Viper

A Verification Infrastructure for Permission-Based Reasoning

Uri Juhasz, Ioannis Kassios, Peter Müller, Milos Novacek,
Malte Schwerhoff, Alex Summers (and several students)

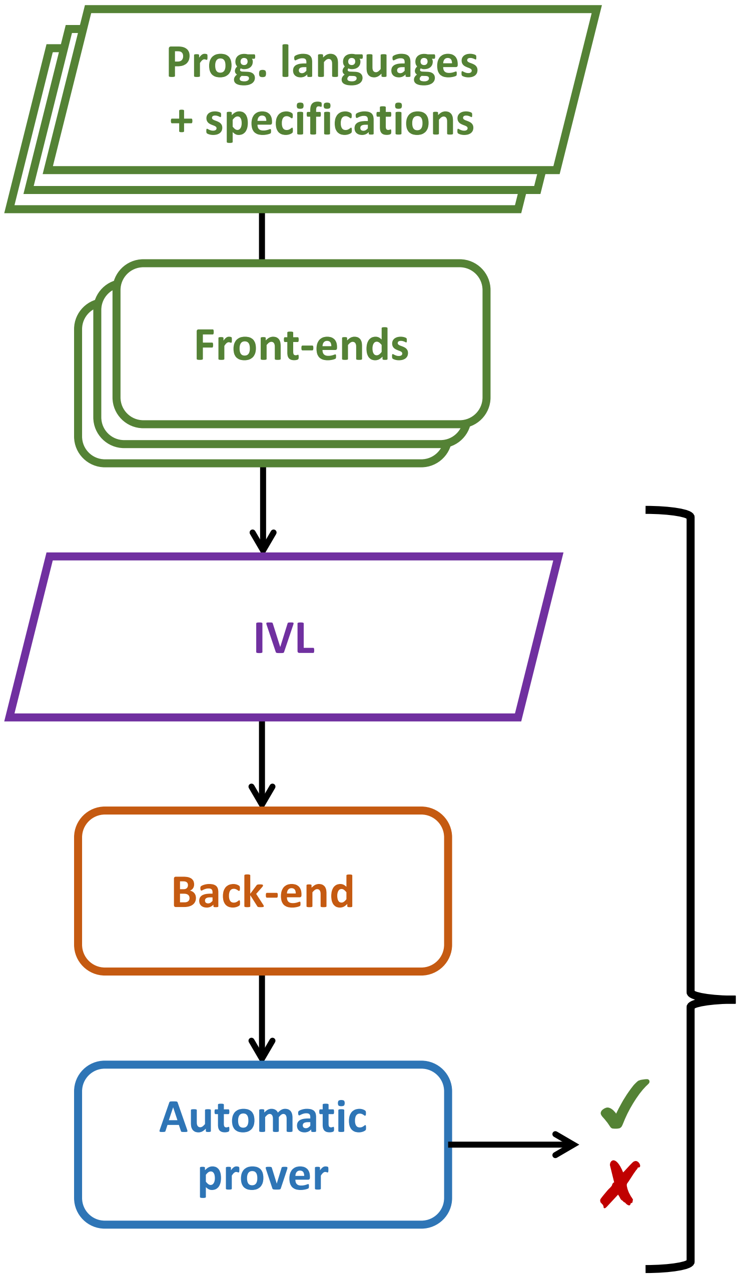
1st March 2015, ECOOP'15 PC Meeting, Zurich

Our Vision

Automatic Program Verification

- Safety (memory accesses, non-null, …)
- Correctness (functional specs)
- Termination, message replies, …

Verification using Automatic Provers



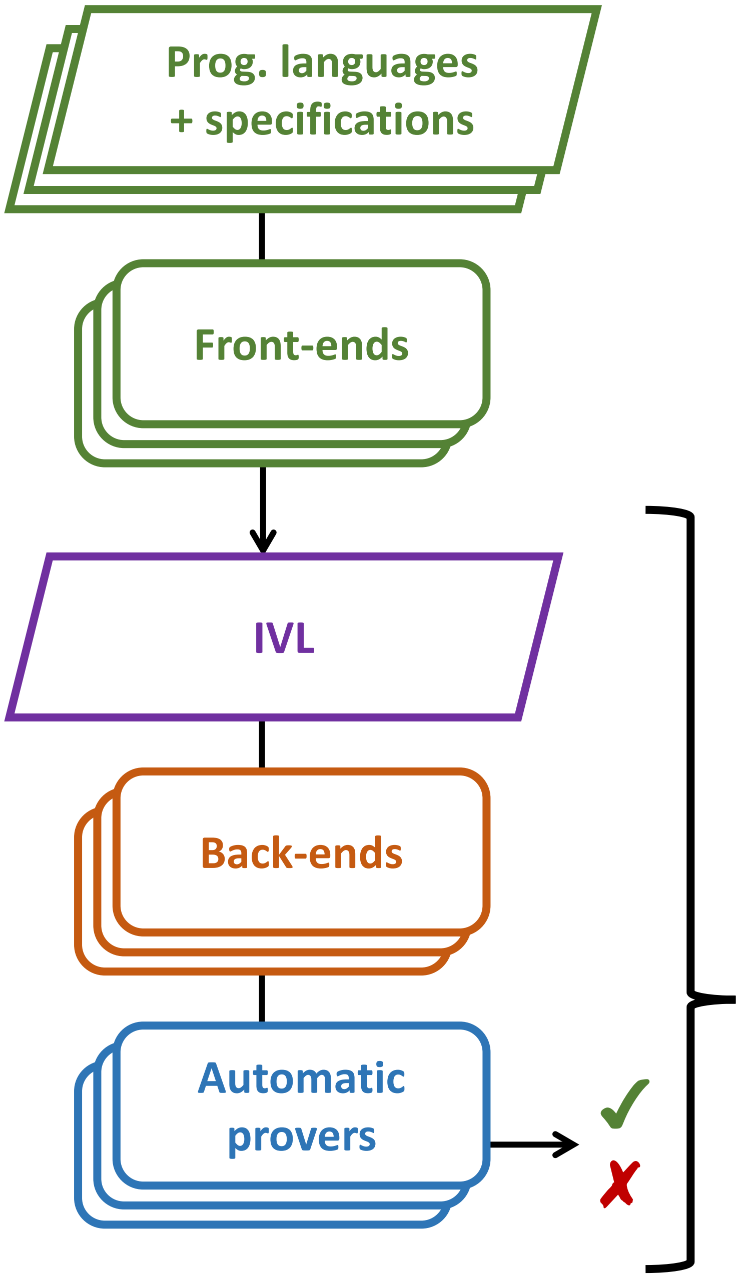
+ Automatic first-order logic tools – major progress in the last decade (SAT, SMT)

+ Intermediate verification languages - Boogie, Why, …

+ Back-end: verifier (verification condition generator)

= **Common infrastructure** for building front-end verifiers

Verification using Automatic Provers



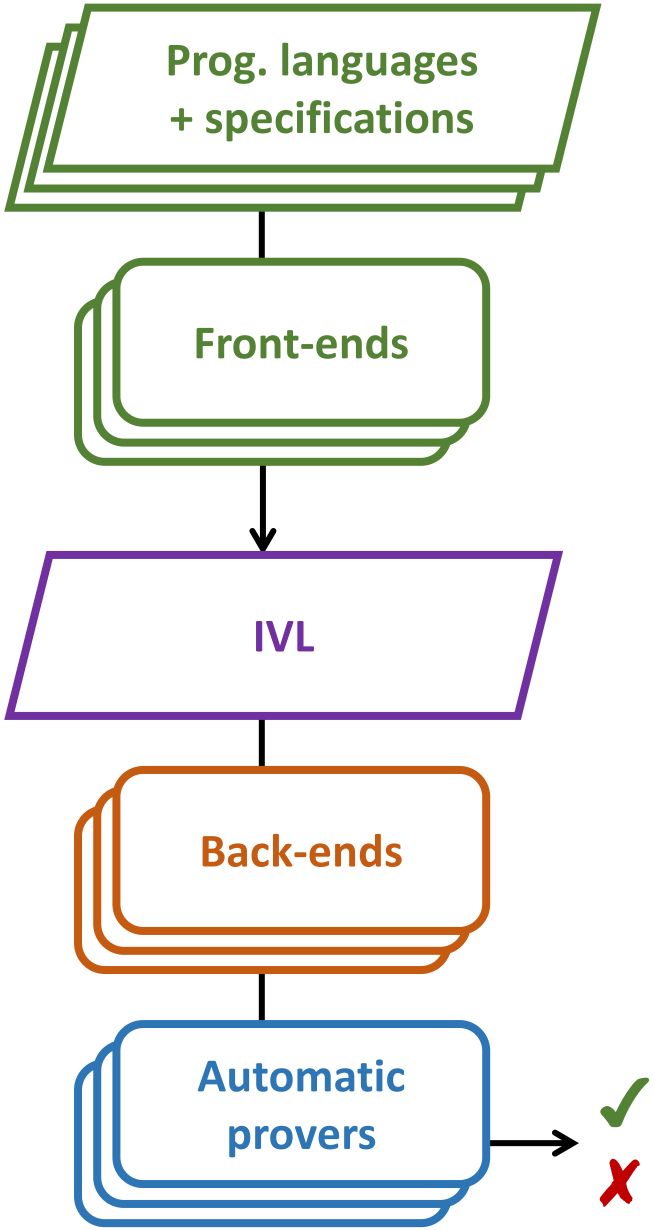
+ Automatic first-order logic tools – major progress in the last decade (SAT, SMT)

+ Intermediate verification languages - Boogie, Why, …

+ Back-ends: verifiers - but also inference engines, slicers, static analysers, …

= **Common infrastructure** for building front-end verifiers

Verification using Automatic Provers



Common infrastructure enabled many *success stories* and *tools*

- Microsoft Hypervisor (VCC)
- Device drivers (Corral)
- Spec#, Dafny
- Krakatoa, Jessie
- Frama-C, Why3
- …

Permission-Based Reasoning

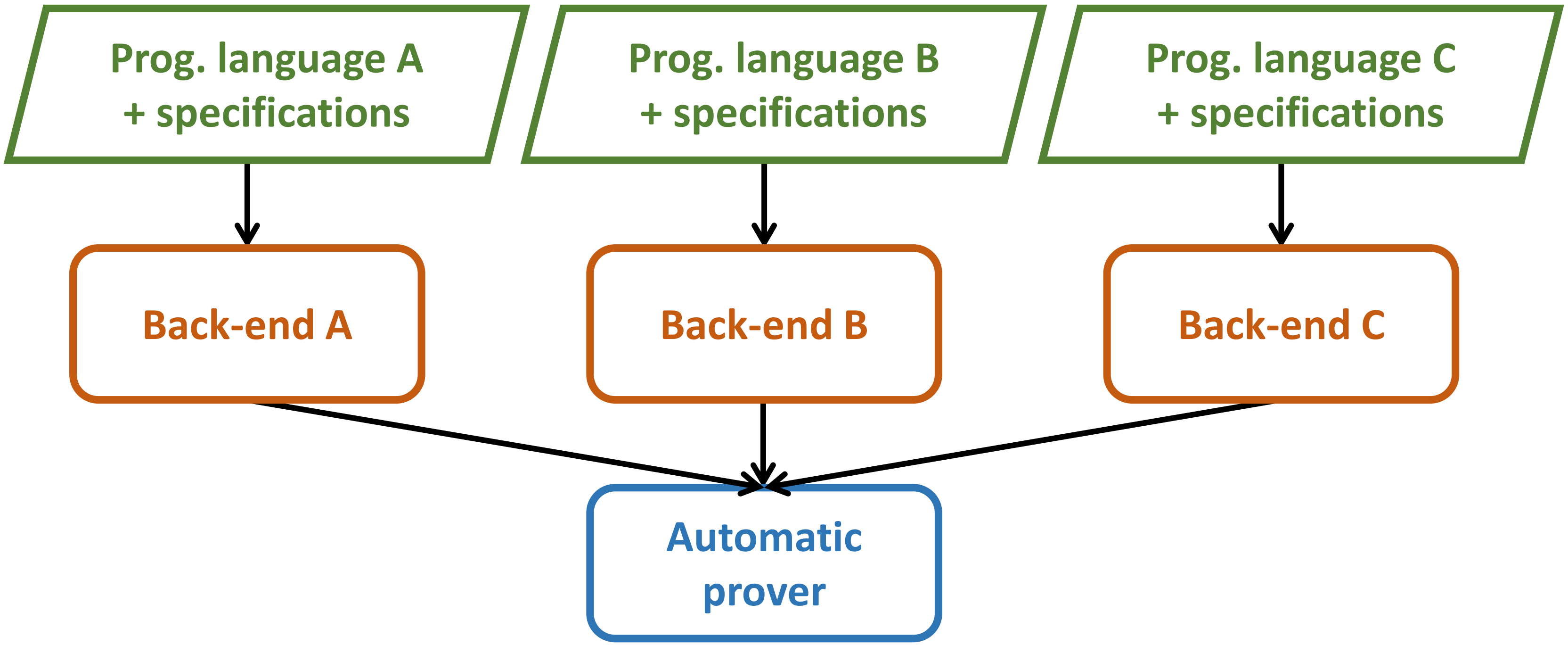
Separation logic and others *permission logics*:

- *Locally* reason about *shared mutable state*
- Many *successful applications*, including
  - Device driver safety (Microsoft)
  - Belgian Electronic Identity Card
- Many on *going developments*
  (esp. fine-grained concurrency)

Not a first-order logic
→ Significantly complicates using existing provers

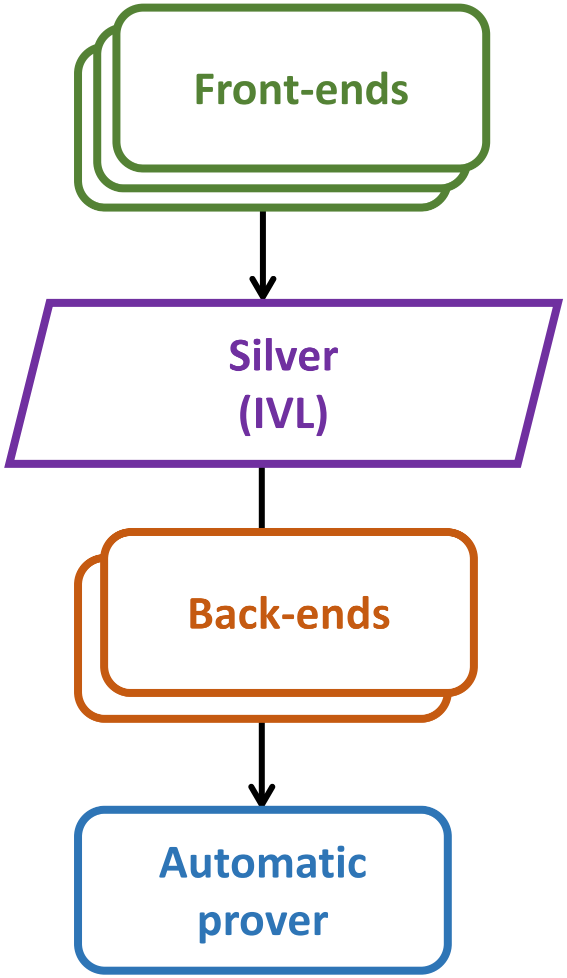
Permission-Based Reasoning

Consequence: many *custom verification engines* (usually based on symbolic execution): Smallfoot, VeriFast, jStar, …



Alternative: Encoding SL into FOL (e.g. Chalice)

Viper: Our Verification Infrastructure



Silver:

- *Native* support for permissions
- Few (but expressive) constructs
- Designed with verification and inference in mind

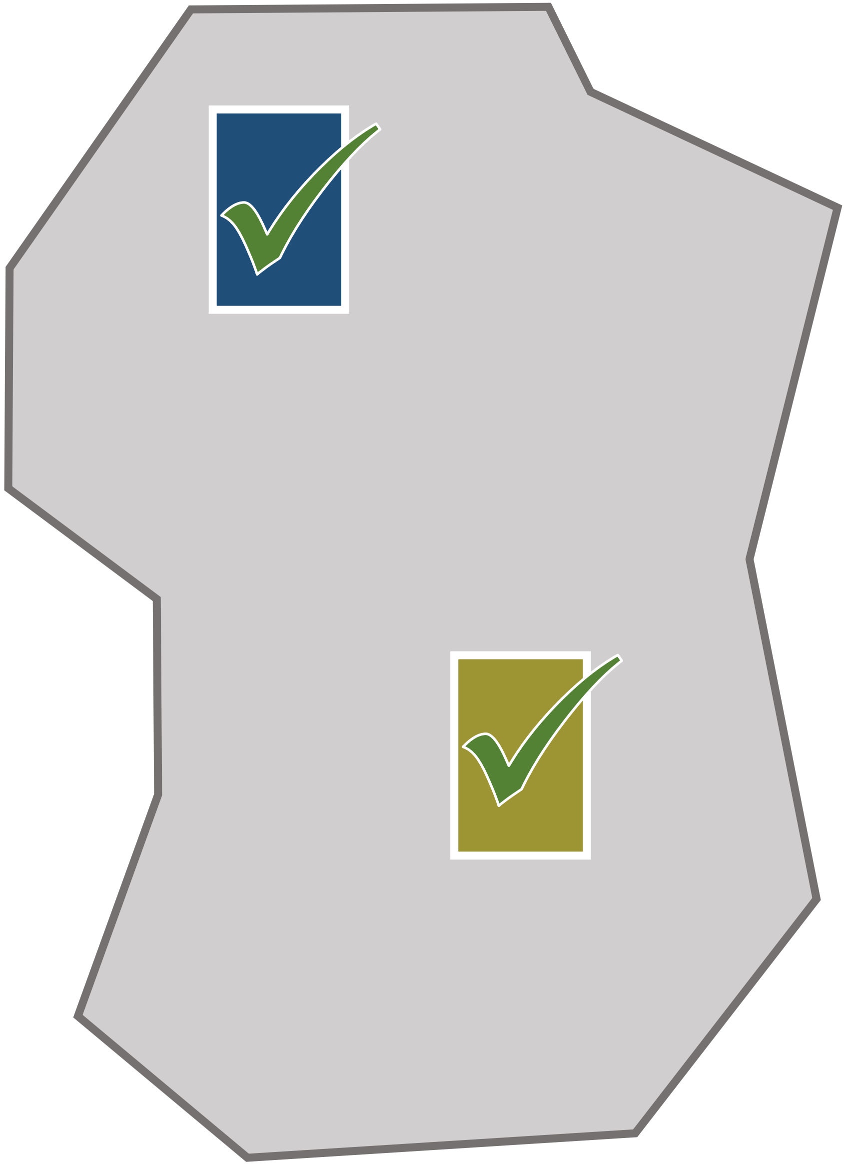
Back-ends: Two verifiers;
plans to develop inference, slicer

Front-ends (proof of concept):

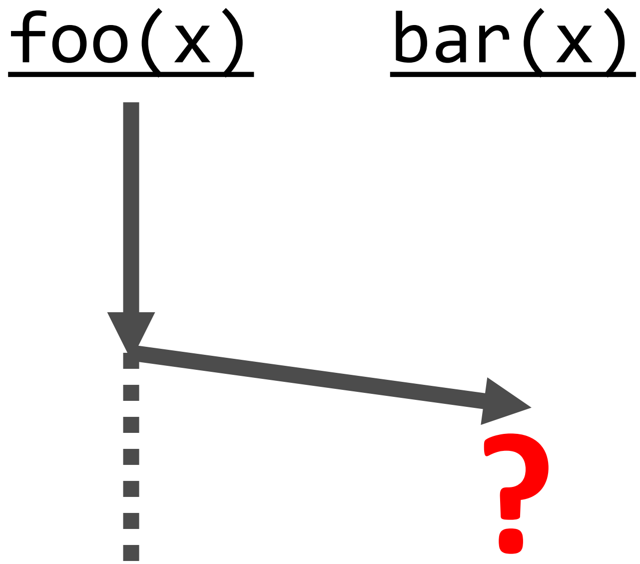
- *Chalice* (concurrency research)
- *Scala* (very small subset)
- *Java* (VerCors, U Twente)
- *OpenCL* (VerCors, U Twente)

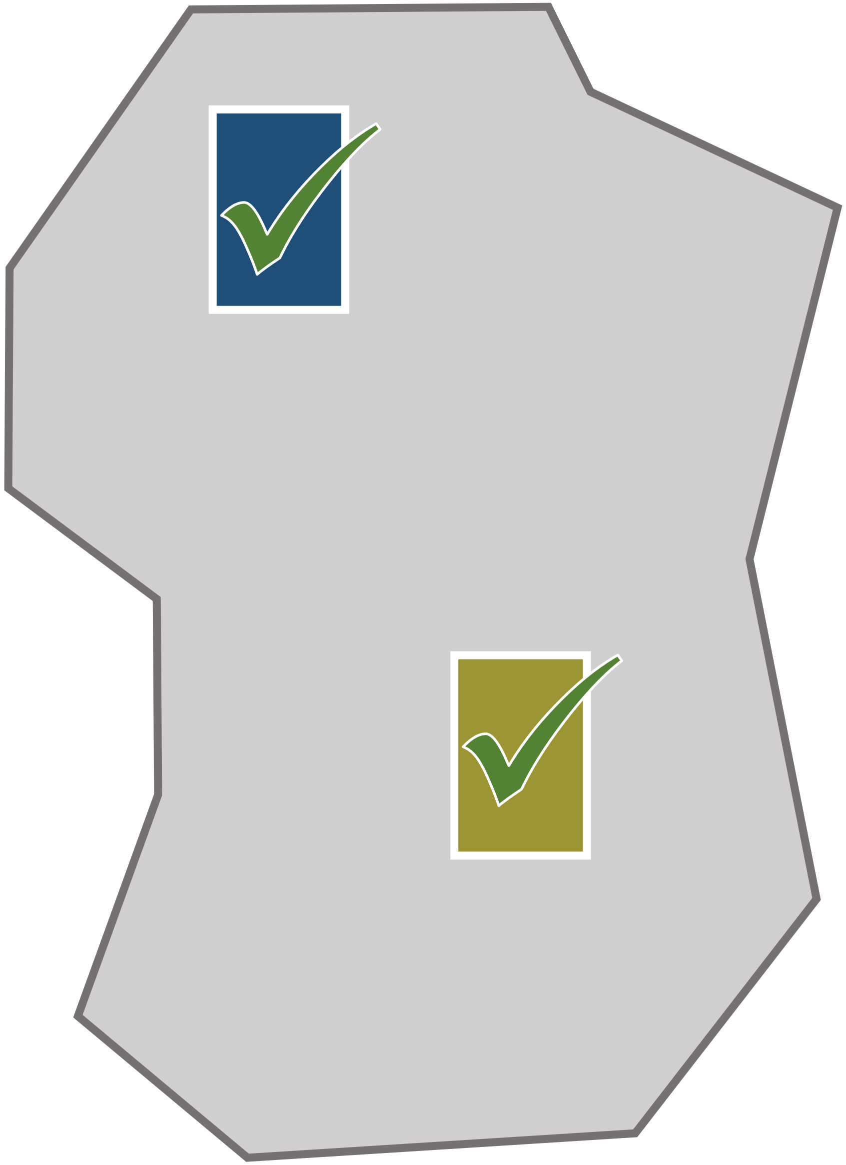
Modular Static Verification + Shared State

`foo(x)`   `bar(x)`

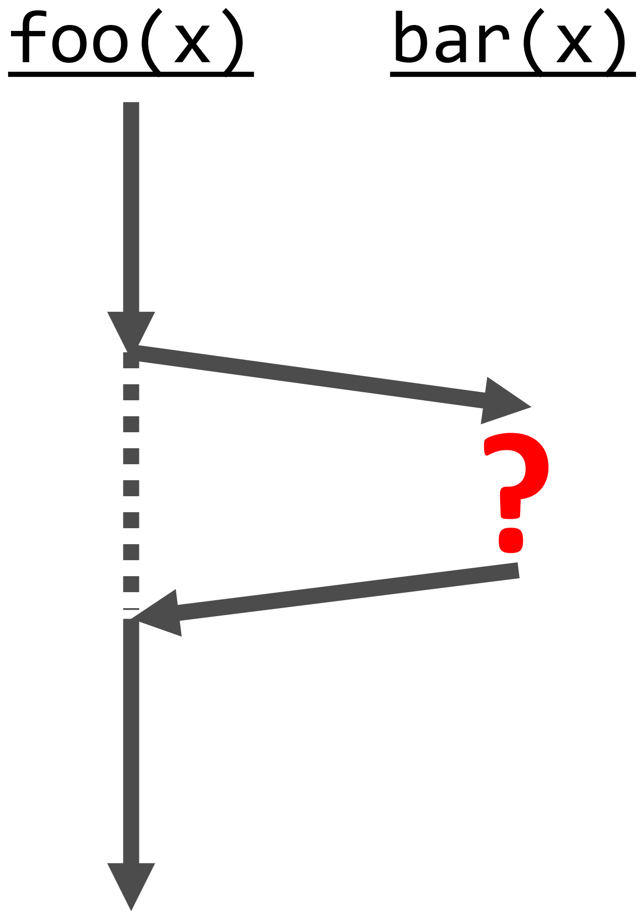


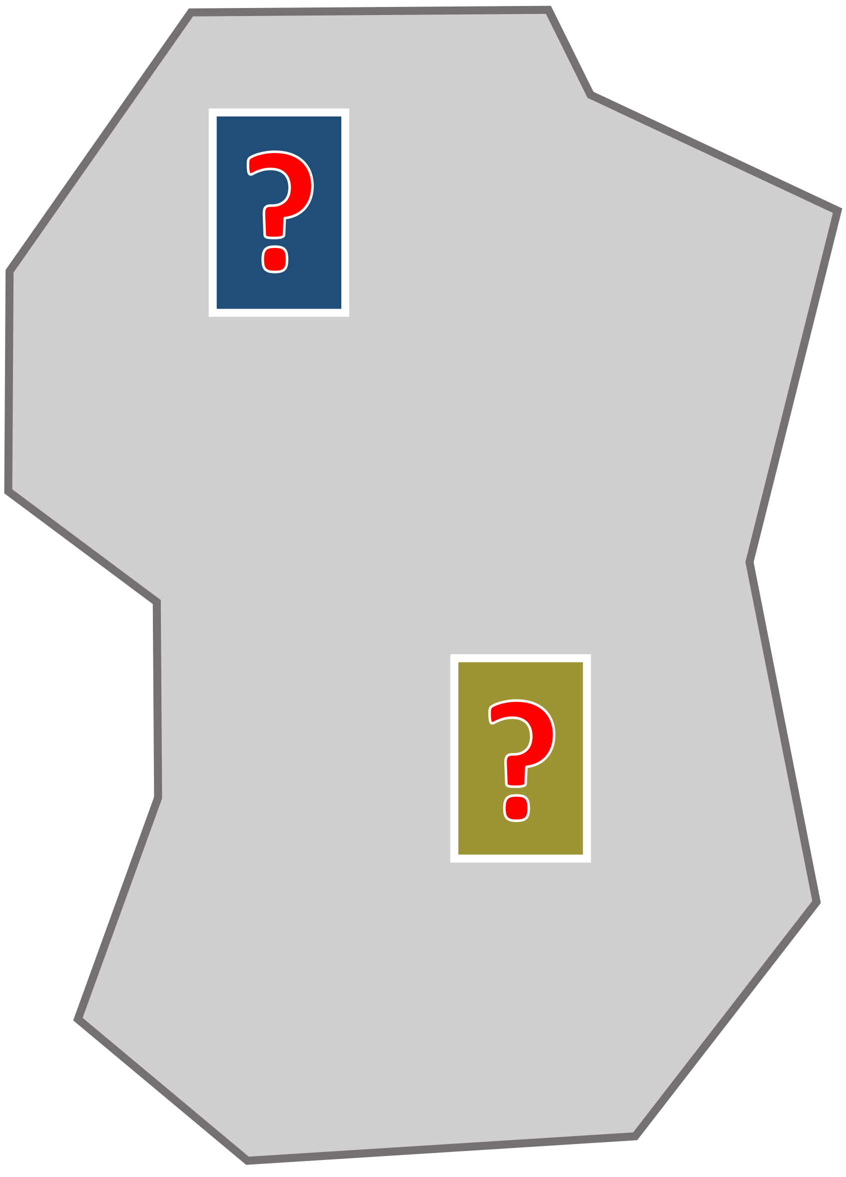
Modular Static Verification + Shared State





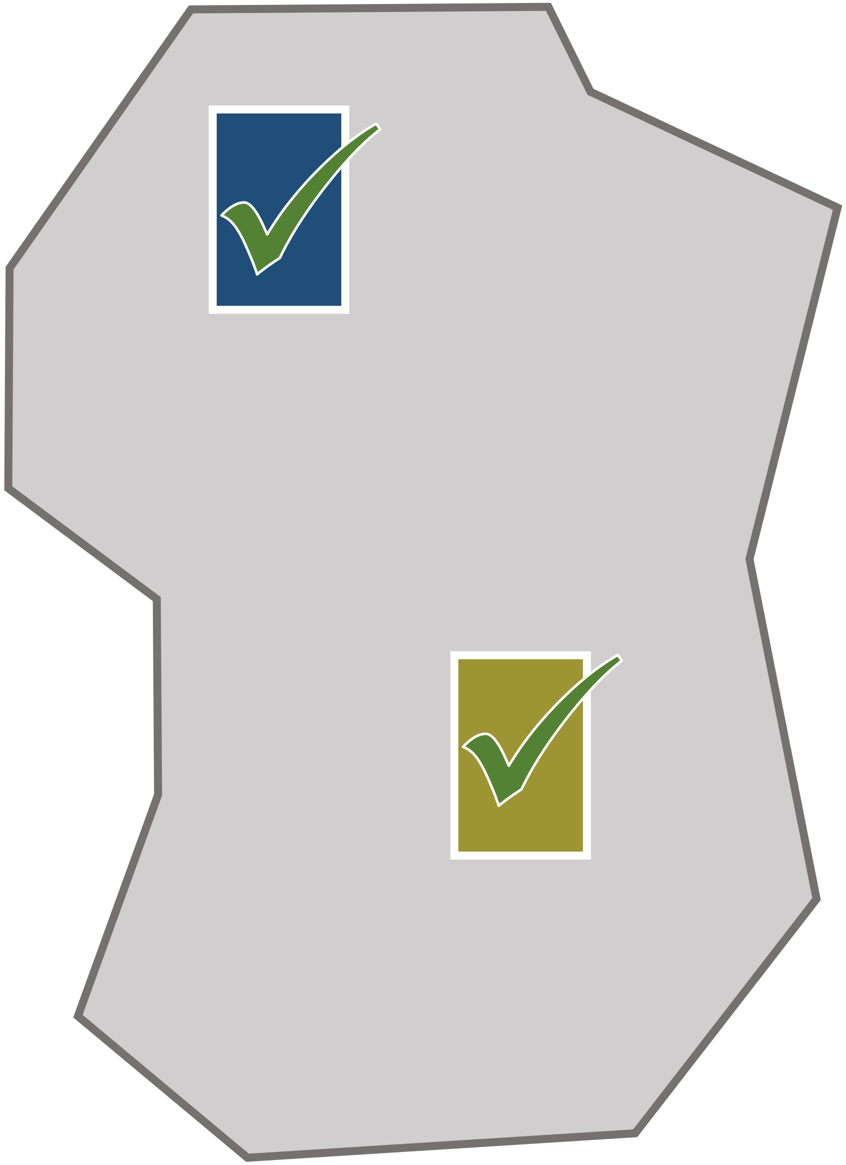
Modular Static Verification + Shared State



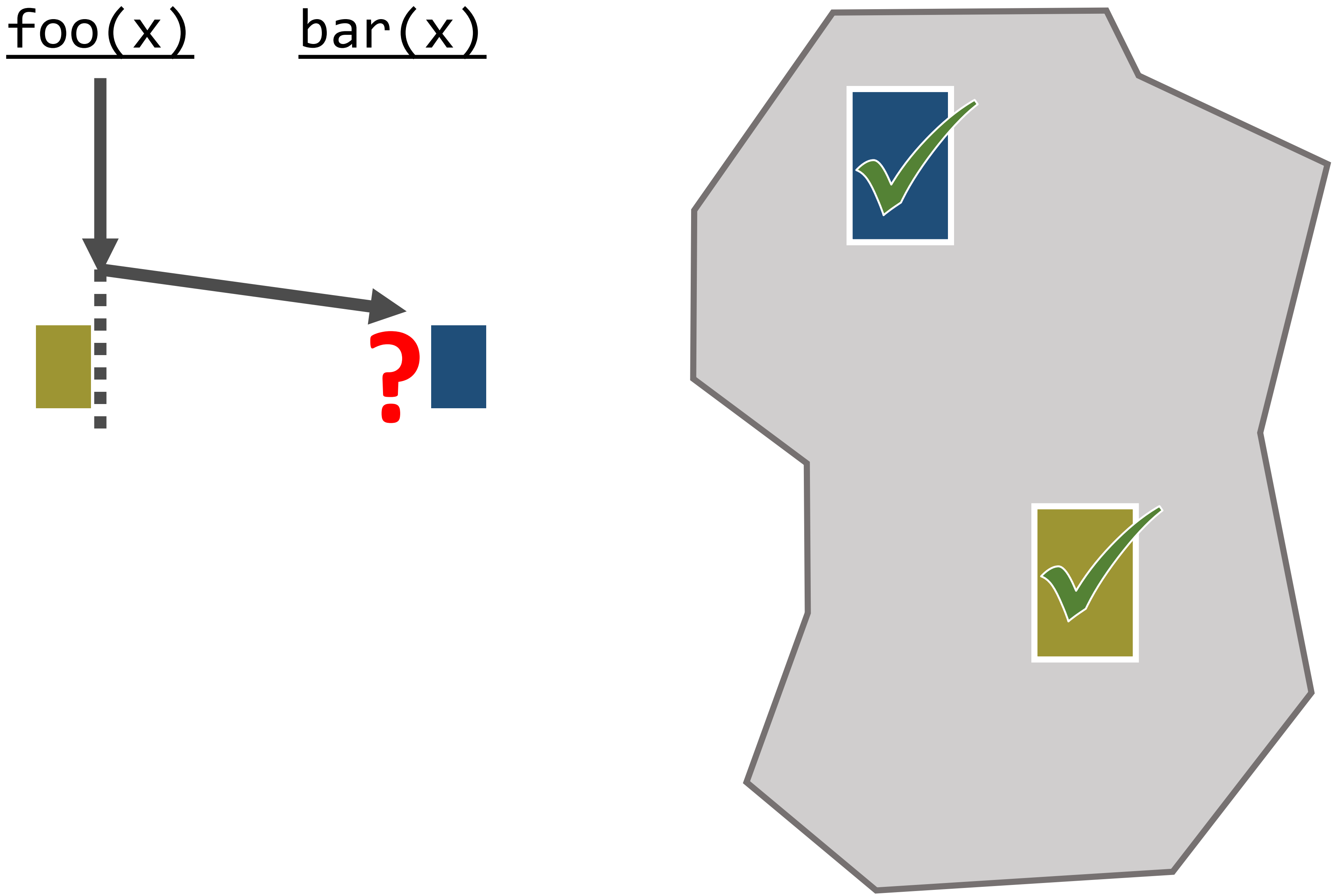


Permissions

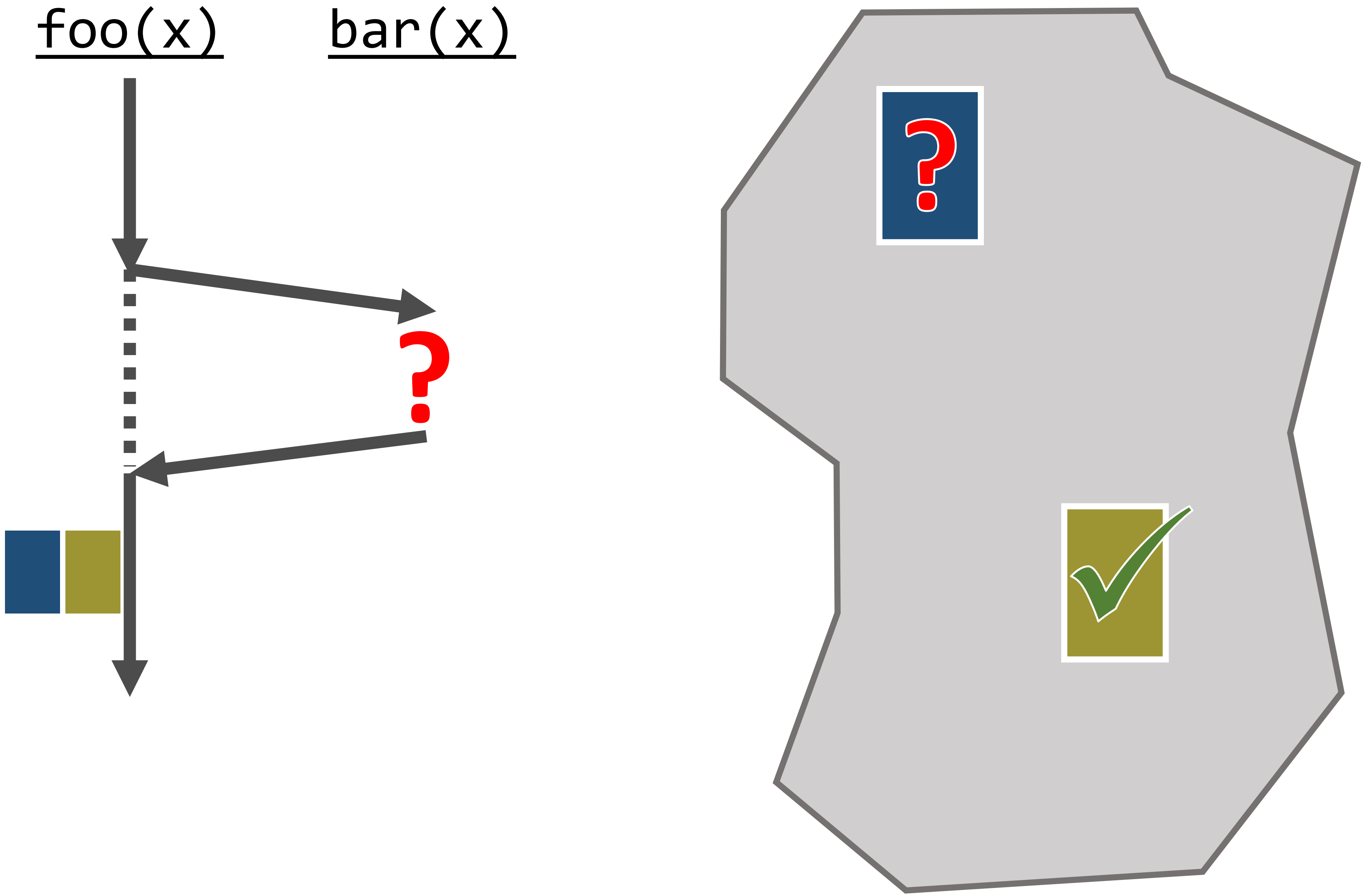
`foo(x)` `bar(x)`



Permission Transfer

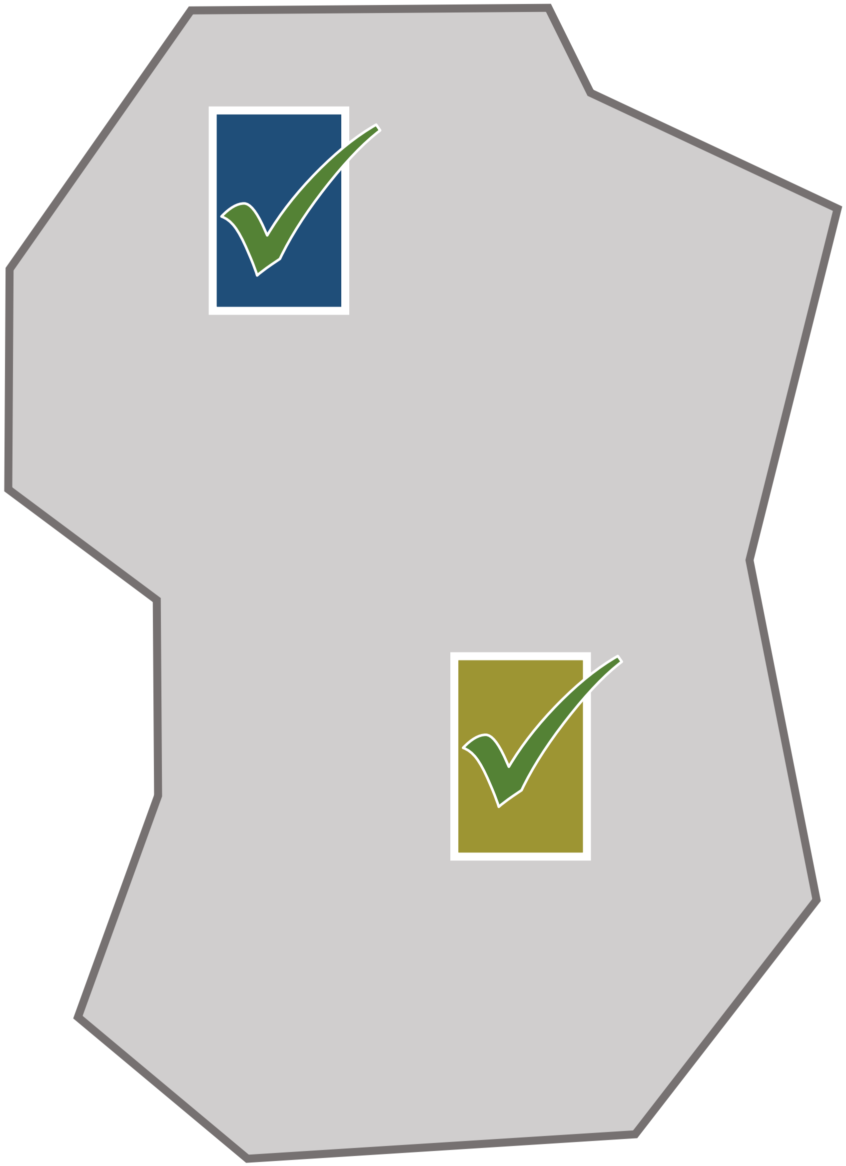


Permission Transfer

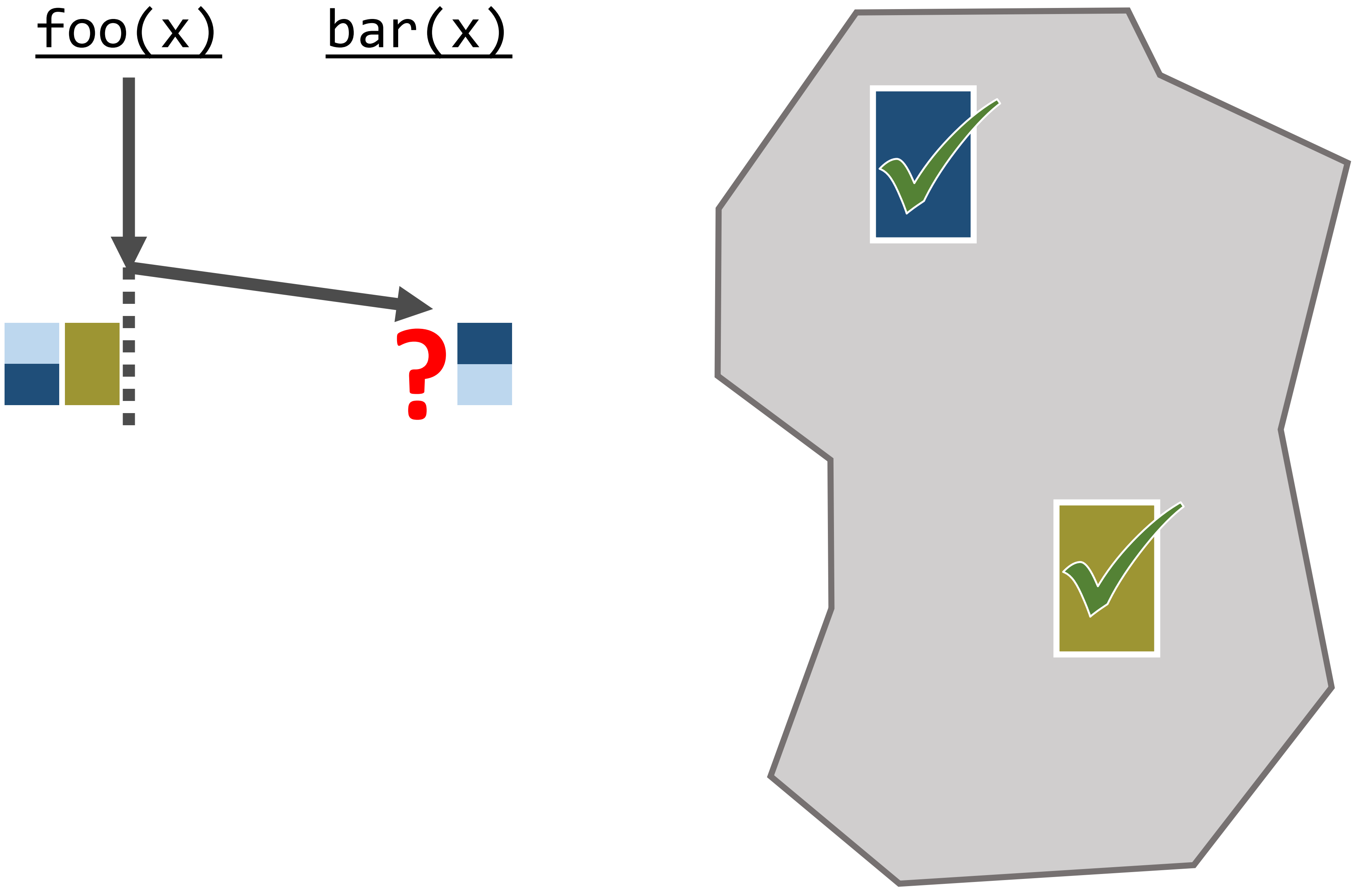


Fractional Permissions

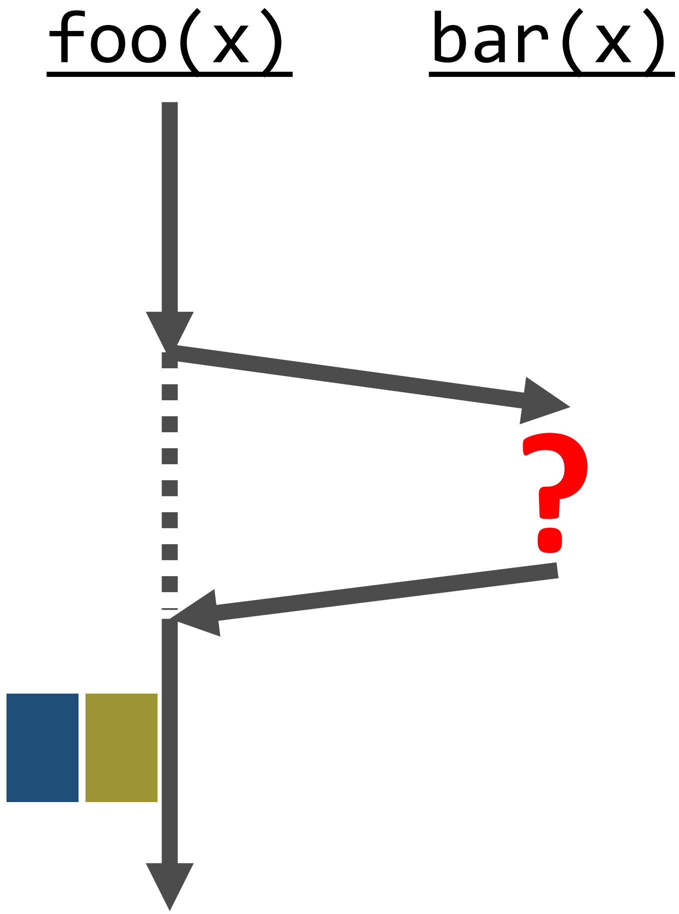
`foo(x)`   `bar(x)`

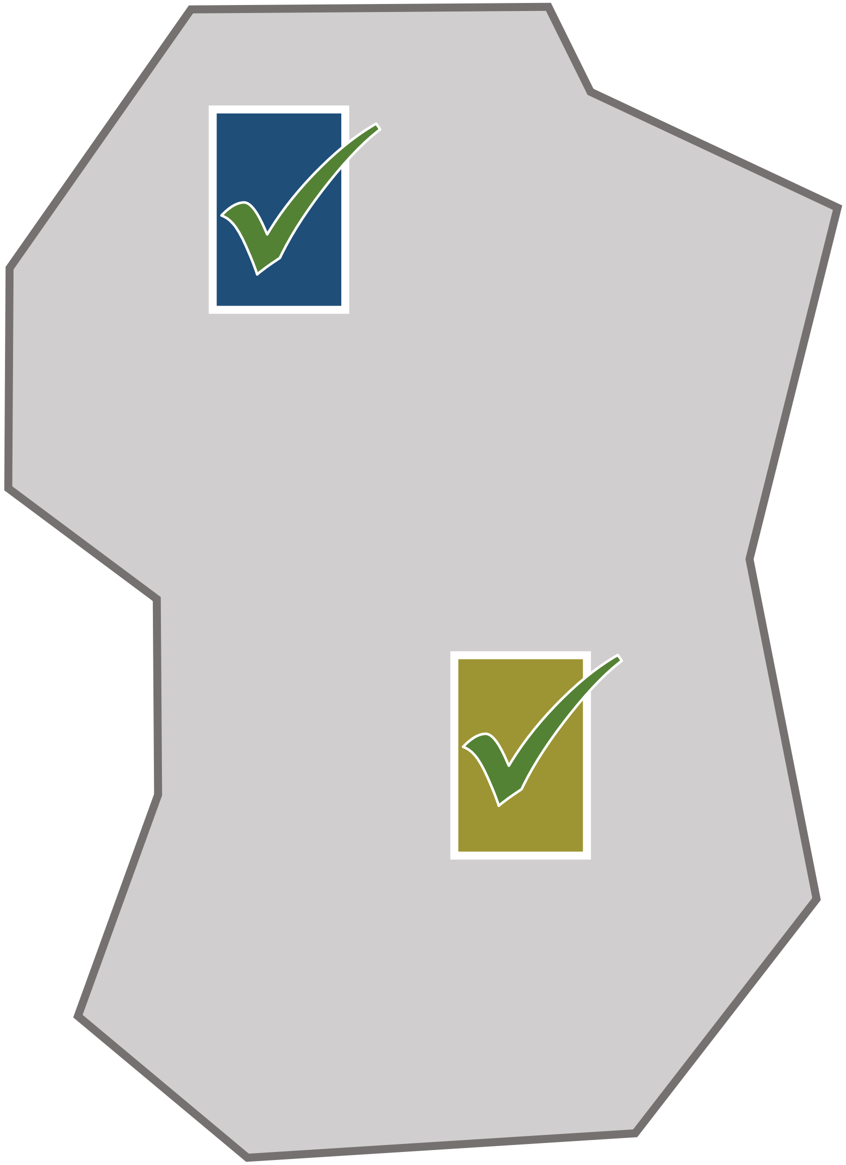


Splitting Fractional Permissions



Merging Fractional Permissions





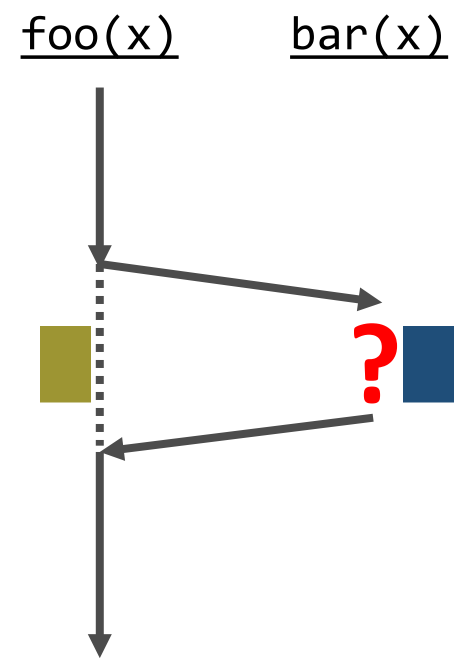
Permission Transfer

Idea of *permission transfer* generalises

- Fork-join (transfer between threads)
- Locks (transfer to/from lock invariant)
- Message passing (pass permissions)

Common operations

- Gain permissions
- Lose permissions



Silver: Inhale and Exhale Statements

Statement `exhale A` means

- Assert and remove permissions required by A
- Assert logical constraints in A (e.g. `c.f == 0`)
- Havoc locations to which all permissions is lost (i.e. forget their values)

Statement `inhale A` means

- Gain permissions required by A
- Assume logical constraints in A

Silver: Assertion Language Basics

Based on *implicit dynamic frames*

Accessibility predicates denote permissions

```
acc(c.f)
```

Assertions may be *heap-dependent*

```
acc(c.f) && c.f == 0
```

Fractional permissions

```
acc(c.f, ½)
```

Conjunction *sums up* permissions (similar to $*$ in separation logic)

```
acc(c.f,½) && acc(c.f,½)
```

Demo

Silver: Language Features

Objects and fields, if-then-else, methods (with pre/post specs), loops (with invariants)

No notion of concurrency (encode via `inhale`/`exhale`)

Simple type system

- `Int`, `Bool`, `Ref`, `Perm`
- Mathematical sets `Set[T]` and sequences `Seq[T]`

Silver: Unbounded Data Structures

Unbounded data structures via *recursive predicates*

```
predicate list(x: Ref) {
      acc(x.val) && acc(x.next)
  && (x.next != null ==> list(x.next))
}
```

`fold/unfold` statements exchange predicate instances for their bodies (not automatic due to recursion)

Heap-dependent, pure abstraction functions

```
function elems(x: Ref): Seq[Int]
  requires list(x)
{ unfolding list(x) in
    [x.val] ++ (x.next == null ? [] : elems(x.next))
}
```

Silver: Custom Mathematical Domains

D*omains* to specify custom mathematical types

- Type-parametric domains
- Domain functions
- Domain axioms

```
domain Pair[X,Y] {
 function pair(x: X, y: Y): Pair[X,Y]
 function first(p: Pair[X,Y]): X

 axiom forall x: X, y: Y • first(pair(x,y)) == x
}
...
method foo(x: Ref, p: Pair[Int, Int])
  requires acc(x.f)
{ x.f := first(p) }
```

Silver: Other Cool Features

Abstract read permissions

- Alternative to fractional permissions
- No need to commit to concrete fractions, e.g. ½

```
method foo(x: Ref, p: Perm)
  requires 0 < p && acc(x.f, p)
{
  // read x.f
  if (*) {
    var q: Ref
    constraining (q) {
      foo(x, q) // give away q < p
    }
  }
}
```

Allows *unbounded splitting and counting*

Silver: Other Cool Features

Paired assertions `[A, B]`

- When inhale, A is used
- When exhaled, B is used
- Asymmetry justified elsewhere
  (type system, soundness proof, proof principle, …)

```
[
 forall x: Nat • P(x),

 forall x: Nat •
   (forall y: Nat • y < x ==> P(y)) ==> P(x)
]
```

http://bitbucket.org/viperproject/