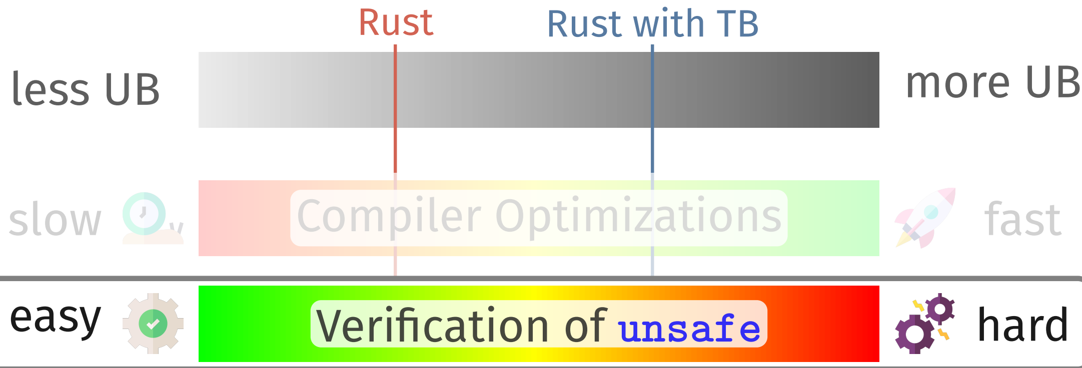

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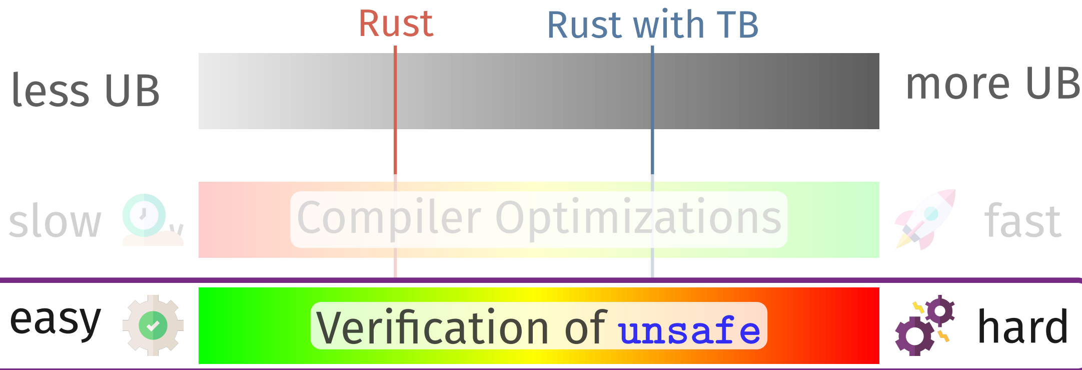
Wrongly aliased references **are defined to have UB!**

change Operational Semantics



The Solution: A Program Logic for Tree Borrows

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Separation Logic

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Separation Logic

Full Tree Details

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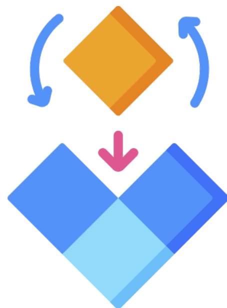

Modular Reasoning

The Solution: A Program Logic for Tree Borrows

Theory at the Foundation of `unsafe` Verification Tools

Prusti, GillianRust, Verifast, Verus, ...

Separation Logic

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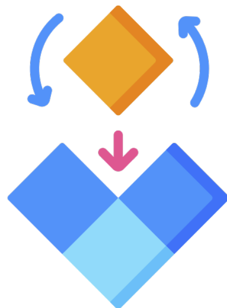

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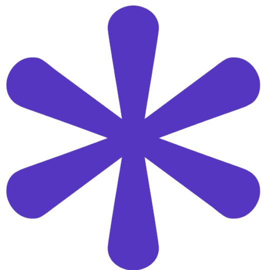

Separation Logic

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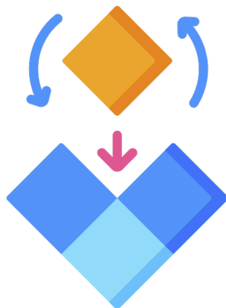
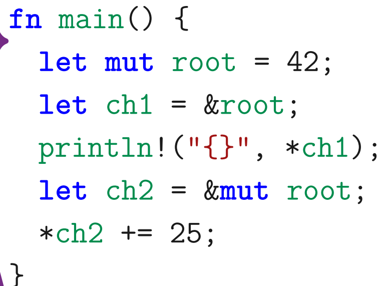


Modular Reasoning

Resources in Action

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

Resources in Action



```rust
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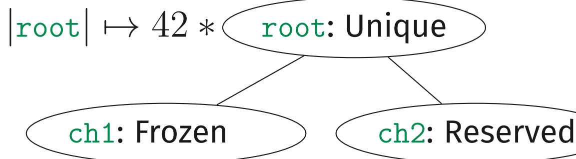

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```

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

ch1: Disabled

ch2: Unique

Resources in Action

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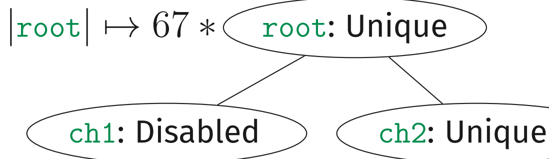

Abstraction

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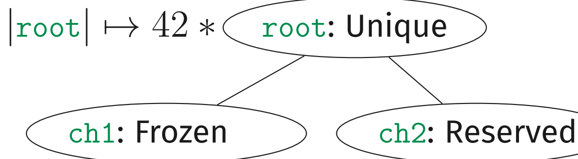

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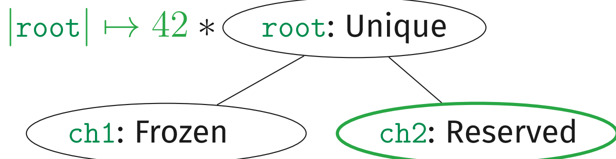

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ch2: ———

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

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

Abstraction

```
fn main() {
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$\{|\mathtt{r}| \mapsto 42 * $ (ch2: Reserved) $\}$

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

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

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

- ch1: Frozen
- ch2: Unique

Abstraction

```
fn main() {
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ch2: ——

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Abstraction

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```

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

ch1: Frozen

ch2:

↑W ↓-

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↑W | ↓-

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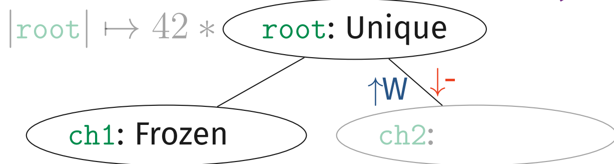

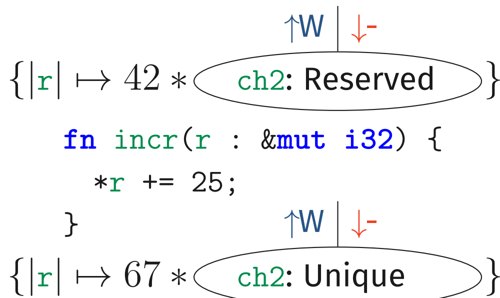

Protocol ↑W↓- imposes:

- ch2 can write
- Others may not access

Abstraction

```
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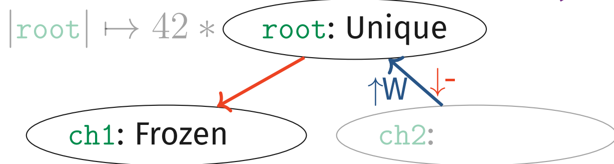

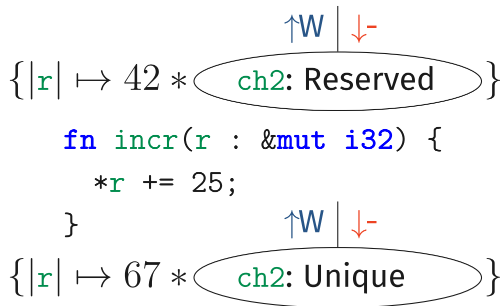

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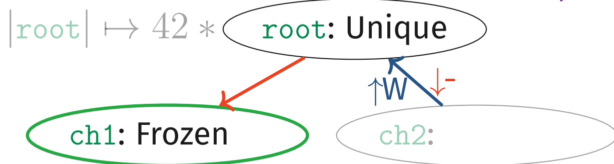

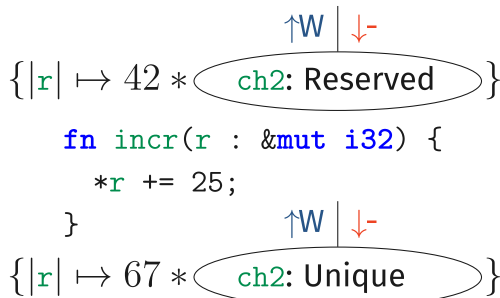

Protocol ↑W↓- imposes:

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Abstraction

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  let mut root = 42;
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}
```

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

ch1: Disabled

ch2:

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↑W | ↓-

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$|\mathtt{root}| \mapsto 42 \, *$ root: Unique

ch1: Disabled

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Protocols + Invariance = Local Reasoning

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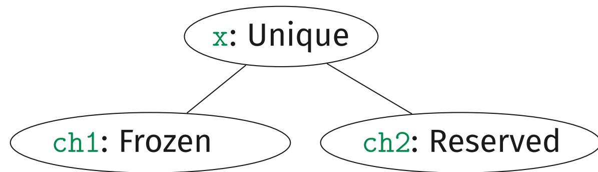

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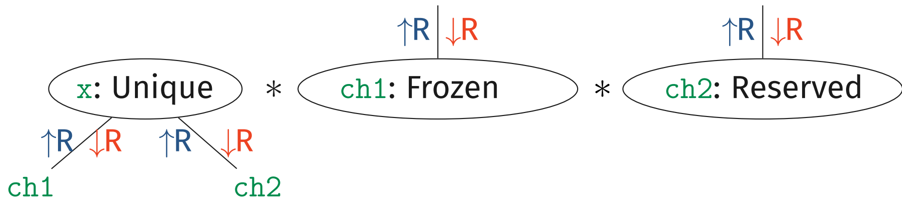

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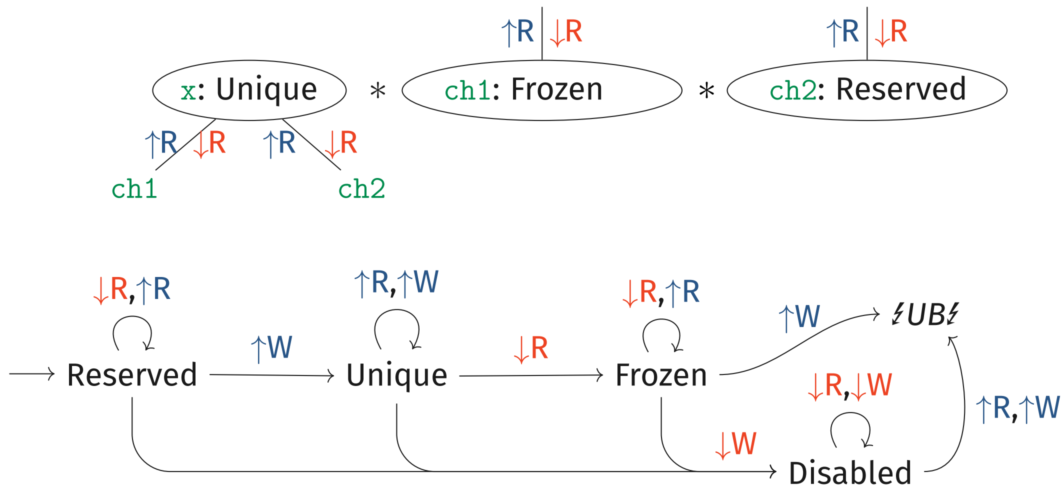

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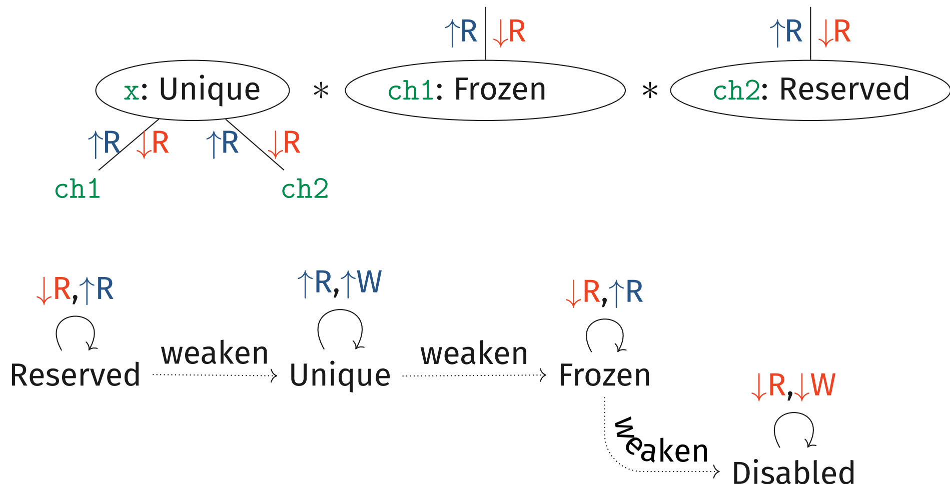

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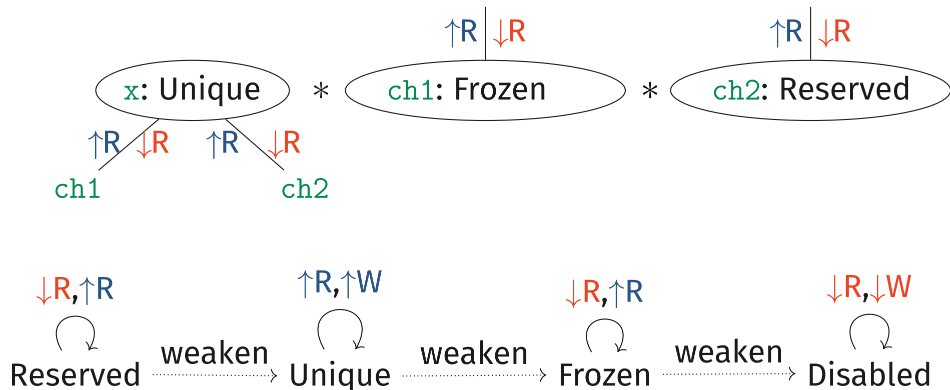

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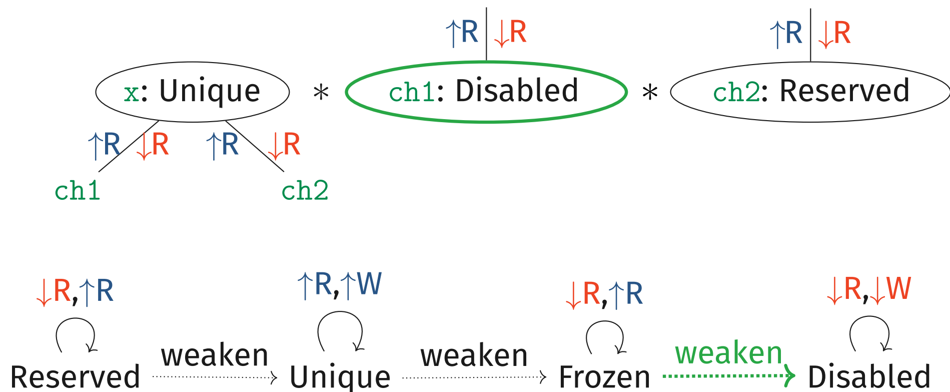

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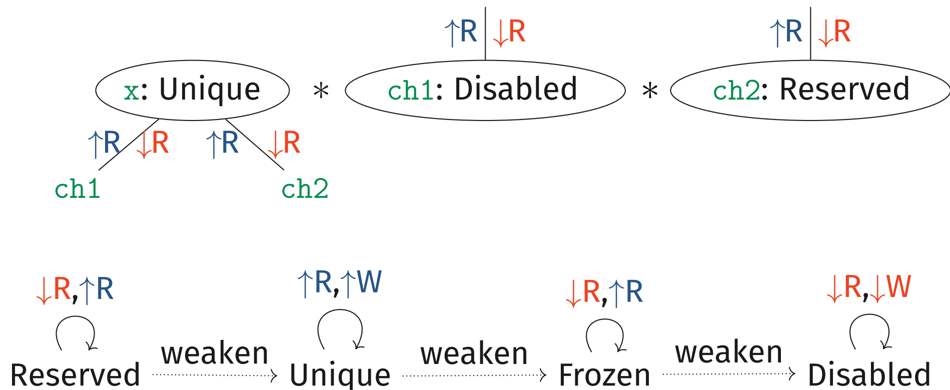

Protocol Compatibility: Nothing (-) $\leq$ Read $\leq$ Write

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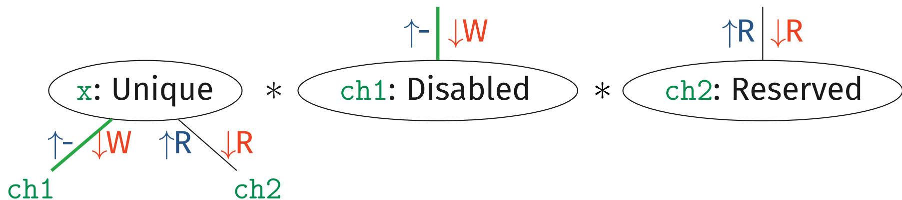

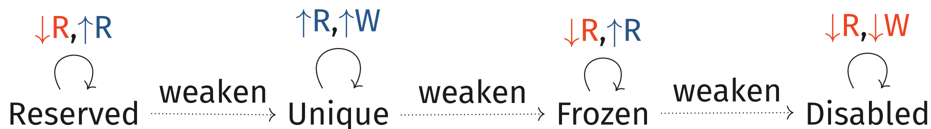

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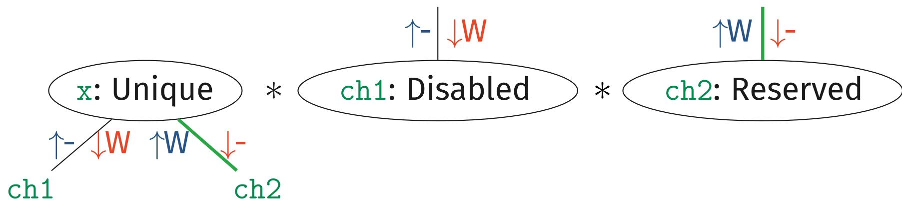

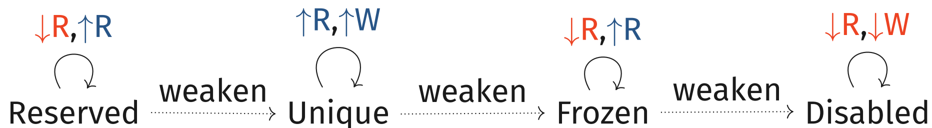

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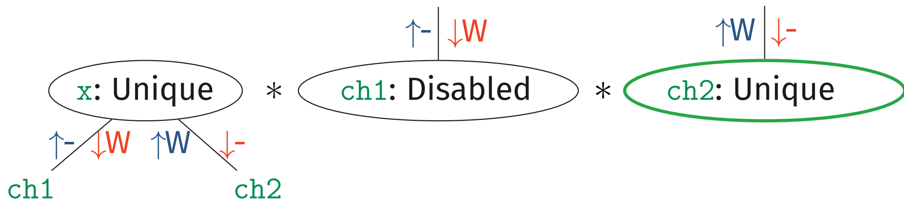

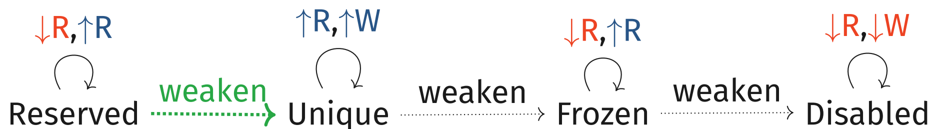

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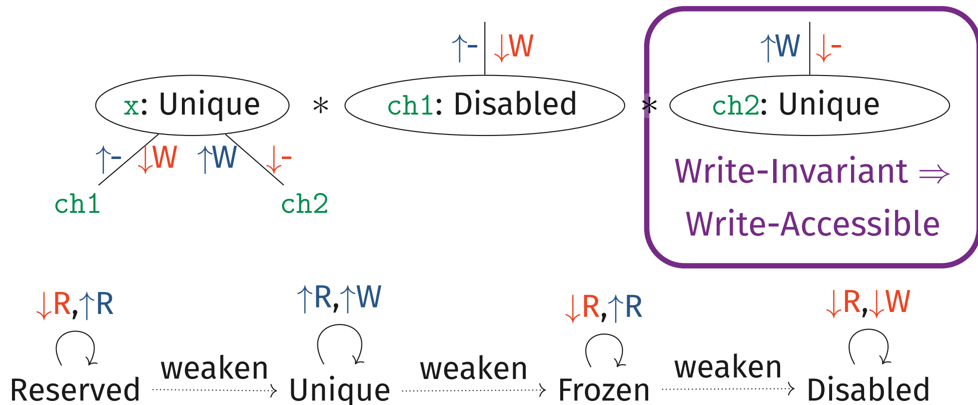

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How Is This Implemented?

I have world's largest view relation

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I have world's largest view relation (I think)

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Definition tree_cloud_internally_consistent nm :=
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  global_iface_consistency_parents nm
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∧ global_iface_consistency_children nm
  (* if a child exists, we must reference it in our list of children (i.e. no dangling children) *)
∧ global_parent_child_consistency nm
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10 000 lines of Rocq in total

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Our logic can do much more:

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- Interior Mutability, ReservedIM, ...

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- *all dark corners* of Tree Borrows

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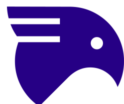

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Current Status: Iris implementation, small case-studies

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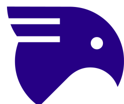

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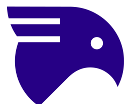

ROCQ
APPROVED

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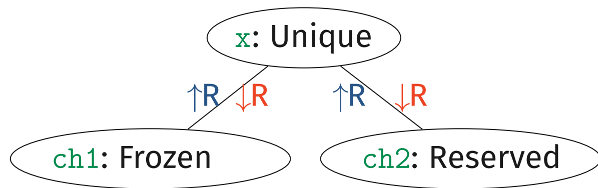
Are Protocols Too Klunky?



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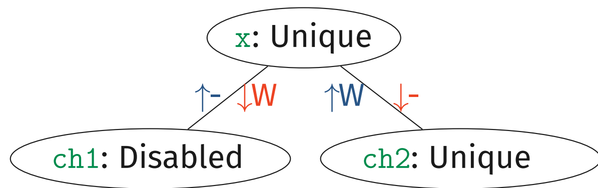
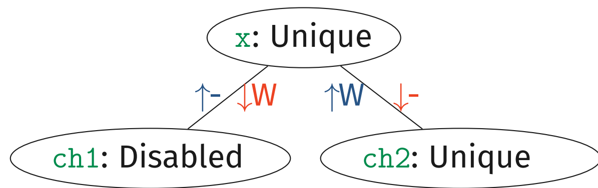


Are Protocols Too Klunky?



+ Proven Sound

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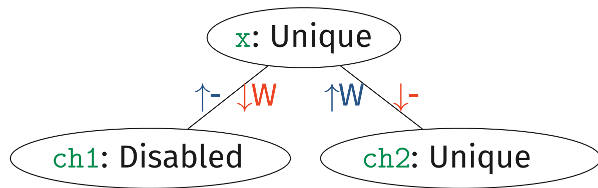

- \+ Proven Sound
- ± Low-Level
  - ⇒ Completeness Obvious

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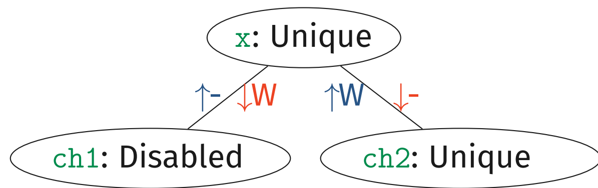

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- \- Idiosyncratic Protocols
- \- Exhausting to Use

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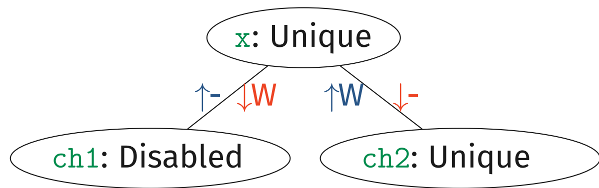
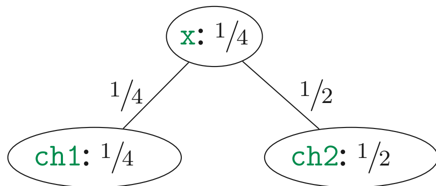


Wannes Tas' idea: use fractions!



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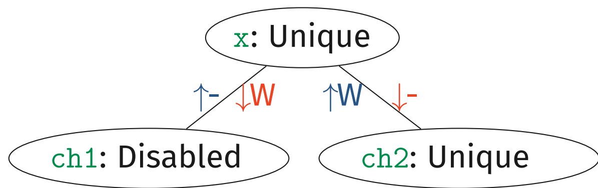

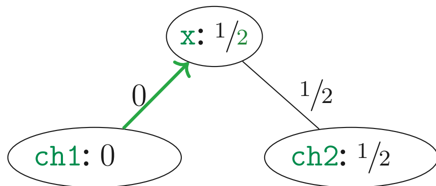

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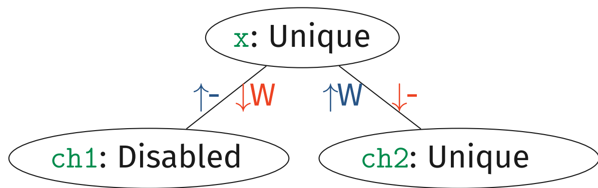

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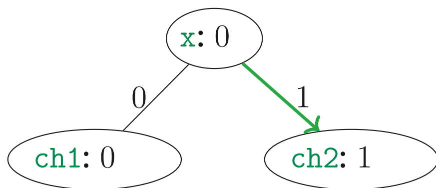

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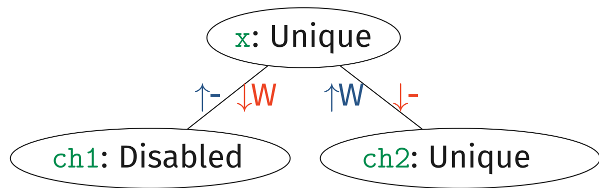

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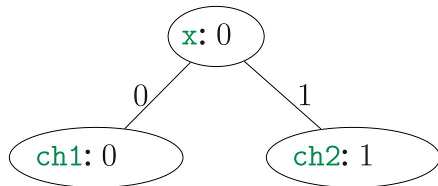
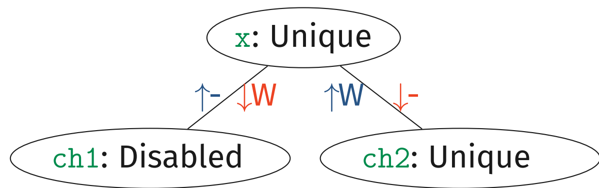


- - Just an idea, no proofs

Are Protocols Too Klunky?



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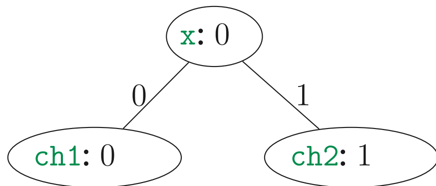

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- \- Just an idea, no proofs
- ± Higher-Level
  - ⇒ Completeness Doubtful

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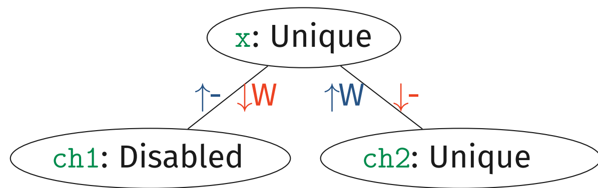

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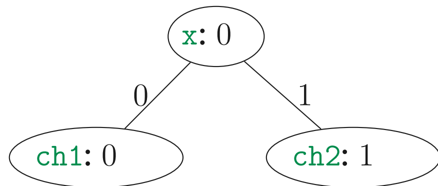


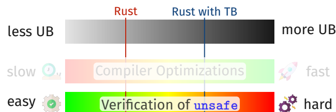
- - Just an idea, no proofs
- ± Higher-Level
  - ⇒ Completeness Doubtful
- + "Natural" Fractions
- + Deeper Intuitions

The End

Thanks for your attention!

What is Tree Borrows?

Wrongly aliased references are defined to **have UB**!
change Operational Semantics

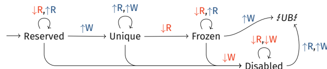


Each Node is a State Machine

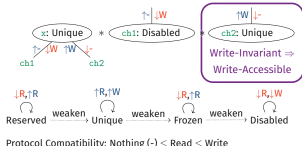
States represent permissions to read or write.

Every access causes transitions at every node, based on

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



Protocols + Invariance = Local Reasoning



Protocol Compatibility: Nothing (-) ≤ Read ≤ Write

This is Just the Beginning

Our logic can do much more:

- Node Deletion, Child Separation (Fractional Retags), ...
- Protectors, thanks to Lazy Protector Ends
- Pointer Arithmetic ("Dynamic Ranges")
- *all dark corners* of Tree Borrows

Current Status: Iris implementation, small case-studies

Further plans: More examples, simplification, completeness?, verifier integration??, RustBelt 2.0???, …

More info:

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