Research vision

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Balliol College, 12.11.2018

Programming Languages

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let r = alloc 0 in r := r + 1; r
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let r = alloc 0 in r := r + 1; r : ref Nat
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lightweight and modular

specification
verification
documentation

correct by construction

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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**

```
Odd ⊑ Nat     Even ⊑ Nat

Vec A n = {l:List A | len l = n}
```

- **Dependent types**

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Vec a h =
| nil : Vec a 0
| cons : ... -> Vec a (n+1)
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- **Agda, Coq, F*, Idris, 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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  - wide range of effects (state, I/O, exceptions, probability, ...)
  - primitive and user-defined effects
  - combinations of effects

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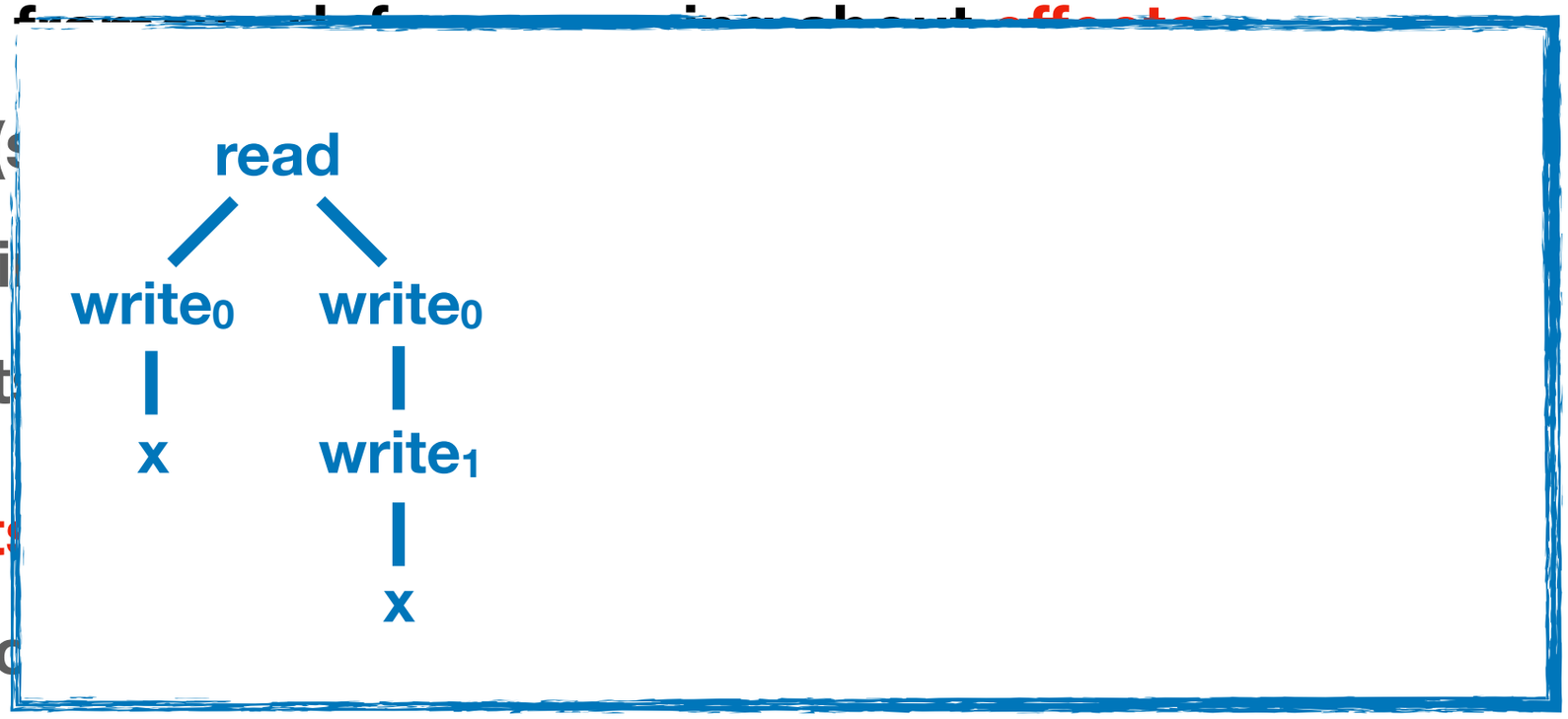

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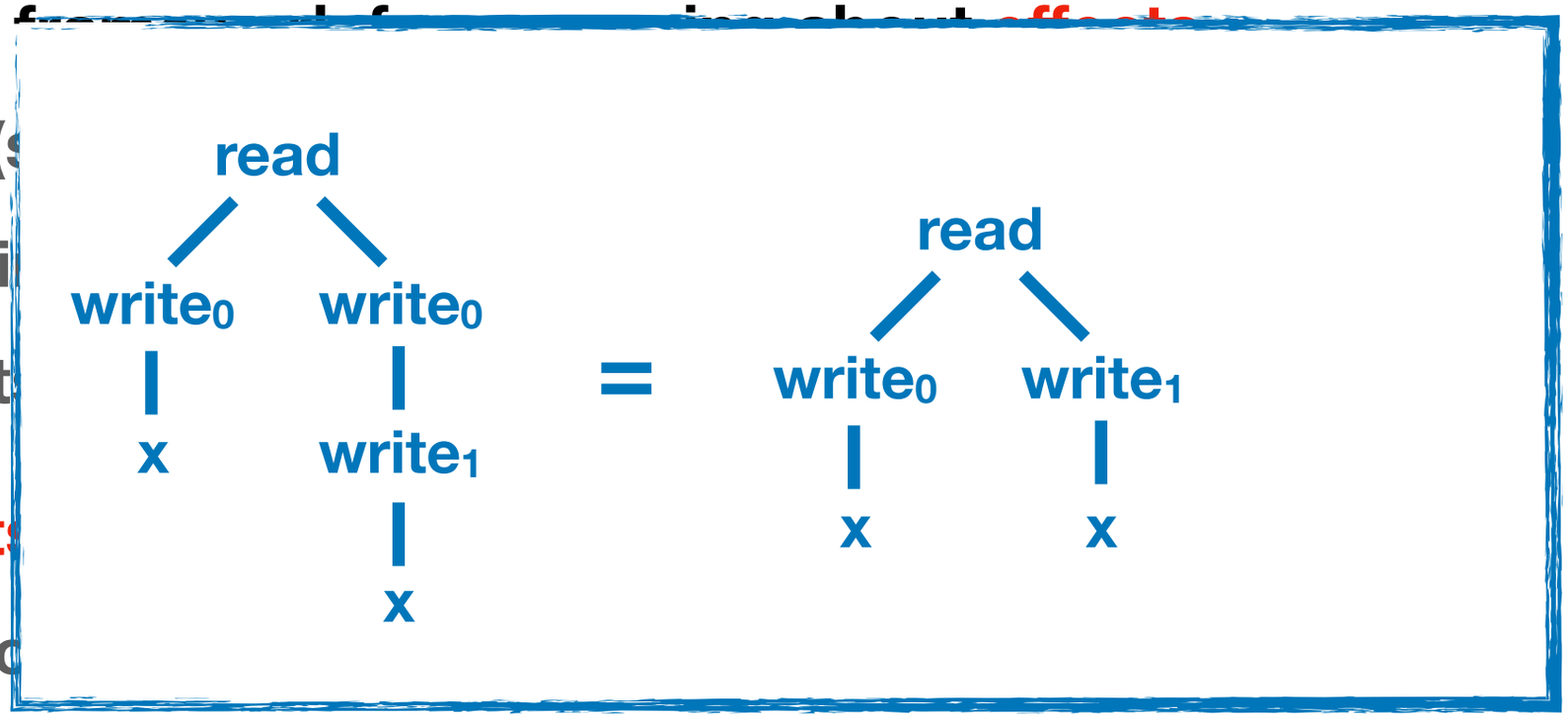

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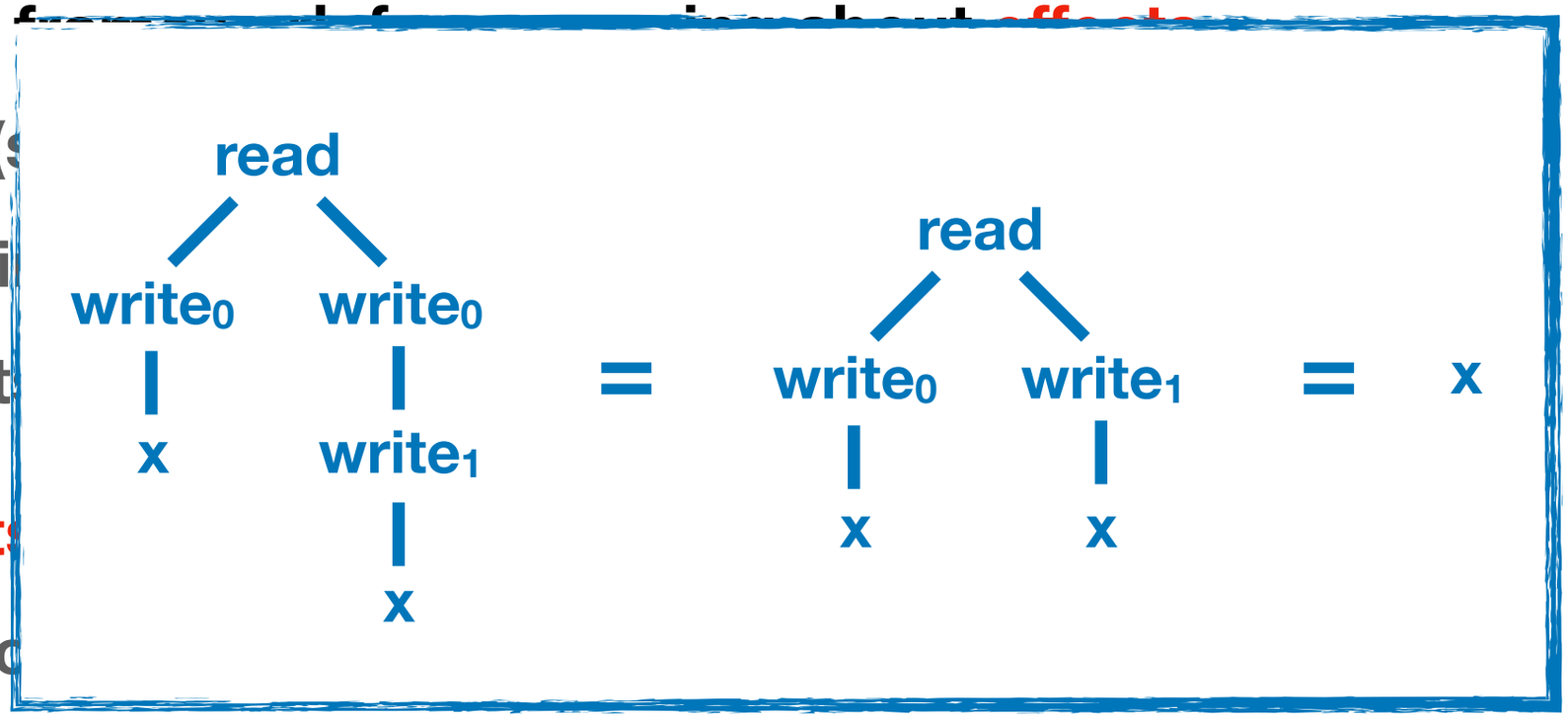

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- **State of the art:** very popular (!) but effect systems too coarse grained (!)
  - concurrency, delimited control, monadic reflection, ...
  - Multicore OCaml, Uber's Pyro tool, Eff, Koka, Frank, ...
  - `M : A ! { read , write, throw }`

Specifics: modal logic based c. ref. types

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  - $\langle op \rangle(\psi_1, \ldots, \psi_n)$ for each n-ary operation symbol (cf TYPES'15)

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

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

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

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- **Probabilistic programming**
  - algebraic effects and handlers as in Uber's Pyro tool

Temporal planning

- **Year 1**

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

- **Year 2**

  - declarative PL design (type-and-effect system)
  - meta-theory (denotational and operational)
  - encodings of existing specification styles

- **Year 3**

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

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**
  - **inspired by algebraic effects and effect handlers**
  - **exploiting modalities in computational refinement types**
  - **with a wide range of potential application areas**