SteelCore: An Extensible Concurrent Separation Logic for Effectful Dependent Programs

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Challenges

- How to reflect the effect of concurrency in the language?
- How to support partial correctness?
- How to enable dynamically allocated invariants?

Steel: A Concurrent Separation Logic (CSL) for F*

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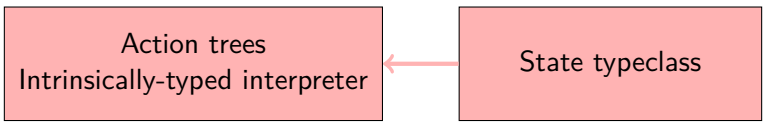

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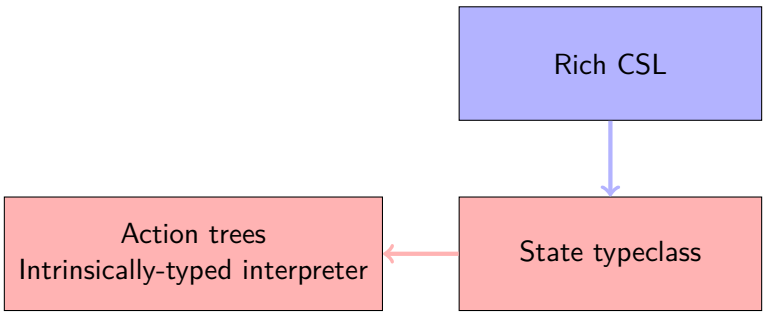

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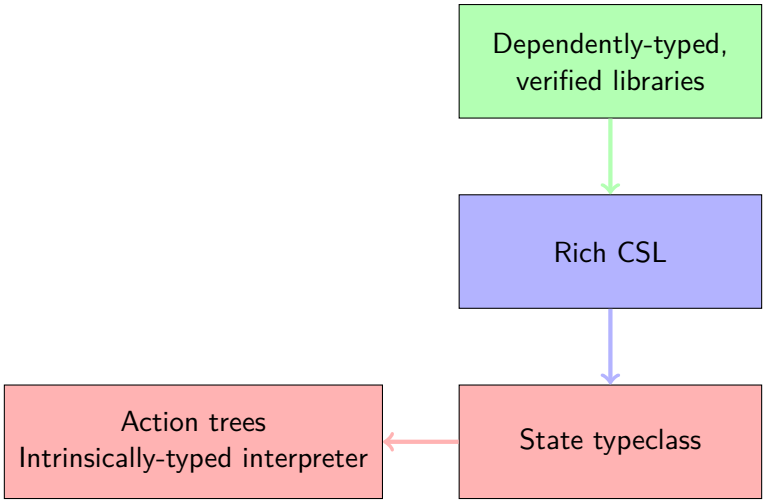

Encoding Computations through Effectful Indexed Action Trees

$$\begin{aligned}\texttt{type state} = \{&\texttt{mem: Type;}\\ &\texttt{slprop:Type; equals; emp; star;}\\ &\texttt{interp: slprop} \to \texttt{mem} \to \texttt{prop}\}\end{aligned}$$

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$$\texttt{type ctree (st:state) : a:Type} \to \texttt{pre:st.slprop} \to \texttt{post:(a} \to \texttt{st.slprop)} \to \texttt{Type} =$$

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type state = {mem: Type;
              slprop:Type; equals; emp; star;
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type ctree (st:state) : a:Type → pre:st.slprop → post:(a → st.slprop) → Type =
 | Ret : y:a → ctree st a (post y) post
 | Act : action a pre post → ctree st a pre post
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  | Par : ctree st a p q → ctree st a' p' q' → ctree st (a & a') (p `st.star` p') (λ (y, y') →
q y `st.star` q' y')
```

Proving Soundness of the Semantics

- We propose an intrinsically-typed definitional interpreter
- Atomic actions are non-deterministically interleaved
- The type of the interpreter states its soundness

```
val run (e:ctree st a p q) : NST a
  (requires λm → st.interp p m)
  (ensures λm0 y m1 → st.interp (q y) m1)
```

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- Invariants

Invariants in Steel

```
let inv_name = nat
val (⇝) (i:inv_name) (p:slprop) : prop
let ival (p:slprop) = i:inv_name{i ⇝p}
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val new_invariant (p:slprop) : Steel (ival p) p emp
```

Using Invariants

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val with_invariant (i:ival p) (f:unit → SteelAtomic a g (p ⋆ q) (λ y → p ⋆ r y))
  : SteelAtomic a g q r
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val with_invariant (i:ival p) (f:unit $\rightarrow$ SteelAtomic a $(i \uplus u)$ g (p $\star$ q) (λ y $\rightarrow$ p $\star$ r y))
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Stacking Abstractions in Steel

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module Steel.Effect
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module Steel.ForkJoin
module Steel.Channels
```

Steel Example: Channel Types

```
val chan (p:prot) : Type
val sender #p (c:chan p) (cur:prot) : slprop
val receiver #p (c:chan p) (cur:prot) : slprop
```

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val send #p (#cur:prot{more cur}) (c:chan p) (x:msg_t cur)
  : Steel unit (sender c cur) (λ _ → sender c (step cur x))
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val send #p (#cur:prot{more cur}) (c:chan p) (x:msg_t cur)
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val recv ... : Steel (msg_t cur) (receiver c cur) (λ x → receiver c (step cur x))
```

Steel Example: PingPong Protocol

```
let pingpong : prot =
  x ← Protocol.send int;
  y ← Protocol.recv (y:int{y > x});
  Protocol.done
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let client (c:chan pingpong) =
  send c 17;
  let y = recv c in
  assert (y > 17);
  return ()
```

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- A shallow embedding of CSL in a dependently-typed language
- A PCM-based memory model
- Concurrency reasoning through dynamically allocated invariants
- 11 kLoC in F*, and a growing stack of verified libraries

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- Implicit Dynamic Frames
- Monotonicity and Preorders for References
- More libraries: Lock-coupling Lists, Counters with local state, ...

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