Type Classes in CaMPL

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What are Type Classes and Why Are They Important?

We first need to talk about overloading

Overloading

- An operator is overloaded if it has two (or more) implementations, distinguished by type of its arguments and its output.
- In many languages, arithmetic operators (like ‘+’) have multiple distinct implementations for different types such as Int or Double.
- The decision on what implementation to use is made at compile time.
- In a language which has type inference and polymorphism, implementing "overloading" is more complicated:
    - When one defines a function, one should be able to use overloaded operators in the definition. However, this can cause the type of the overloaded operators to be polymorphic.

Type Classes: Haskell's Solution to Overloading

- Haskell uses type classes for implementing overloading.
- A type class declares a set of operations based on a type variable.
- An instance of a type class provides an implementation for the type class operations.
- If the type class operator is used in a function definition, the type need to be tagged with the type class name to indicate that the compiler must convert the operator into an instance.

Haskell

```haskell
class Eq a where
    (==) :: a -> a -> Bool

instance Eq Int where
    (==) :: Int -> Int -> Bool
    a == b = eq_int a b
```

```haskell
instance Eq a => Eq [a] where
    (==) :: Eq a => [a] -> [a] -> Bool
    [] == [] = True
    (x:xs) == (y:ys) = (x == y) && (xs == ys)
    _ == _ = False
```

Type Classes: Not Only Overloading!

- The benefit of type classes is not only for providing overloading.
- Type Classes can allow succinct and more understandable programs.
- One can make type classes depend on type constructors: this adds further power to type classes ...

Haskell

```haskell
class Functor f where
    fmap :: (a → b) → f a → f b
```

```haskell
instance Functor [] where
    fmap :: (a → b) → [a] → [b]
    fmap f [] = []
    fmap f (x:xs) = f x : fmap f xs
```

More Examples of Higher Order Type Classes

- One can define the Monad type class. In order for a type constructor to be a Monad it needs to be a Functor.
- One can make a type constructor (e.g List) an instance of Monad type class by implementing the return and sequence operations for it.

Haskell

```
class Functor m ⇒ Monad m where
    return :: a → m a
    (>>=) :: m a → (a → m b) → m b
```

```
instance Monad [] where
    return :: a → [a]
    return x = [x]

    (>>=) :: [a] → (a → [b]) → [b]
    xs >>= f = concatMap f xs
```

How are Type Classes Implemented?

- At compile time, after type inference, any usage of type class operators is translated to the core Haskell.
- Each type class operator is an input function to the function that uses it, and type class tags are also converted to the type of the function instance.

Haskell

```haskell
member :: Eq a ⇒ [a] → a → Bool
member list x = case list of
    [] → False
    (y:ys) → y == x || member ys x

r = member [1,2,3] 1
```

```haskell
--translation
member' :: (a → a → Bool) → [a] → a → Bool
member' = \eq_a list x → case list of
    [] → False
    (y:ys) → eq_a y x || member' eq_a ys x

r' = member' eq_int [1,2,3] 1
```

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What is CaMPL?

Categorical Message Passing Language

CaMPL: Categorical Message Passing Language

- CaMPL is a polymorphic concurrent language with type inference.
- Its sequential tier is an implementation of lambda-calculus with data types.
- Its concurrent tier is an implementation of a linear actegory (a linear actegory is given by a monoidal category acting on a linearly distributive category).
- CaMPL was implemented by Robin Cockett, Prashant Kumar and Jared Pon at the University of Calgary.

Say “Hello World!” in CaMPL

- The helloworld process has an output channel of type StringTerminal.
- It puts the string “Hello World” on the terminal
- At the end it halts the terminal.

CaMPL

```
proc helloworld :: | => StringTerminal =
    | => terminal -> do
       hput StringTerminalPut on terminal
       put "Hello World! press any key to exit..." on terminal
       hput StringTerminalGet on terminal
       get input on terminal
       hput StringTerminalClose on terminal
       halt terminal
```

```
proc run :: | => StringTerminal =
     | => terminal -> helloworld( | => terminal)
```

Categorical Semantics of the Concurrent Part

The categorical semantics of the concurrent side of CaMPL is defined by a linearly distributive category:

- Objects are concurrent channel types.
- Maps are concurrent processes (from input polarity to output polarity channels).
- Identity is a channel.
- Composition is given by plugging two processes to each other.
- The $\otimes$ and $\oplus$ functors allow bundling the channels together.

Categorical Semantics of the Sequential Part

The categorical semantics of the sequential side of CaMPL is defined by a cartesian closed category with data types:

- Objects are sequential types
- Maps are sequential functions.
- Identity is an identity function
- Composition is given by composition of functions

As for a functional language

Categorical Semantics of Message Passing

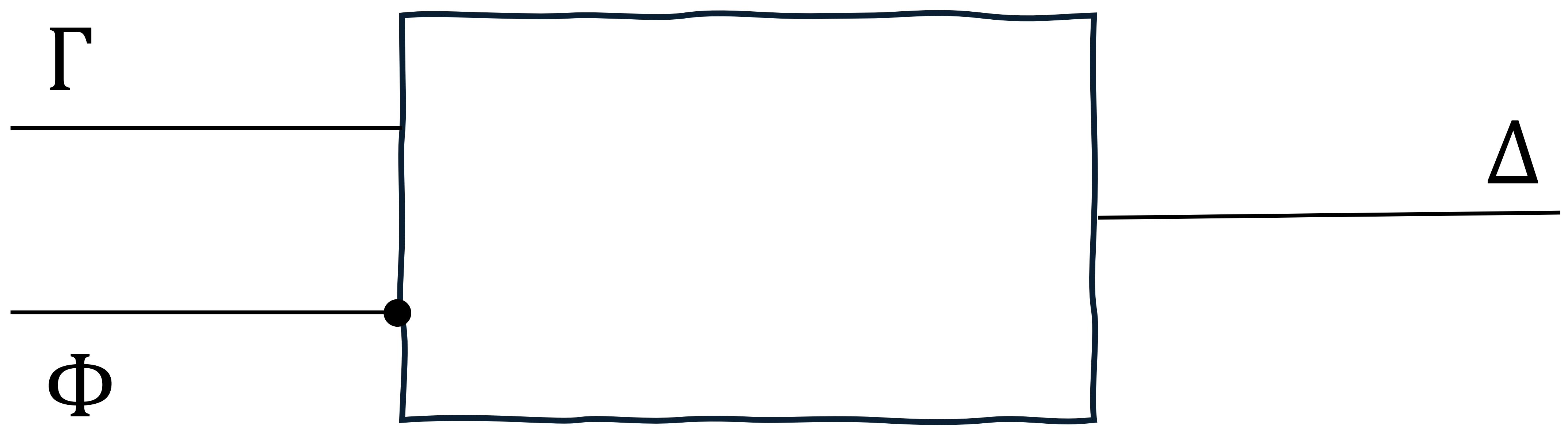
The categorical semantics of the message passing is a linear actegory:

- It consists of a cartesian closed category $\mathbb{S}$ (sequential part) acting on a linearly distributive category $\mathbb{C}$ (concurrent part).
- There are two functors for $\mathbb{S}$ acting on $\mathbb{C}$:
  - ○ (:= Put) : $\mathbb{S} \times \mathbb{C} \to \mathbb{C}$
  - ● (:= Get) : $\mathbb{S}^{op} \times \mathbb{C} \to \mathbb{C}$

Proof Theory of CaMPL

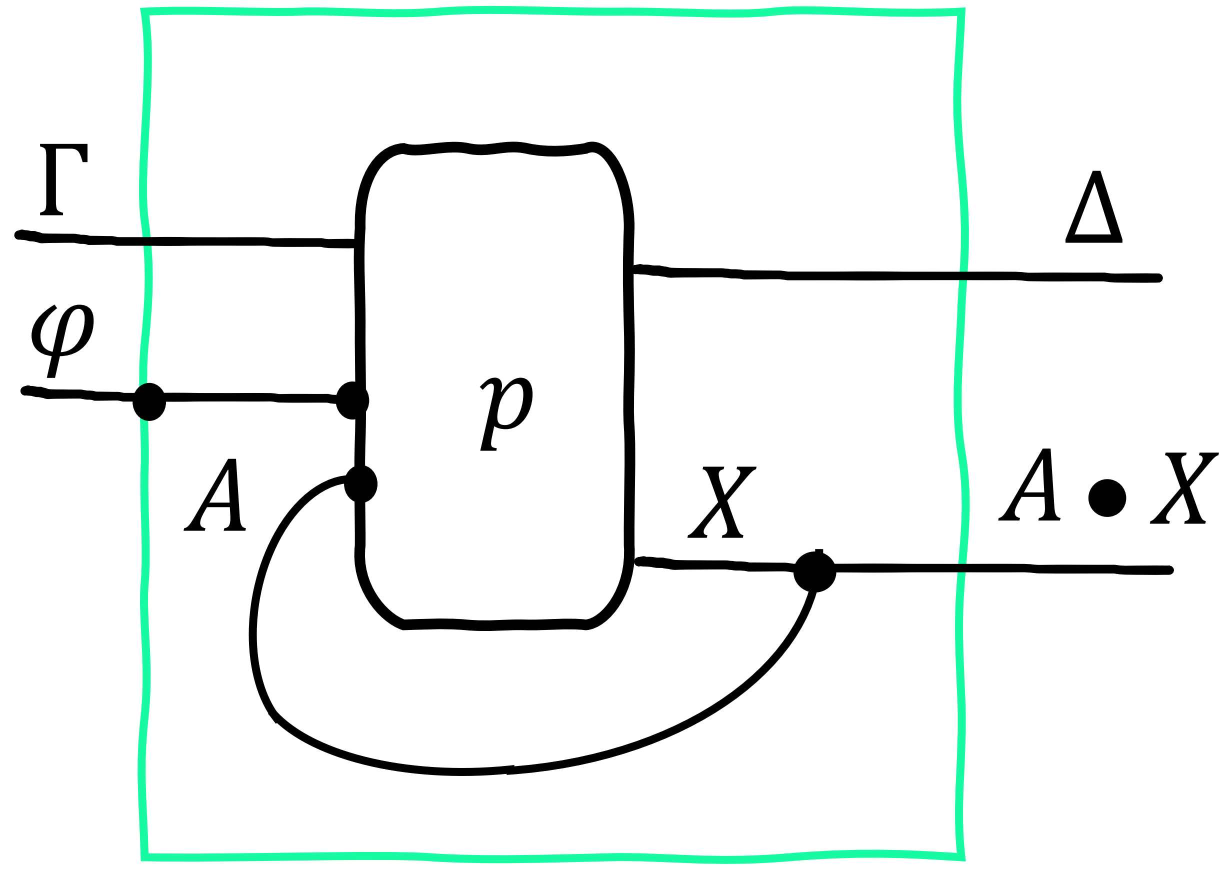
- The concurrent side of CaMPL is specified by the proof theory of linear actegories.
- It is specified by inference rules for concurrent sequents.
- Programming features of CaMPL can also be described equivalently by circuit diagrams.

$$\Phi \mid \Gamma \Vdash \Delta$$



Summary of CaMPL Concurrent Constructs

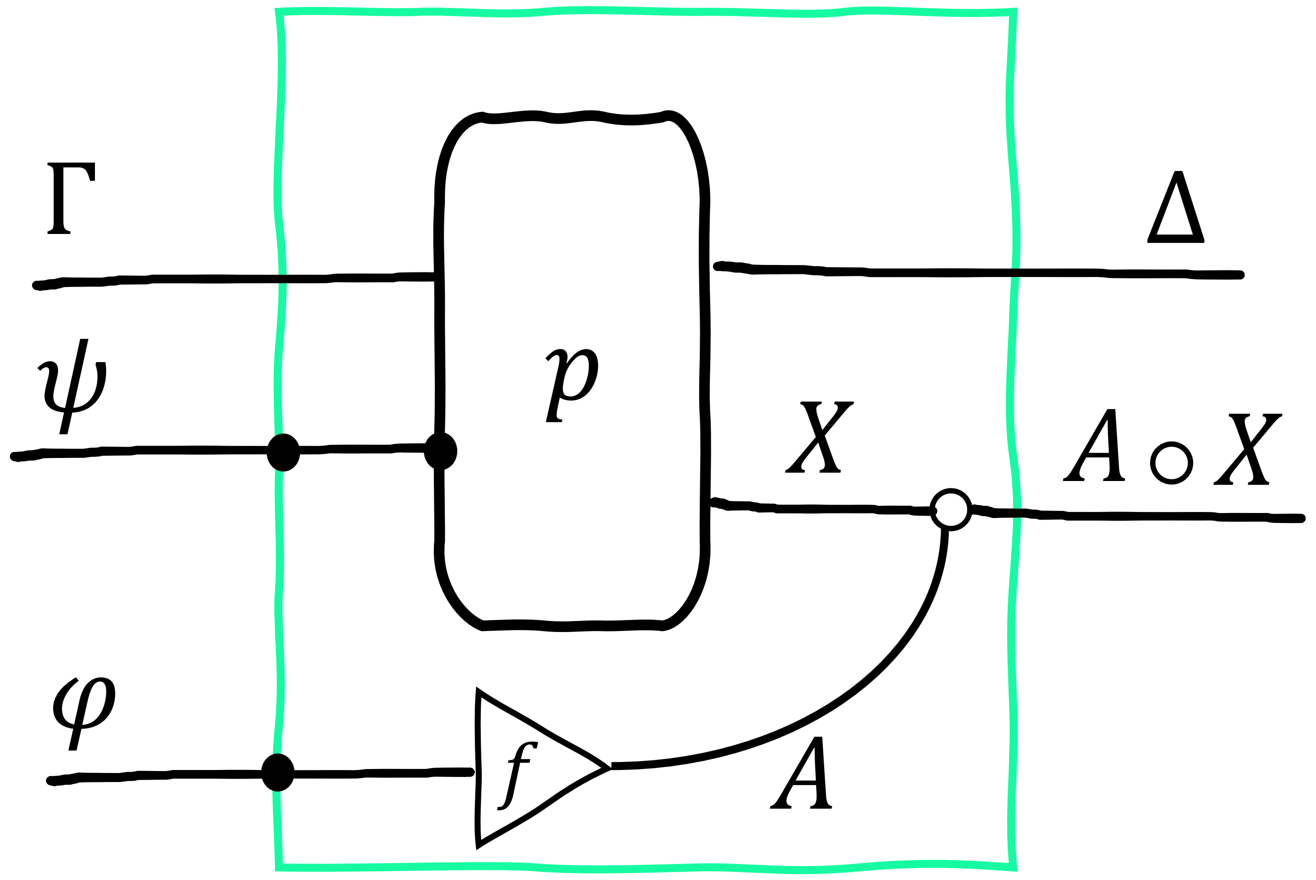
$$\frac{\Phi, A \mid \Gamma \Vdash X, \Delta}{\Phi \mid \Gamma \Vdash A \bullet X, \Delta} \bullet_r$$



CaMPL

```
proc q ::
   Phi | Gamma => Delta, Get(A|X) =
     phi | gamma => delta, alpha -> do
        get a on alpha
        p(phi, a | gamma => delta, alpha)
```

$$\frac{\Phi \vdash A \quad \Psi \mid \Gamma \Vdash X, \Delta}{\Phi, \Psi \mid \Gamma \Vdash A \circ X, \Delta} \circ_r$$

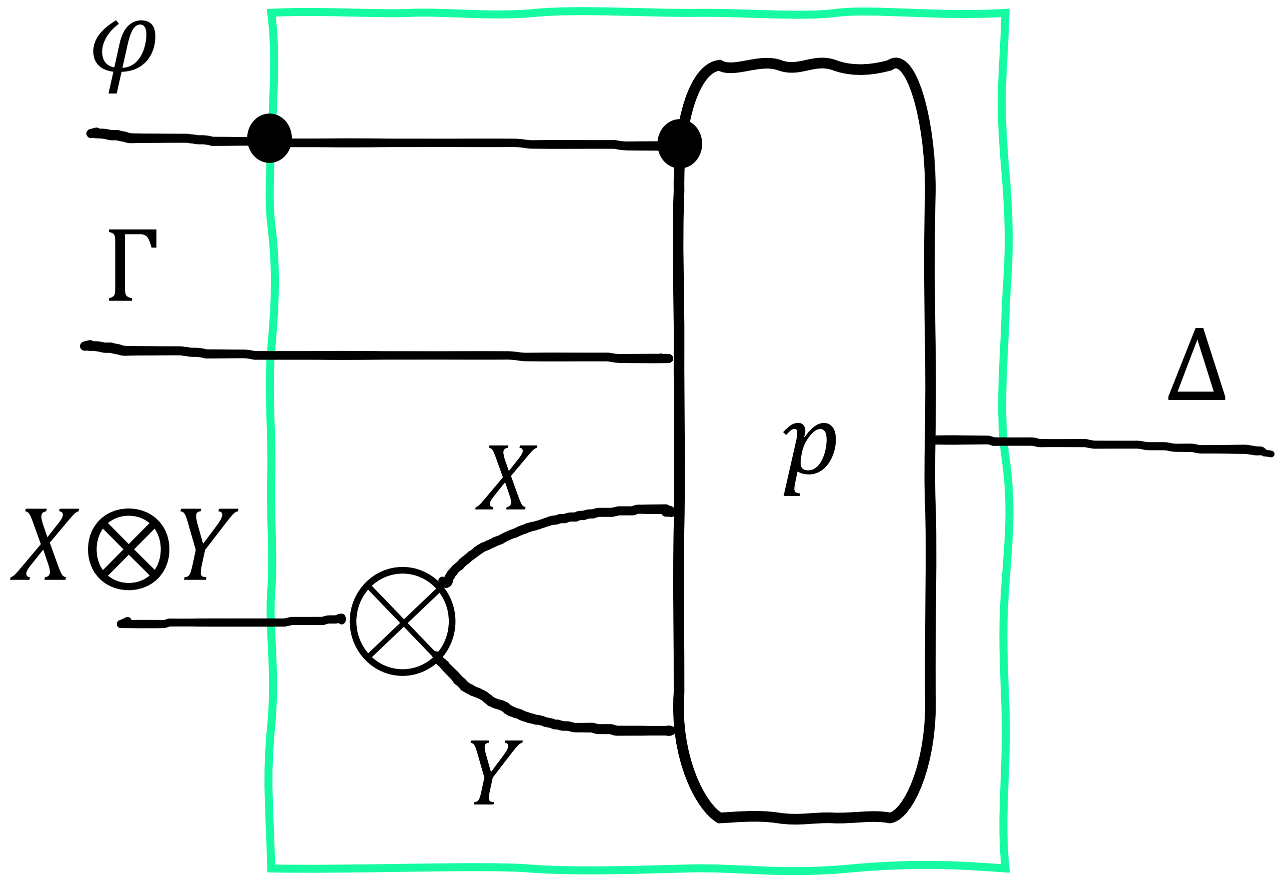


CaMPL

```
proc q ::
   A, Phi | Gamma => Delta, Put(A|X) =
     a, phi | gamma => delta, alpha -> do
        put a on alpha
        p(phi | gamma => delta, alpha)
```

Summary of CaMPL Concurrent Constructs

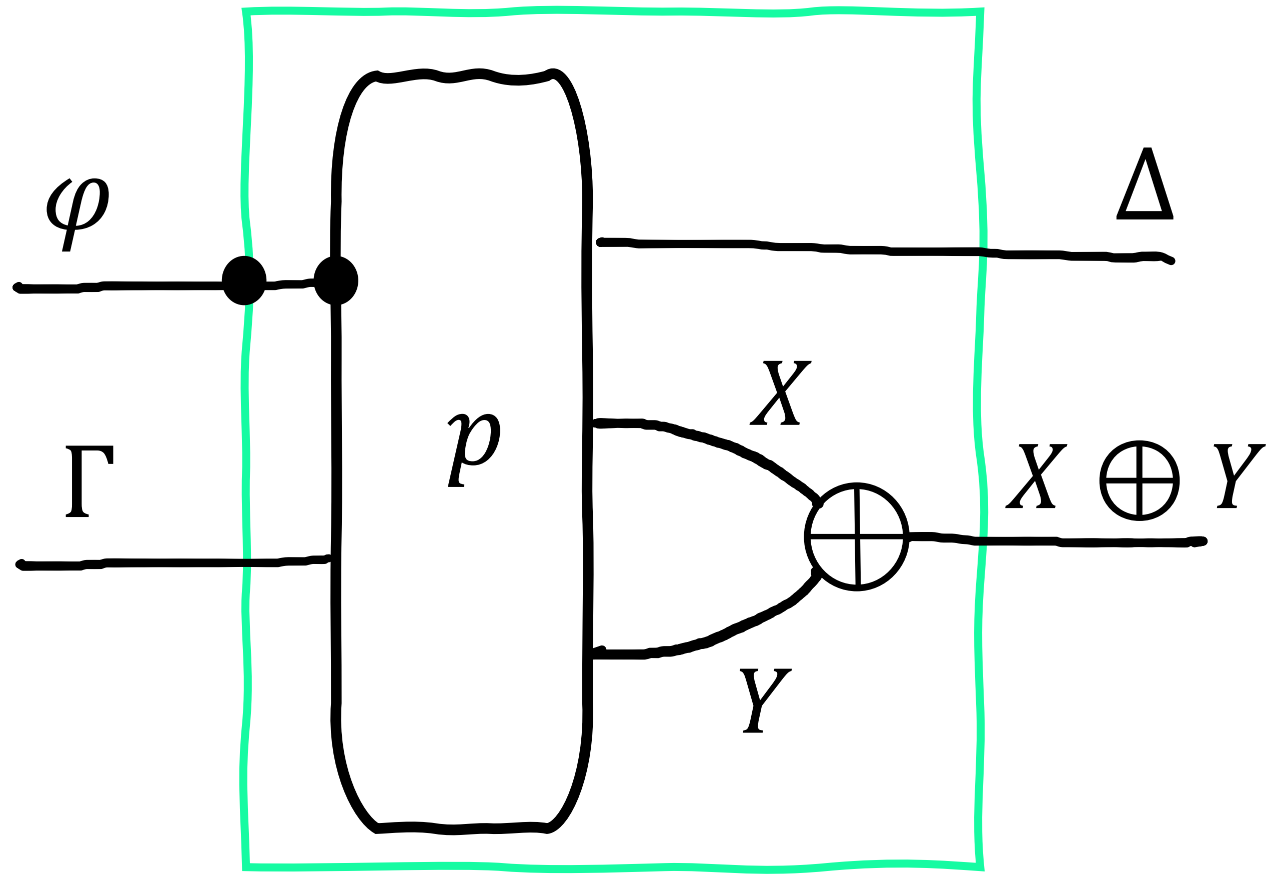
$$\frac{\Phi \mid \Gamma, X, Y \Vdash \Delta}{\Phi \mid \Gamma, X \otimes Y \Vdash \Delta} \otimes_{\ell}$$



CaMPL

```
proc q ::
  Phi | Gamma, X (*) Y => Delta =
   phi | gamma, alpha => delta -> do
     split alpha into aplpha1, alpha2
     p(phi| gamma, alpha1, alpha2 => delta)
```

$$\frac{\Phi \mid \Gamma \Vdash X, Y, \Delta}{\Phi \mid \Gamma \Vdash X \oplus Y \Delta} \oplus_{r}$$



CaMPL

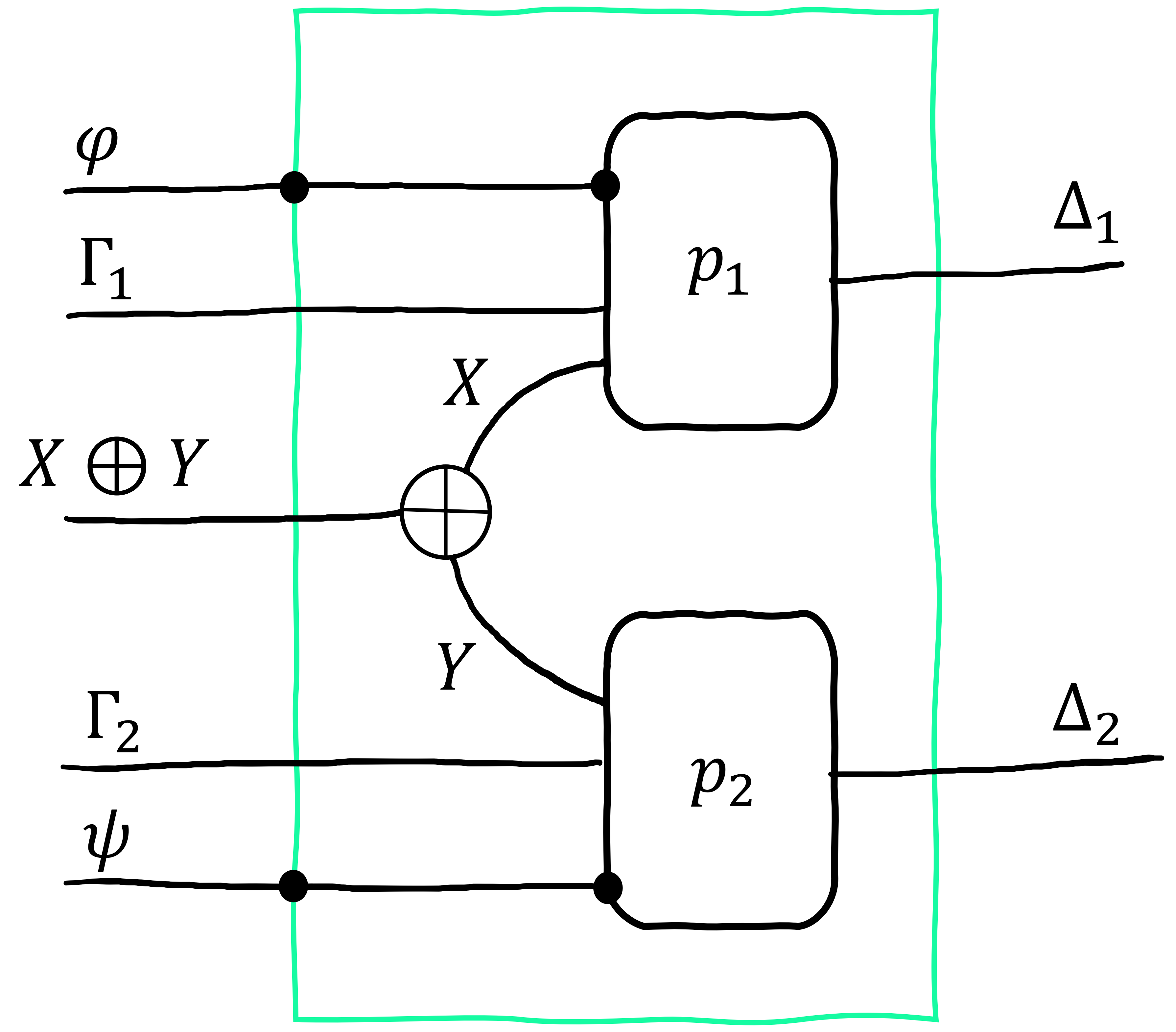
```
proc q ::
  Phi | Gamma => Delta, X (+) Y =
   phi | gamma => delta, alpha -> do
     split alpha into aplpha1, alpha2
     p(phi| gamma => delta, alpha1, alpha2)
```

Summary of CaMPL Concurrent Constructs

$$\frac{\Phi \mid \Gamma_1, X \Vdash \Delta_1 \quad \Psi \mid Y, \Gamma_2 \Vdash \Delta_2}{\Phi, \Psi \mid \Gamma_1, X \oplus Y, \Gamma_2 \Vdash \Delta_1, \Delta_2} \oplus_\ell$$

CaMPL

```
proc q ::
  Phi, Psi | Gamma1, Gamma2 => X (*) Y, Delta1, Delta2 =
   phi | gamma1, gamma2 => alpha, delta1, delta2 -> do
     fork alpha as
        alpha1 -> p1(psi|gamma1 => delta1, alpha1)
        alpha2 -> p2(phi|gamma2 => delta2, alpha2)
```

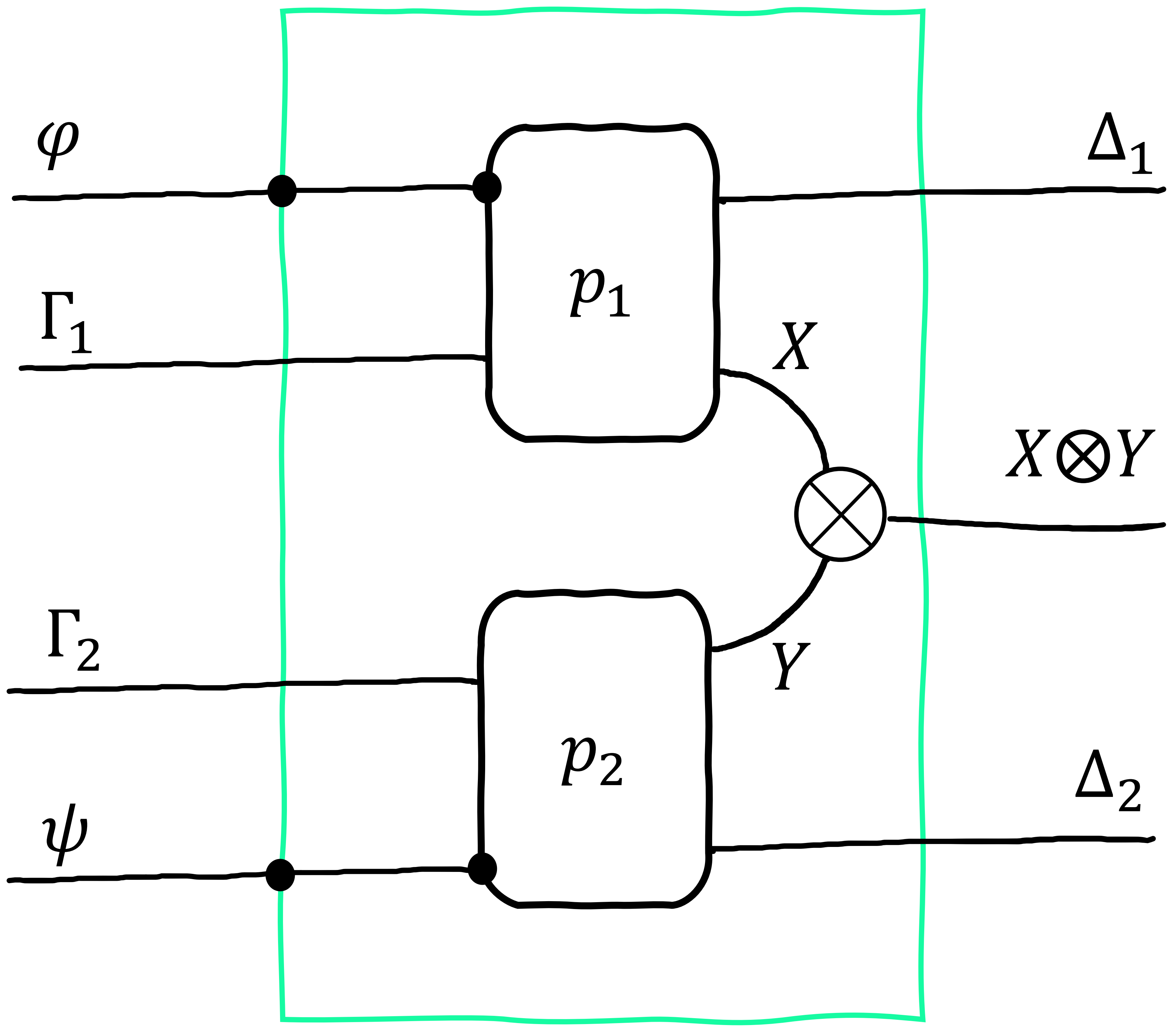


Summary of CaMPL Concurrent Constructs

$$\frac{\Phi \mid \Gamma_1 \Vdash \Delta_1, X \qquad \Psi \mid \Gamma_2 \Vdash Y, \Delta_2}{\Phi, \Psi \mid \Gamma_1, \Gamma_2 \Vdash \Delta_1, X \otimes Y, \Delta_2} \otimes_r$$

CaMPL

```
proc q ::
 Phi, Psi | Gamma1, Gamma2, X (+) Y => Delta1, Delta2 =
   phi | gamma1, gamma2, alpha => delta1, delta2 -> do
     fork alpha as
        alpha1 -> p1(psi|gamma1 => delta1, alpha1)
        alpha2 -> p2(phi|gamma2 => delta2, alpha2)
```

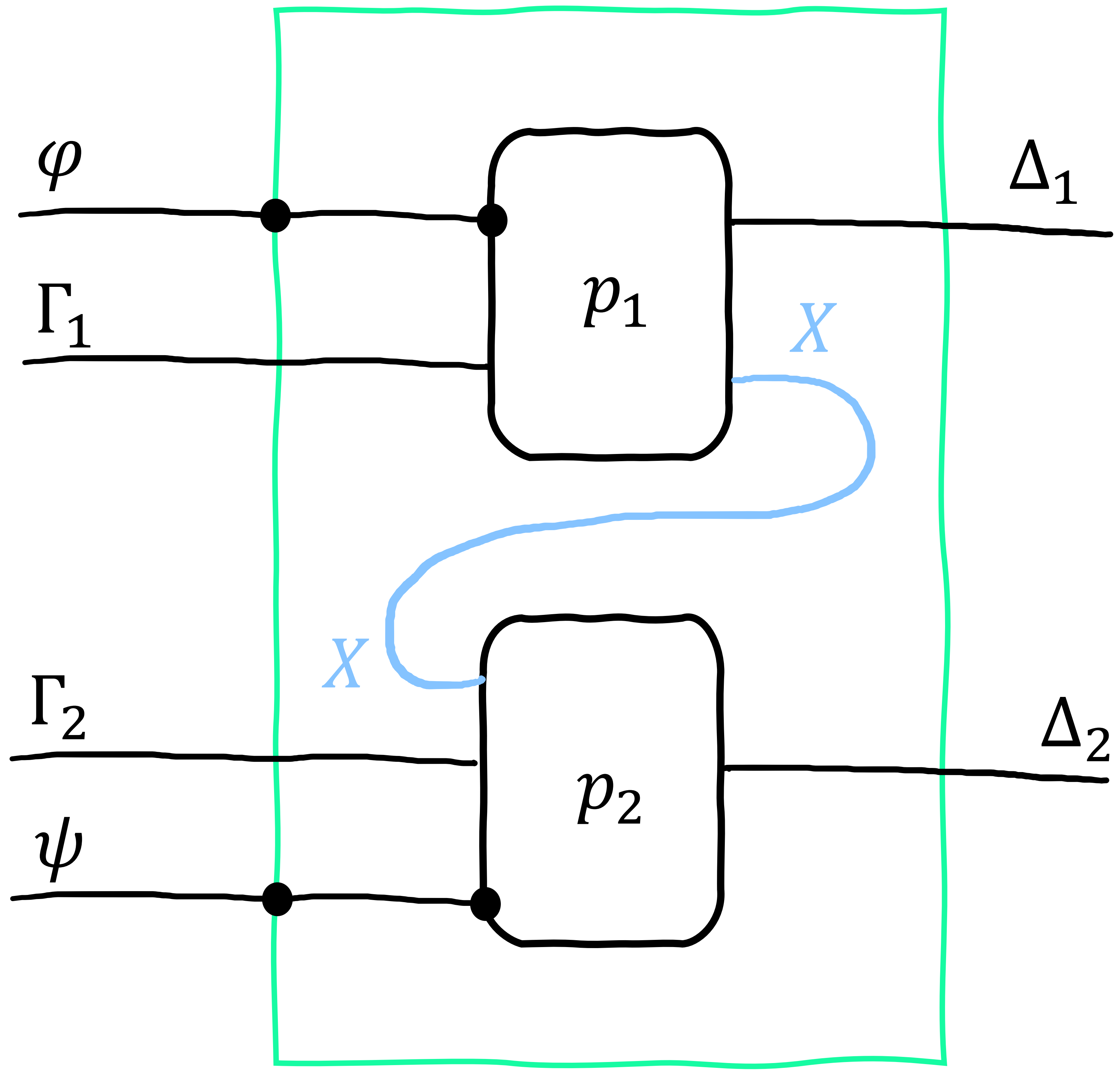


Summary of CaMPL Concurrent Constructs

$$\frac{\Phi \mid \Gamma_1 \Vdash \Delta_1, X \qquad \Psi \mid X, \Gamma_2 \Vdash \Delta_2}{\Phi, \Psi \mid \Gamma_1, \Gamma_2 \Vdash \Delta_1, \Delta_2} \text{ cut}$$

CaMPL

```
proc q ::
   Phi, Psi | Gamma1, Gamma2 => Delta1, Delta2 =
       phi, psi | gamma1, gamma2 => delta1, delta2 ->
           plug
              p1(phi | gamma1 => delta1, x)
              p2(psi | gamma2, x => delta2)
```



3.1

How to add type classes to the sequential CaMPL?

Inspired by Haskell

Type Classes in Sequential CaMPL

For the sequential side of CaMPL as it is a functional-style language one can use the same approach to type classes as Haskell.

CaMPL

```
proc getFromTerminal ::
  Parse A ⇒ | Get(A | TopBot) ⇒ StringTerminal =
    | ch ⇒ strterm → do
      hput StringTerminalPut on strterm
      put "enter something" on strterm
      hput StringTerminalGet on strterm
      get input on strterm

      case parse(input) of
       Just(a_val) → do
           put a_val on ch
       Nothing → getFromTerminal(|ch ⇒ strterm)
```

CaMPL

```
-- translation
proc getFromTerminal ::
  Fun([Char],Maybe(A))| Get(A | T) ⇒ StringTerminal =
    parseA |ch ⇒ strterm → do
      hput StringTerminalPut on strterm
      put "enter something" on strterm
      hput StringTerminalGet on strterm
      get input on strterm

      case App(input, parseA) of
        Just(a_val) → do
          put a_val on ch
        Nothing → getFromTerminal(parseA|ch ⇒ strterm)
```

3.2 What about concurrent type classes?

As far as we know, there is no implementation for concurrent type classes …

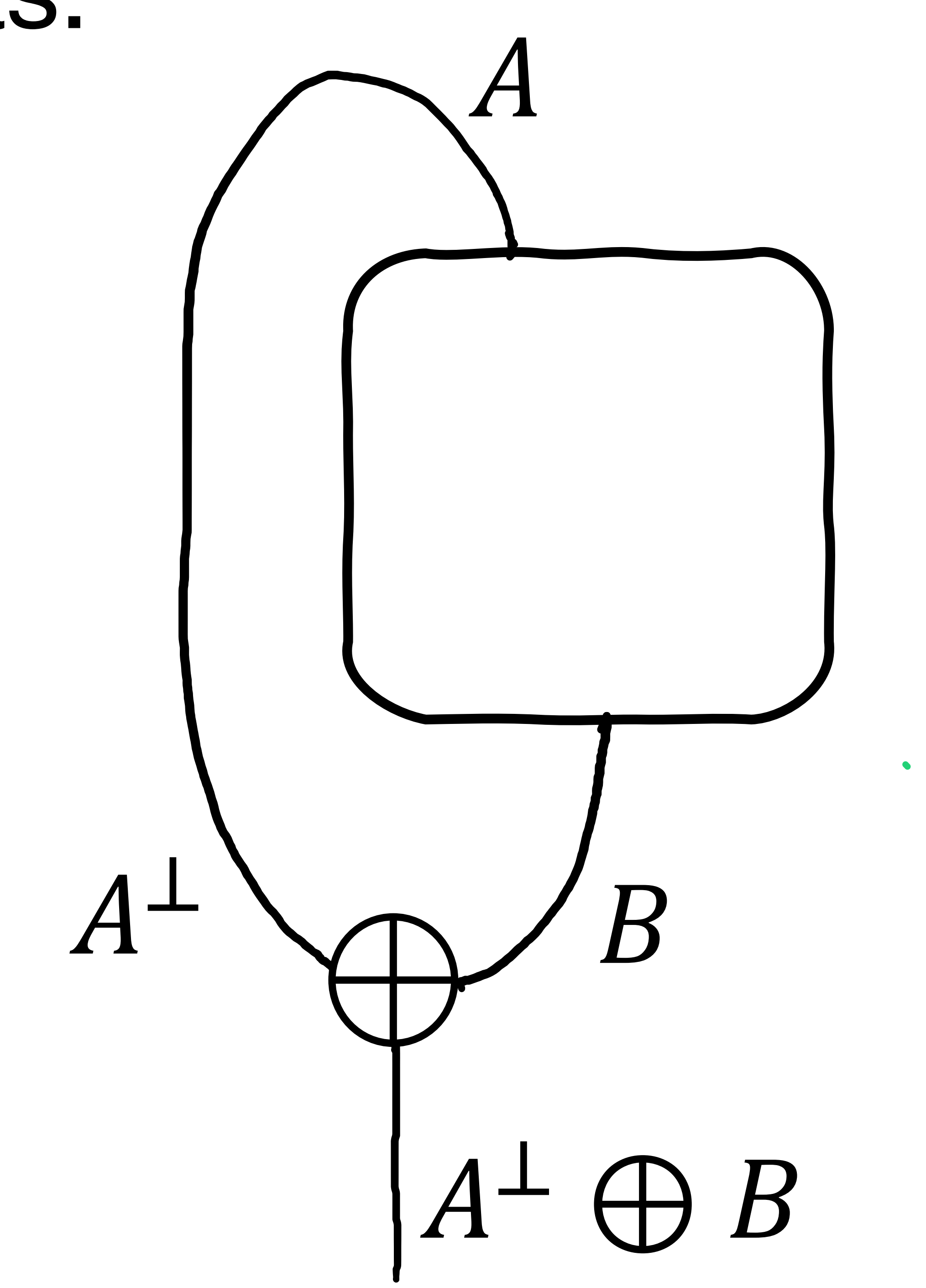
Type Classes in Concurrent CaMPL

- CaMPL is one of the first languages with a strongly typed concurrent side.
- CaMPL's rich concurrent type system is a necessary basis for investigating concurrent type classes.
- As far as we know, this is the first time that concurrent type classes have been considered for a concurrent language.

Type Classes in Concurrent CaMPL

- The concurrent side of CaMPL is already higher order as:

$$\frac{\Gamma \otimes A \vdash B}{\Gamma \vdash A \multimap B := A^{\perp} \oplus B}$$



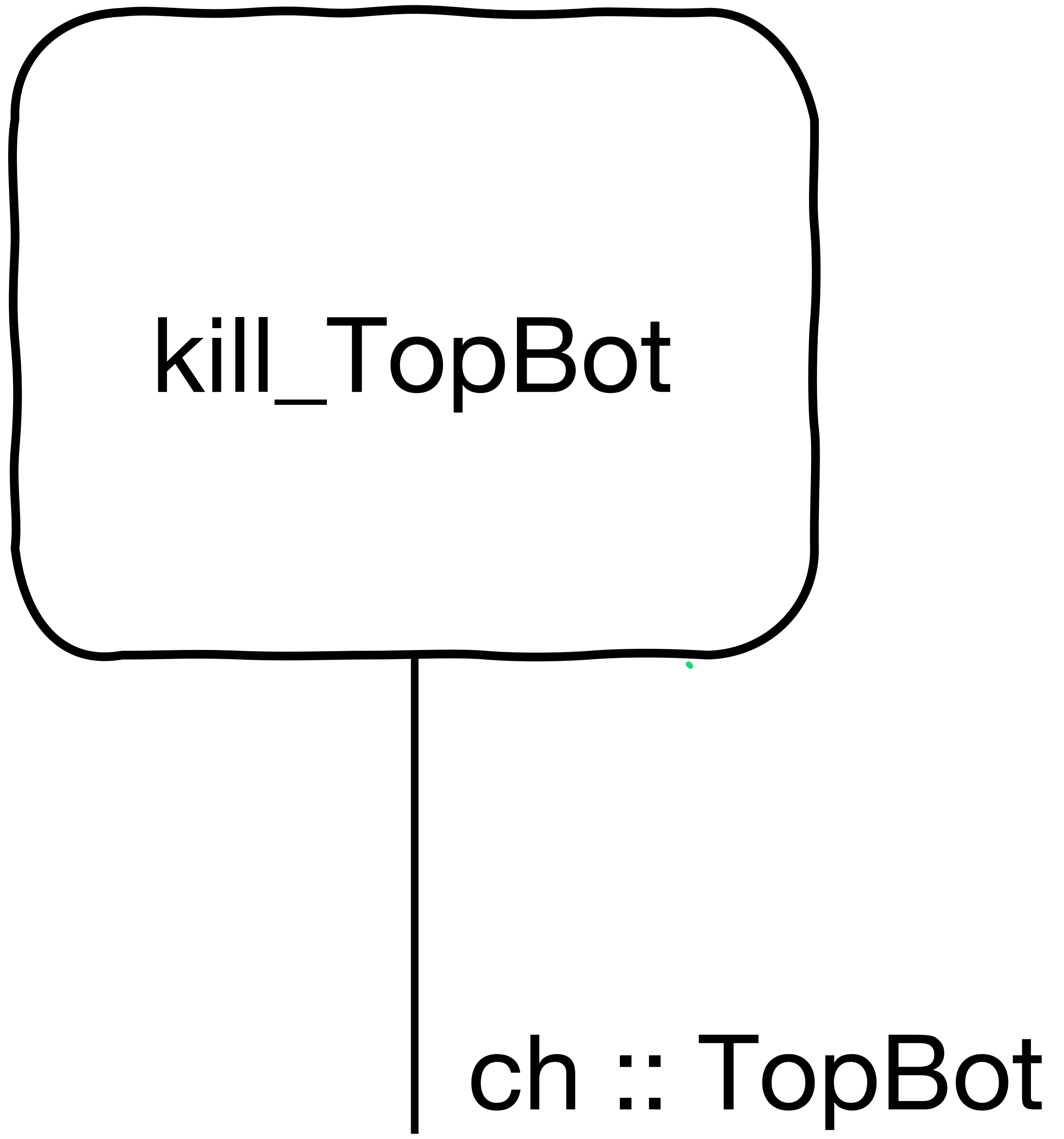
- We can pass a process with input type A and output type B, to the other process using the type Neg(A) (+) B.

Example: The Kill Type Class

CaMPL

```
class Kill T where
  proc kill :: | ⇒ T

instance Kill TopBot where
  proc kill :: | ⇒ TopBot =
    | ⇒ ch → halt ch
```

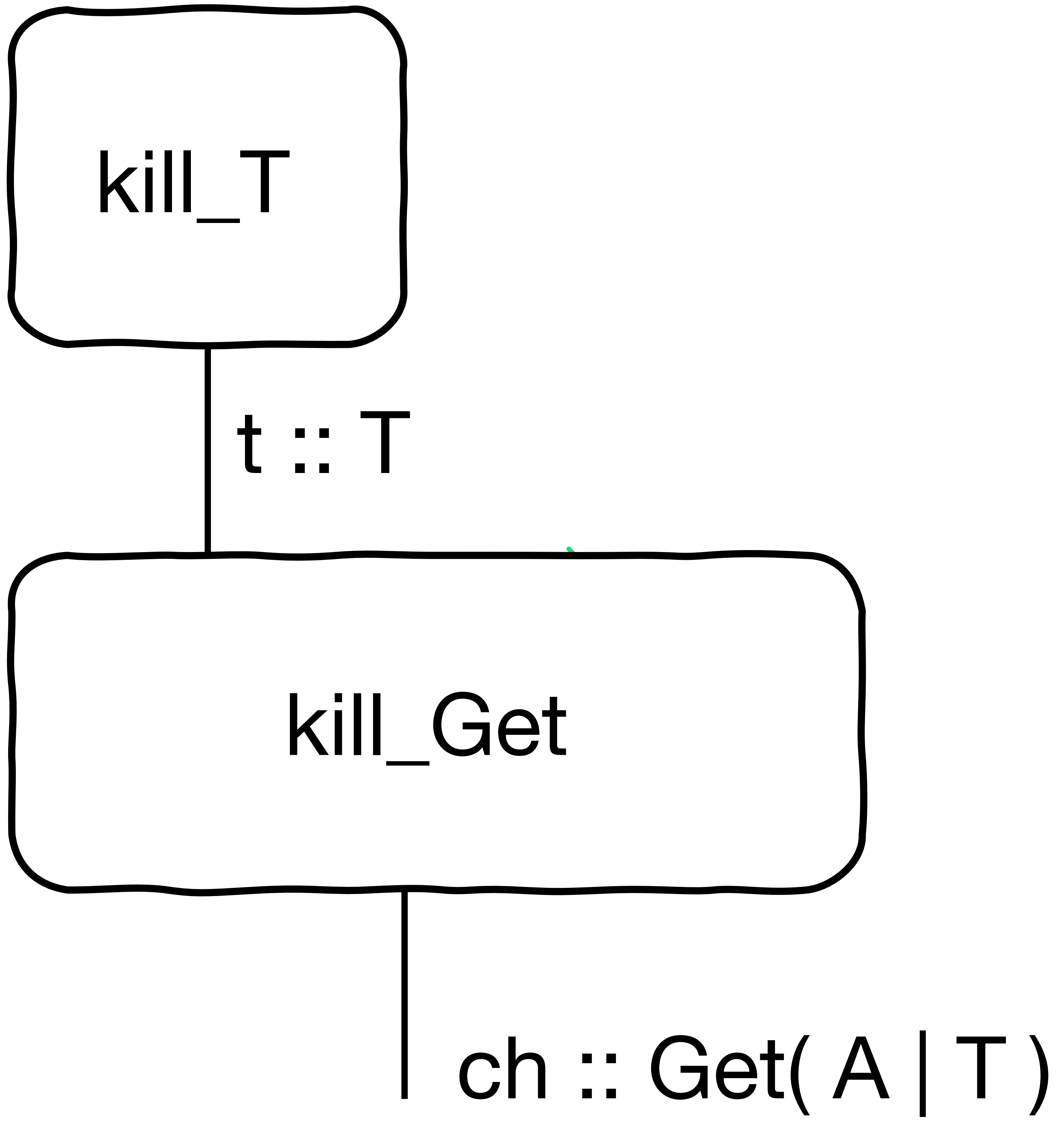


Example: The Kill Type Class

CaMPL

```
instance Kill T ⇒ Kill Get(A | T) where
  proc kill :: | ⇒ Get(A | T) =
        | ⇒ ch → do
          get a on ch
          kill( | ⇒ ch)


-- translation
proc kill_Get :: | T ⇒ Get(A | T) =
    | t ⇒ ch → do
        get a on ch
        t ⟛ ch
```

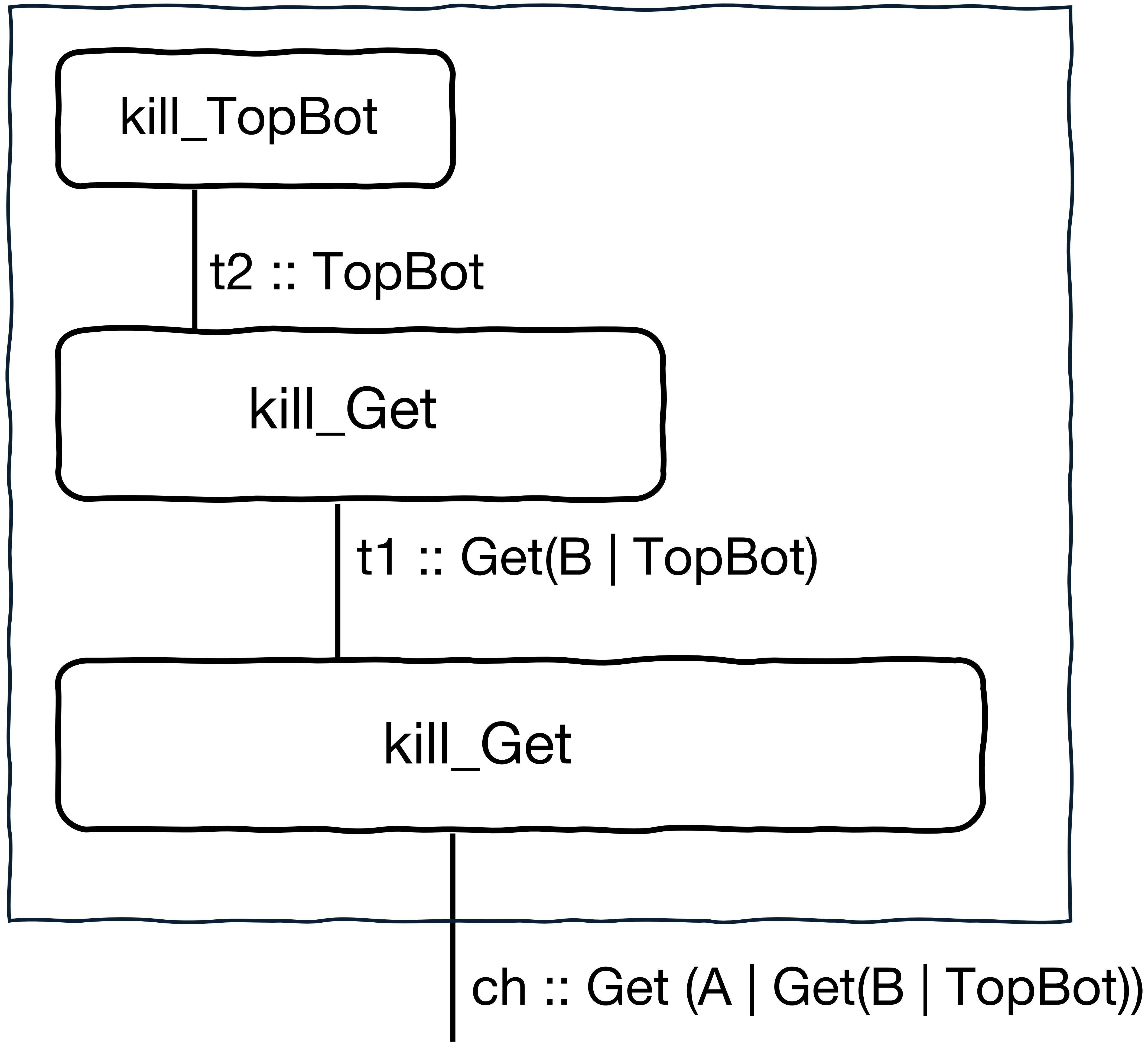


Example: The Kill Type Class

CaMPL

```
proc p :: | => Get(A | Get (B | TopBot)) =
    | => ch -> kill(ch)


-- translation:
proc p :: | => Get(A | Get (B | TopBot)) =
      | => ch -> do
        plug
          kill_Get( | t1 => ch)
          kill_Get( | t2 => t1)
          kill_TopBot( | => t2)
```



Type Classes in Concurrent CaMPL

- It is also probably useful to have higher order type classes such as Functor and Monad in the concurrent side of CaMPL.
- For example: One can define a concurrent list (list of channels) and make it a Functor.
- In our first try, we attempt to implement the Functor type class using the same way we did for first order type classes (like the Kill type class)
- Let's see if it works!

Example: Functor Type Class

CaMPL

```
class Functor \S → T( | S) where
| proc fmap :: | B (+) Neg(A), T( | A) ⇒ T( | B)

protocol List(| A) ⇒ S =
| | Cons :: A (*) S ⇒ S
| | Nil :: A ⇒ S

proc cons :: | T, List( | T) ⇒ List( | T) =
| | | t, ts ⇒ ts' → do
| | | | hput Cons on ts'
| | | | fork ts' as
| | | | | | t'' → t |=| t''
| | | | | | ts'' → ts |=| ts''
```

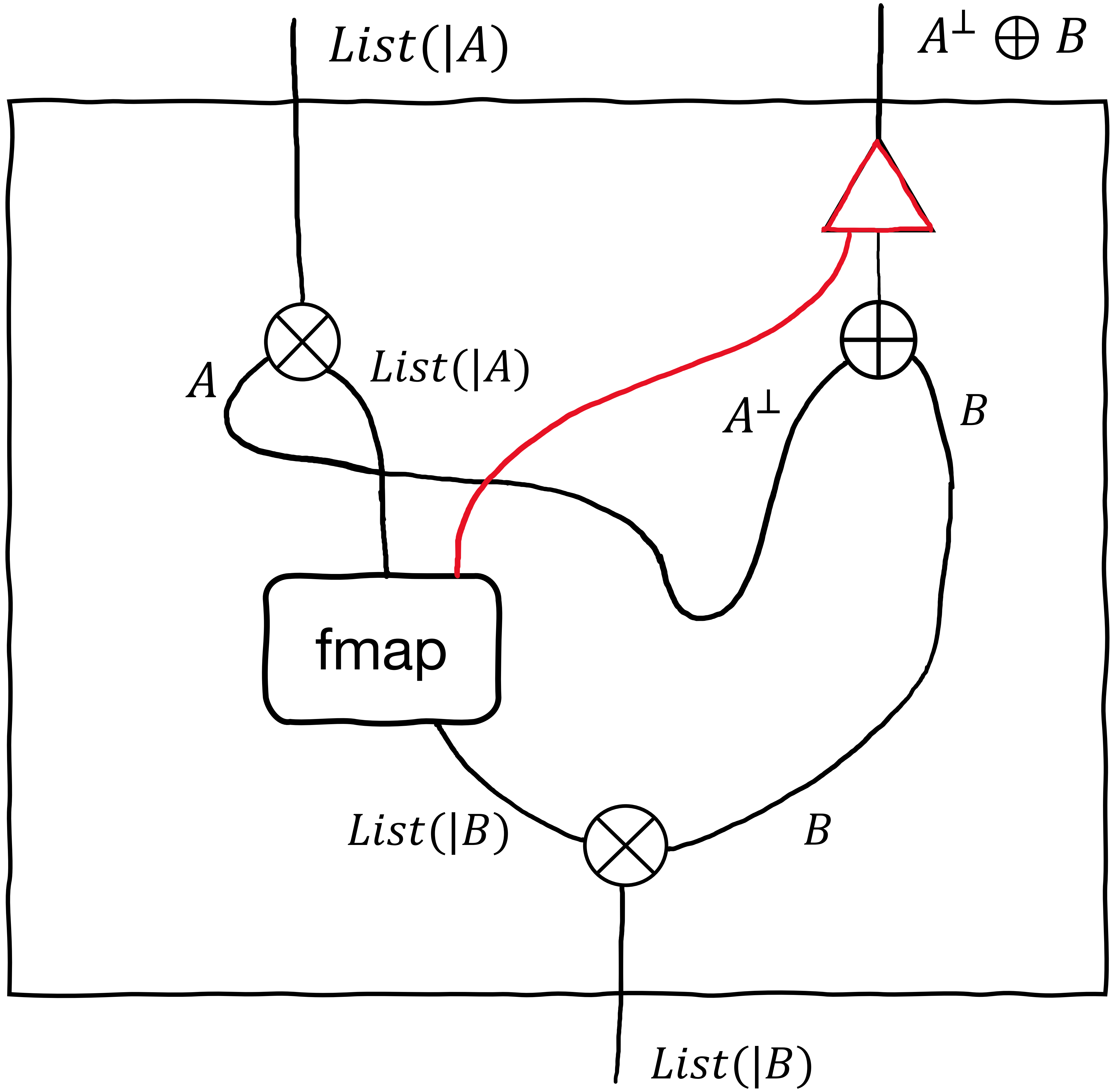
```
proc nil :: | T ⇒ List(| T) =
| | | t ⇒ ts → do
| | | | hput Nil on ts
| | | | ts |=| t

proc apply :: | Neg(A) (+) B, A ⇒ B =
| | | negAandB, a ⇒ b → do
| | | | fork negAandB as
| | | | | | nega → nega |=| neg a
| | | | | | b' → b' |=| b
```

Example: Functor Type Class

CaMPL

```
instance Functor \S → List(S) where
proc fmap :: | Neg(A) (+) B, List( | A) ⇒ List( | B) =
    | negAandB, la ⇒ lb →
        hcase la of
            Cons → do
                split la into hla, tla
                plug
                    apply(| negAandB, hla ⇒ hlb)
                    cons(| hlb, tlb ⇒ lb)
                    fmap(| negAandB, tla ⇒ tlb)
            Nil →
                plug
                    apply( | negAandB, la ⇒ b)
                    nil( | b ⇒ lb)
```



Are there any solutions?

Hmm… There might be!

Store and Use

- *Store* is a **sequential** data type that takes in a **concurrent** process type.
- One can store a process and make it sequential data, then it can behave like other sequential resources so it can be duplicated!
- One can call a stored process using the *use* command.

CaMPL

```
proc p =
    a | ⇒ b → do
        ...

proc q =
    a | b ⇒ → do
        -- store process p and
        -- pass it as sequential data to z
        z (Store(p) | b ⇒ )

proc z :: Store(A | ⇒ B ), A | b ⇒ =
    p, a | b ⇒ →
        plug
            -- use process p
            use(p)( a | ⇒ b)
            -- call z recursively,
            -- pass the stored process p to it
            z(p, a | b ⇒ )
```

Store and Use

- *Store* and *use* can help us solve the problem we had in writing fmap for concurrent lists.

- We can pass the **stored** process that we want to call on each channel in the list, to the fmap process and **use** it as needed.

- But what is the semantics of the *store* and *use*? We don't know! Although it is reminiscent of the bang of linear logic.

CaMPL

```
instance Functor \S → List(S) where
  proc fmap :: Store( | A ⇒ B) | List( | A) ⇒ List( | B) =
    p | la ⇒ lb →
      hcase la of
        Cons → do
          split la into hla, tla
          plug
            use(p)( | hla ⇒ hlb)
            cons(| hlb, tlb ⇒ lb)
            fmap(p | tla ⇒ tlb)
        Nil →
          plug
            use(p)( | la ⇒ b)
            nil( | b ⇒ lb)
```

Conclusion

- Type Classes are important and useful.
- CaMPL is a strongly typed concurrent language and it has the basis for adding type classes to its sequential and concurrent side.
- We are working on adding type classes to CaMPL: The sequential side seems to be going well but there are some challenges in concurrent side.
- Duplicating concurrent resources is not allowed, but one can store them in a sequential data and duplicate them and use them.
- We are working on providing this facility in CaMPL that enables us to implement type classes for both sequential and concurrent sides.

References

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