Research vision

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Programming Languages

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Typed Programming Languages

But what about behaviour?

```
let r = alloc 0 in r := !r + 1; r : ref Nat
```

- r is fresh
- !r > 0
- other effects like I/O ?
- user-defined effects ?
- ...

State of affairs in type-based reasoning

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Values

Well-understood, uniform,

and thoroughly studied! :)

◉ Refinement types

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Odd ⊑ Nat     Even ⊑ Nat

Vec A n = { l:List A | len l = n }
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◉ Dependent types

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◉ Homogeneous implementations

- Agda, Coq, Idris, F*, L.Haskell, ...

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Effects and behaviour

Scattered landscape, effect-specific, little uniformity! :(

- **Hoare Type Theory** (state)

```
M : Ψ.X.{P}x:A{Q}
```

- **F*** (state, exceptions, but no I/O)

```
M : ST A wpST
```

~~`M : IO A wpIO`~~

- **Session Types** (I/O & channels)

```
c : ?Nat.!String.!Nat.T
```

- **Graded monads, param. monads**

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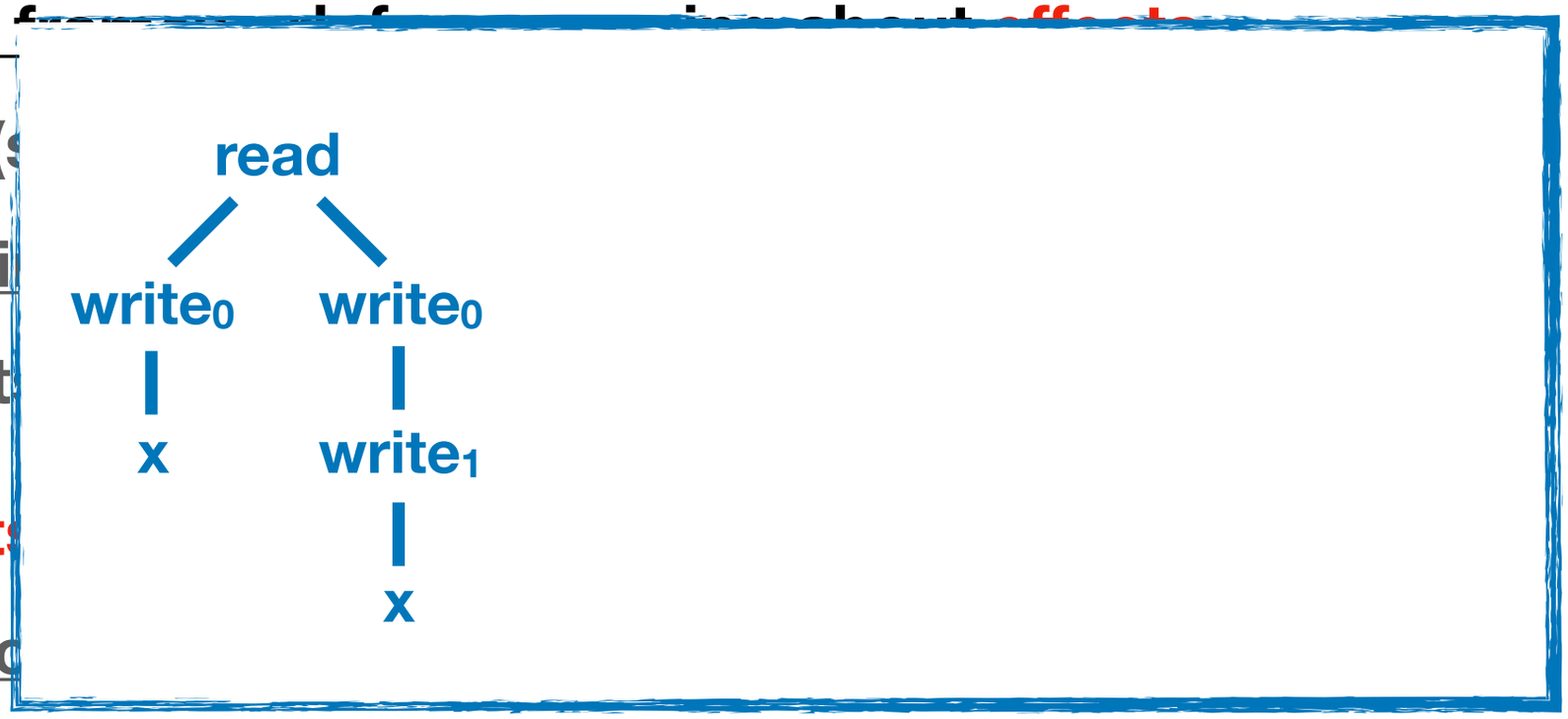

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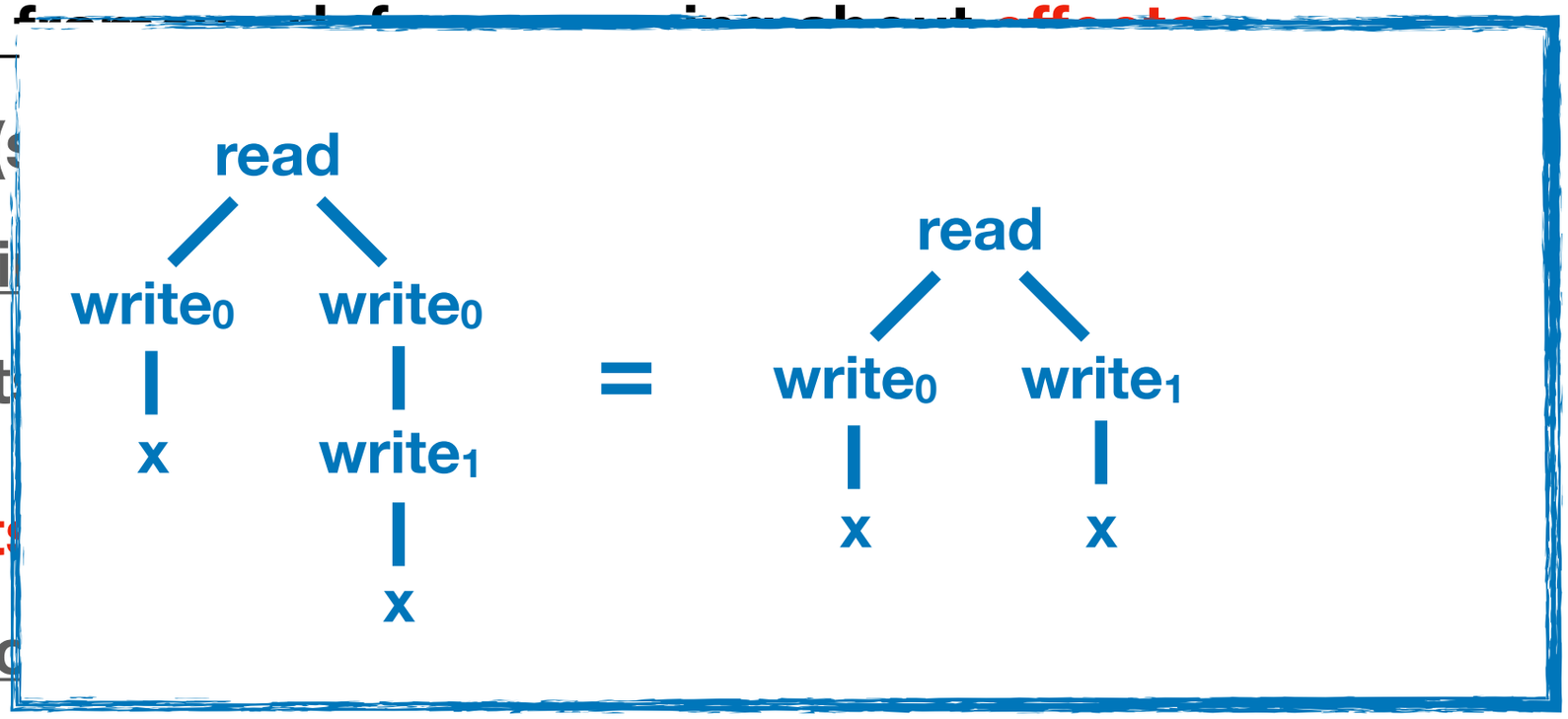

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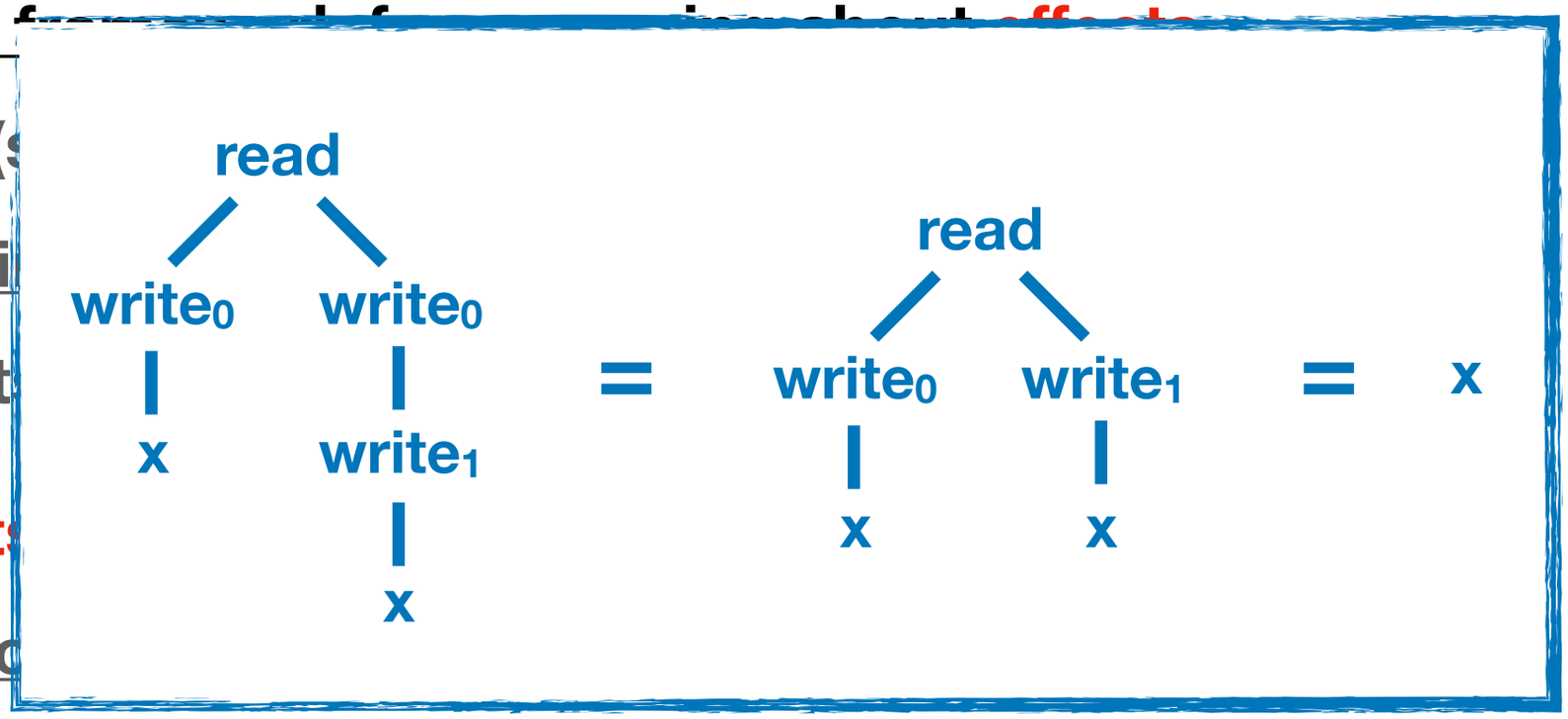

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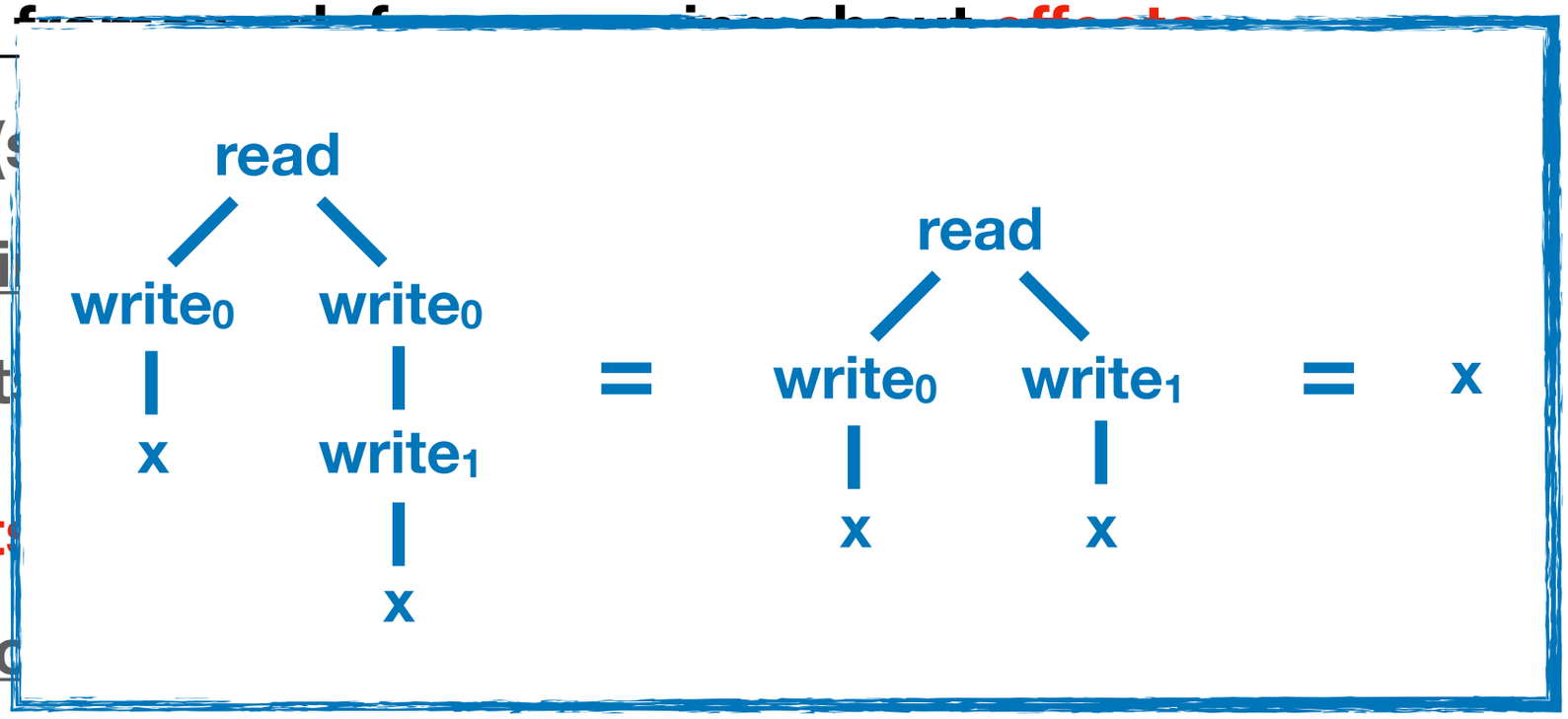

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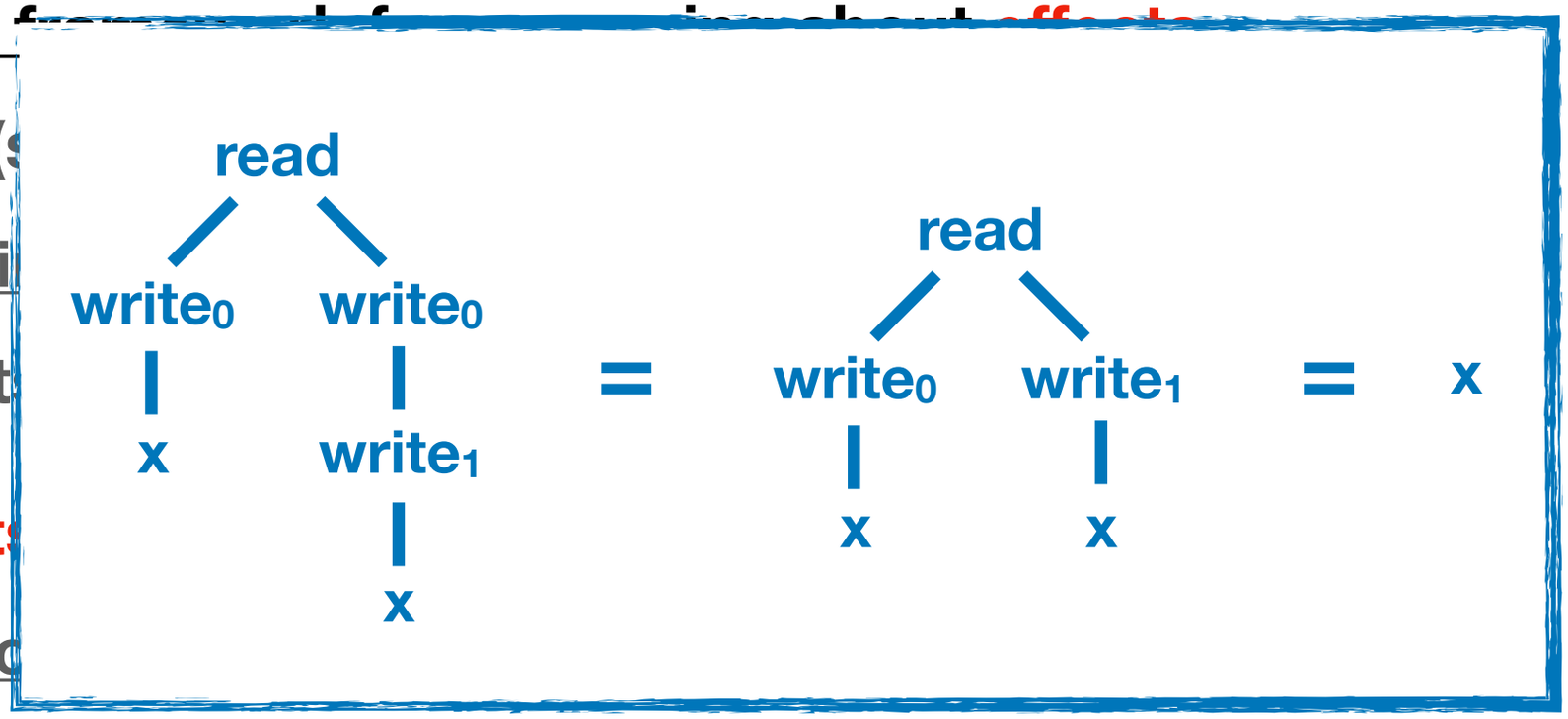

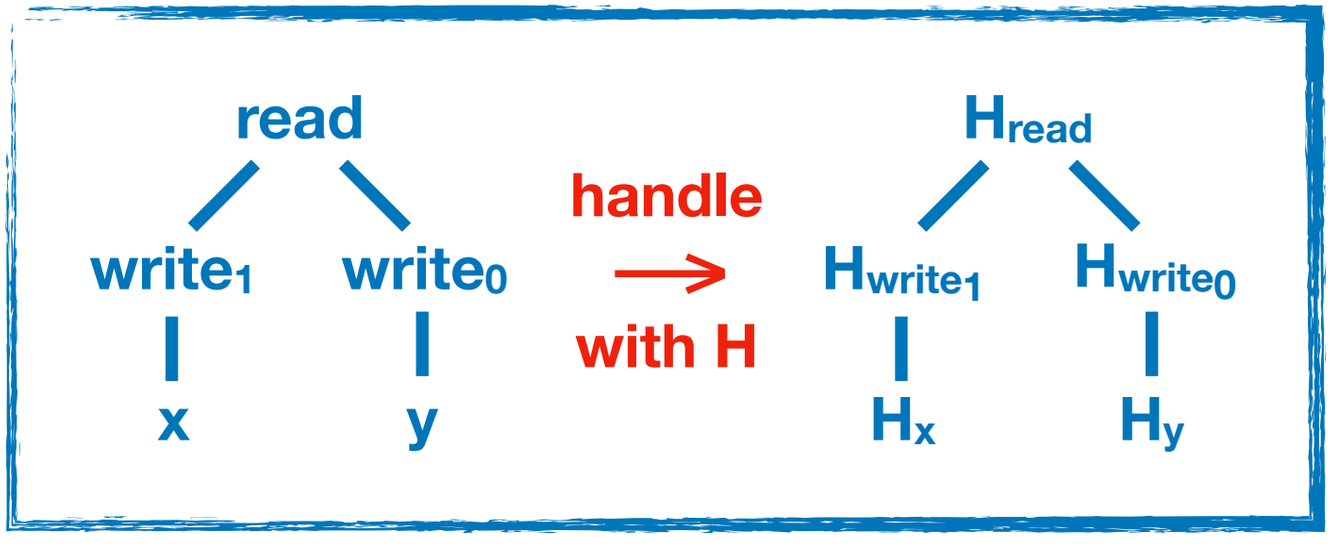

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- **State of the art:** very popular (!) but effect systems too coarse grained (!)
  - concurrency, probability, delimited control, monadic reflection, ...
  - Multicore OCaml, Uber's Pyro tool, Eff, Koka, Frank, ...
  - `M : A ! { read , write, throw }`

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$$\langle op \rangle(\psi_1, \ldots, \psi_n) = \left\{ \begin{array}{ccccc} & & op & & \\ & \swarrow & & \searrow & \\ t_1 & & \cdots & & t_n \end{array} \;\middle|\; t_1 \in \psi_1 \wedge \cdots \wedge t_n \in \psi_n \right\}$$

$$M : A \,!\, \psi$$

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$$\{\{1\}\}\ A\ \{Q\} = A\ !\ \bigvee_{i\in\{0,1\},q\in Q} \langle rd\rangle(\langle wr_i\rangle(ret), \langle wr_q\rangle(ret))$$

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- **Challenges:**
  - non-linear effect equations (read x x = x)
  - operations with value params. and variable binding
  - effect instances, generativity, and locality (my current focus in LJ)
  - dynamic nature of handlers

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- **Probabilistic programming**
  - `sample` as an **algebraic effect**; `condition` as a **handler** (cf Pyro)

Temporal view

- **Year 1**

  - modal logic (design, model and proof theory)
  - instances, generativity, locality
  - case studies and applications

- **Year 2**

  - declarative PL design (type-and-effect system)
  - meta-theory (denotational and operational)
  - case studies and applications

- **Year 3**

  - algorithmic PL design (type-and-effect inference)
  - implementation
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  - case studies

- **In parallel**
  - continue collaborations with the F* team
  - continue collaborations on container datatypes
  - forge new collaborations in Oxford (and elsewhere)

Conclusions

- **Software is everywhere!**
- **We had better know what it does!**
- **General and uniform frameworks already exist for values!**
- **But only scattered, effect-specific frameworks for behaviour!**
- **My research will seek to rectify this situation**
  - a uniform and widely applicable approach
  - inspired by algebraic effects and effect handlers
  - both foundational theory and exciting applications