Retrofiting OCaml modules

Clément Blaudeau, Cambium team, Inria

Ocaml meetup - *11/05/23*

PhD advisors : Didier Rémy, Gabriel Radanne

Modularity

Modularity

Reusable modules / Structural modules

Modularity

Reusable modules / Structural modules

Interfaces / Abstraction

The power of ML-modularity

Basic modularity: modules, signatures and abstraction

As a module developer

```
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
```

As a module user

```
1
2
3
4
5
6
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8
```

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1
2
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Basic modularity: modules, signatures and abstraction

As a module developer

```
1  module Complex  = struct
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module Complex  = struct
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As a module user

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module type Ring = sig
  type t
  val zero : t
  val one : t
  val add : t -> t -> t
  val mult : t -> t -> t
end
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As a module user

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Basic modularity: modules, signatures and abstraction

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As a module user

```
module Polynomials =




end
```

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Basic modularity: modules, signatures and abstraction

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  val mult : t -> t -> t
end
```

As a module user

```
module Polynomials =
  functor (R: Ring) -> struct



end
```

Basic modularity: modules, signatures and abstraction

As a module developer

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module Complex : Ring = struct
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As a module user

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module Polynomials =
  functor (R: Ring) -> struct
    type t = R.t list
    let zero = []
    let one = [R.one]
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Basic modularity: modules, signatures and abstraction

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module Complex : Ring = struct
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```
module CX =
```

Basic modularity: modules, signatures and abstraction

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module Complex : Ring = struct
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As a module user

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module Polynomials =
  functor (R: Ring) -> struct
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```
module CX =
  Polynomials(Complex)
```

Basic modularity: modules, signatures and abstraction

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  type t = float * float
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module CX =
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Basic modularity: modules, signatures and abstraction

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As a module user

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✓ Interface control

As a module user

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Basic modularity: modules, signatures and abstraction

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✓ Polymorphism

Basic modularity: modules, signatures and abstraction

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✓ Polymorphism

✓ Composition

Abstraction and dependencies - functors

Abstraction and dependencies - functors

Generative

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Generative

Applicative

Abstraction and dependencies - functors

Generative

Functors as parameterized *sub-programs*

Applicative

Abstraction and dependencies - functors

Generative

Functors as parameterized *sub-programs*

- Internal state / effects

Applicative

Abstraction and dependencies - functors

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Functors as parameterized *sub-programs*

- Internal state / effects
- *Strong* abstraction barrier

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Functors as parameterized *sub-programs*

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```
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Applicative

Abstraction and dependencies - functors

Generative

Functors as parameterized *sub-programs*

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Functors as parameterized *libraries*

Abstraction and dependencies - functors

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Abstraction and dependencies - functors

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Functors as parameterized *libraries*

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- *Weak* abstraction barrier

```
1  module OrderedSet (E:OrderedType) = struct
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Abstraction and dependencies - functors

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Abstraction and dependencies - functors

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Applicative

Functors as parameterized *libraries*

- Purity
- *Weak* abstraction barrier

→ *same applications* produce same results

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Applicativity granularity

```
1  module X1 = struct
2    type t = int
3    ...
4  end
5
6  module X2 = struct
7    type t = int
8    ...
9  end
10
11 OrderedSet(X1).t =? OrderedSet(X2).t
```

Applicativity granularity

Types only

```
1  module X1 = struct
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Applicativity granularity

Types only

- Sound: types only depend on types

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Applicativity granularity

Types only

- Sound: types only depend on types
  $\rightarrow$ assumes the functor's body only depends on types fields

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Applicativity granularity

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```
1  module X1 = struct
2    type t = int
3    let compare = (<)
4  end
5
6  module X2 = struct
7    type t = int
8    let compare = (>)
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11 OrderedSet(X1).t =? OrderedSet(X2).t
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Types and values

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Applicativity granularity

Types only

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Types and values

- *Abstraction safe*

```
1  module X1 = struct
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Types and values

- *Abstraction safe*
  $\rightarrow$ tracking equality of values

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  $\rightarrow$ tracking equality of values

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Applicativity granularity

Types only

- Sound: types only depend on types
  $\rightarrow$ assumes the functor's body only depends on types fields

Types and values - *fine grained*

- *Abstraction safe*
  $\rightarrow$ tracking equality of values

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1  module X1 = struct
2    type t = int
3    let compare = (<)
4  end
5
6  module X2 = struct
7    type t = int
8    let compare = X1.compare
9  end
10
11 OrderedSet(X1).t =? OrderedSet(X2).t
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Who needs module aliases ?

<footer>6 ⟨1⟩/ 11</footer>

Who needs module aliases ?

```
module type VS = sig (* Vector space *)


end
```

Who needs module aliases ?

```
module type VS = sig (* Vector space *)
  module Scalar : Field

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Who needs module aliases ?

```
module type VS = sig (* Vector space *)
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  ... (* more fields *)
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```

Who needs module aliases ?

```
module type VS = sig (* Vector space *)
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module LinearAlg(V:VS) = struct
  ...


end
```

Who needs module aliases ?

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module type VS = sig (* Vector space *)
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```
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Structural functors

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Structural functors

Reusable (applicative) functors

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Transparent ascription

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Specifying OCaml modules

Position-dependent meaning of syntax

Enriched syntax

$\rightarrow$ F^{ω} quantifiers

Key mechanisms

- module M
  - module X
    - type t
    - val $x : t$
    - type $u = \mathsf{int} \times t$
  - module F $(Y : \mathsf{sig}\ \mathsf{type}\ t\ \mathsf{end})$
    - type t
    - type $u = Y.t$
  - module G $()$
    - type t
    - val $x : t$
  - module type T
    - type t
    - val $x : t$

Position-dependent meaning of syntax

Enriched syntax

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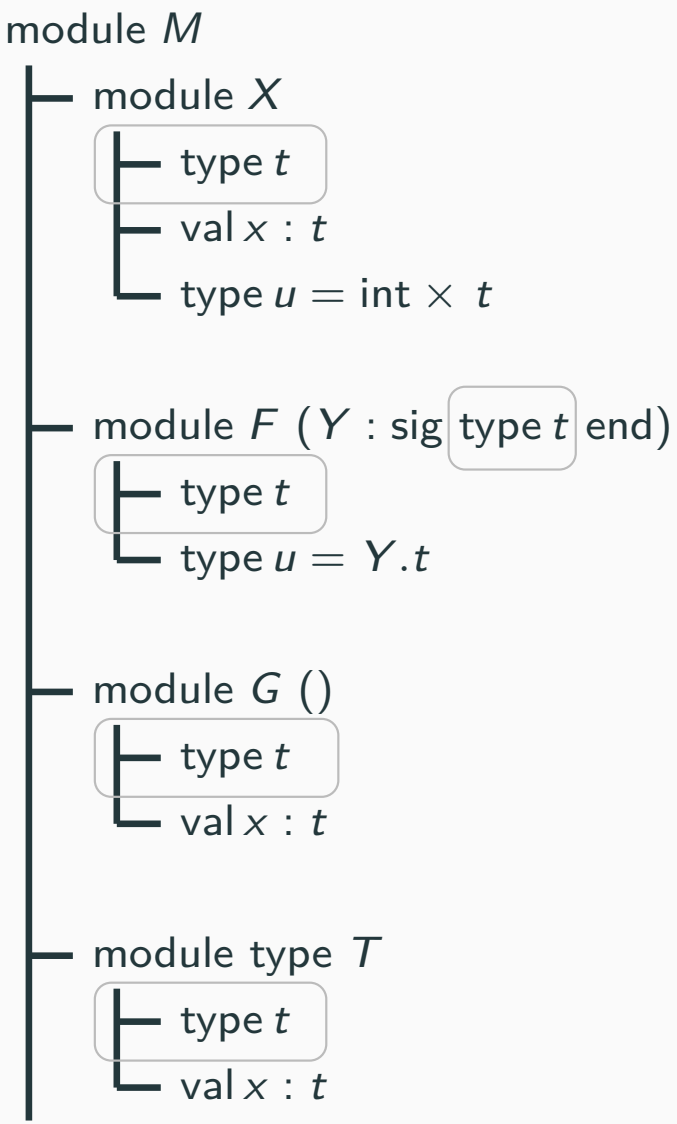
Key mechanisms



Position-dependent meaning of syntax

Enriched syntax

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- Existential for ascription

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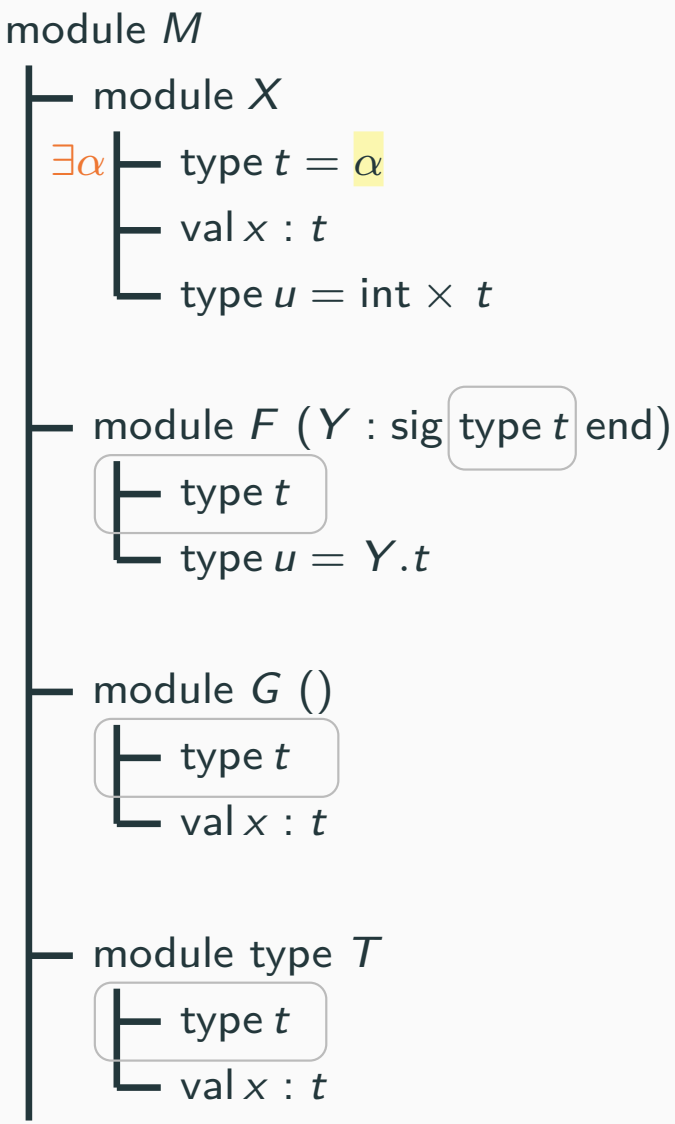

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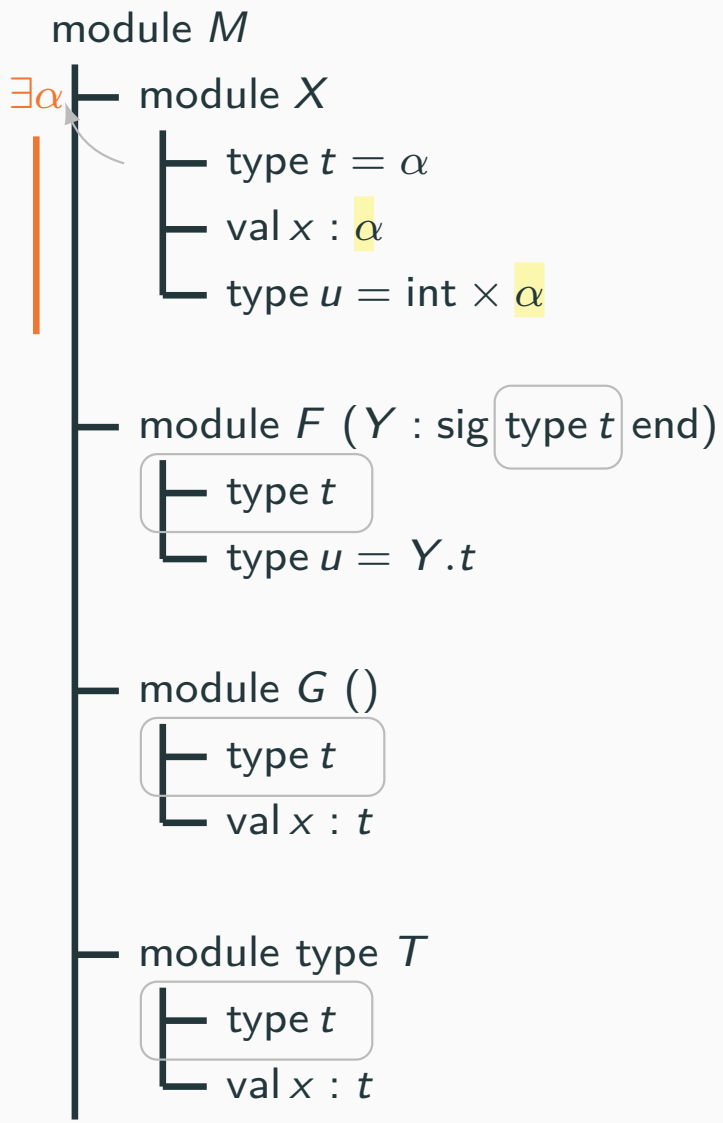
- Existential lifting



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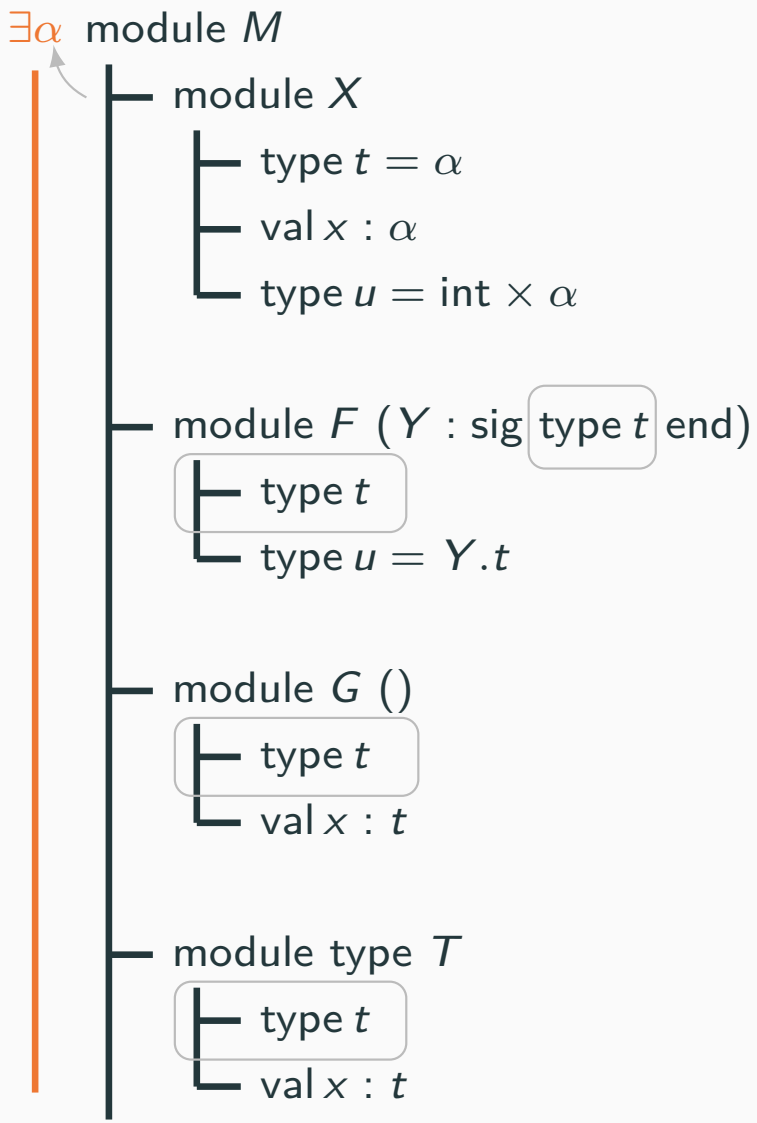

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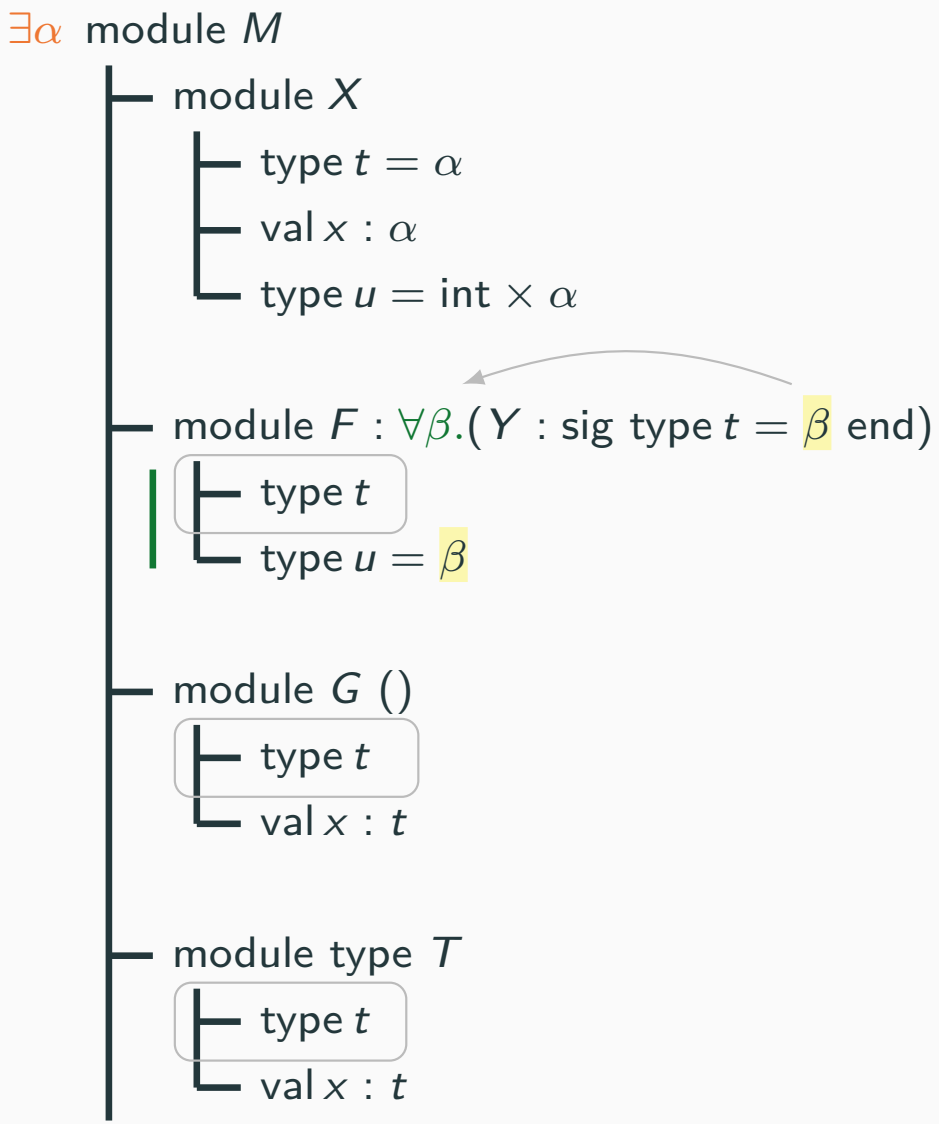

Position-dependent meaning of syntax

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- Existential lifting

$\exists\alpha$ module M
- module X
  - type $t = \alpha$
  - val $x : \alpha$
  - type $u = \mathsf{int} \times \alpha$
- module $F : \forall\beta.(Y : \mathsf{sig\ type}\ t = \beta\ \mathsf{end})$
  - $\exists\gamma$ type $t = \gamma$
  - type $u = \beta$
- module G ()
  - type t
  - val $x : t$
- module type T
  - type t
  - val $x : t$

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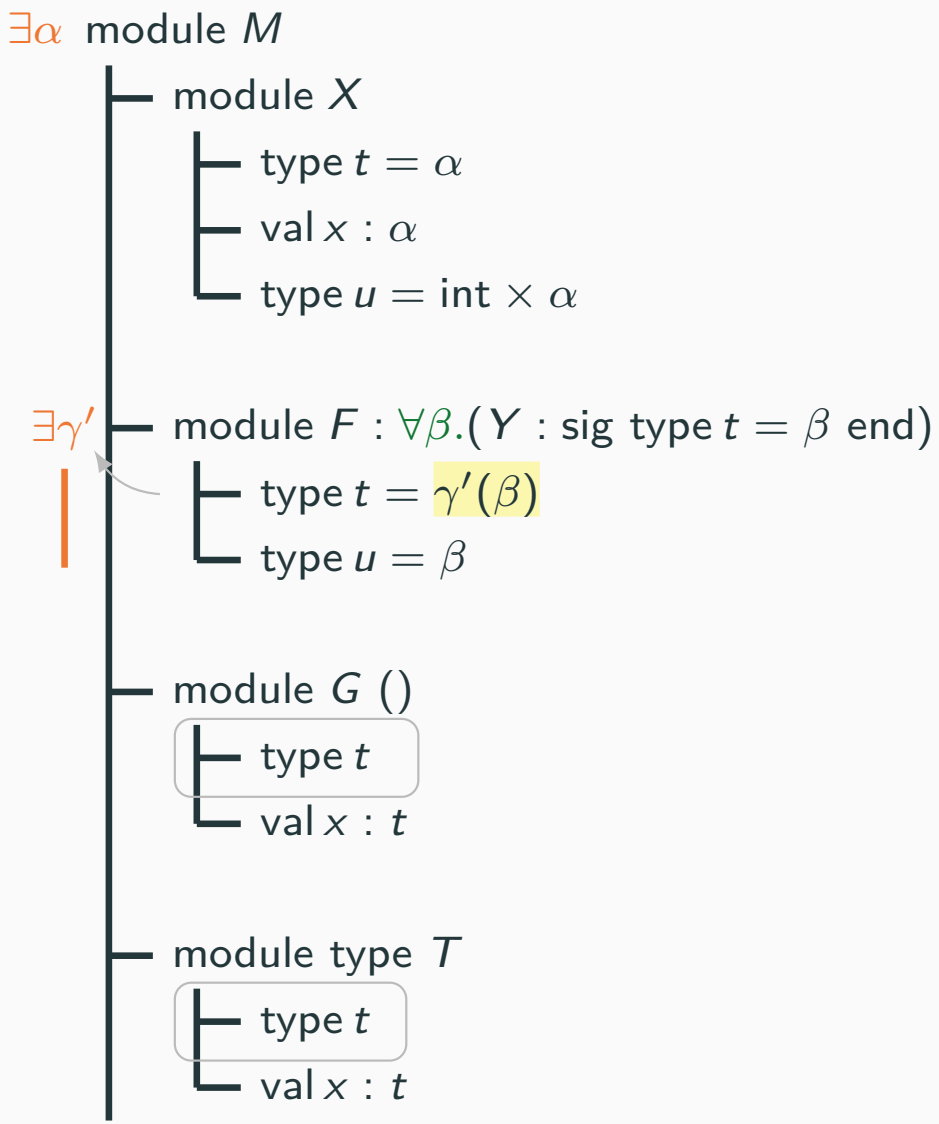
- Skolemization



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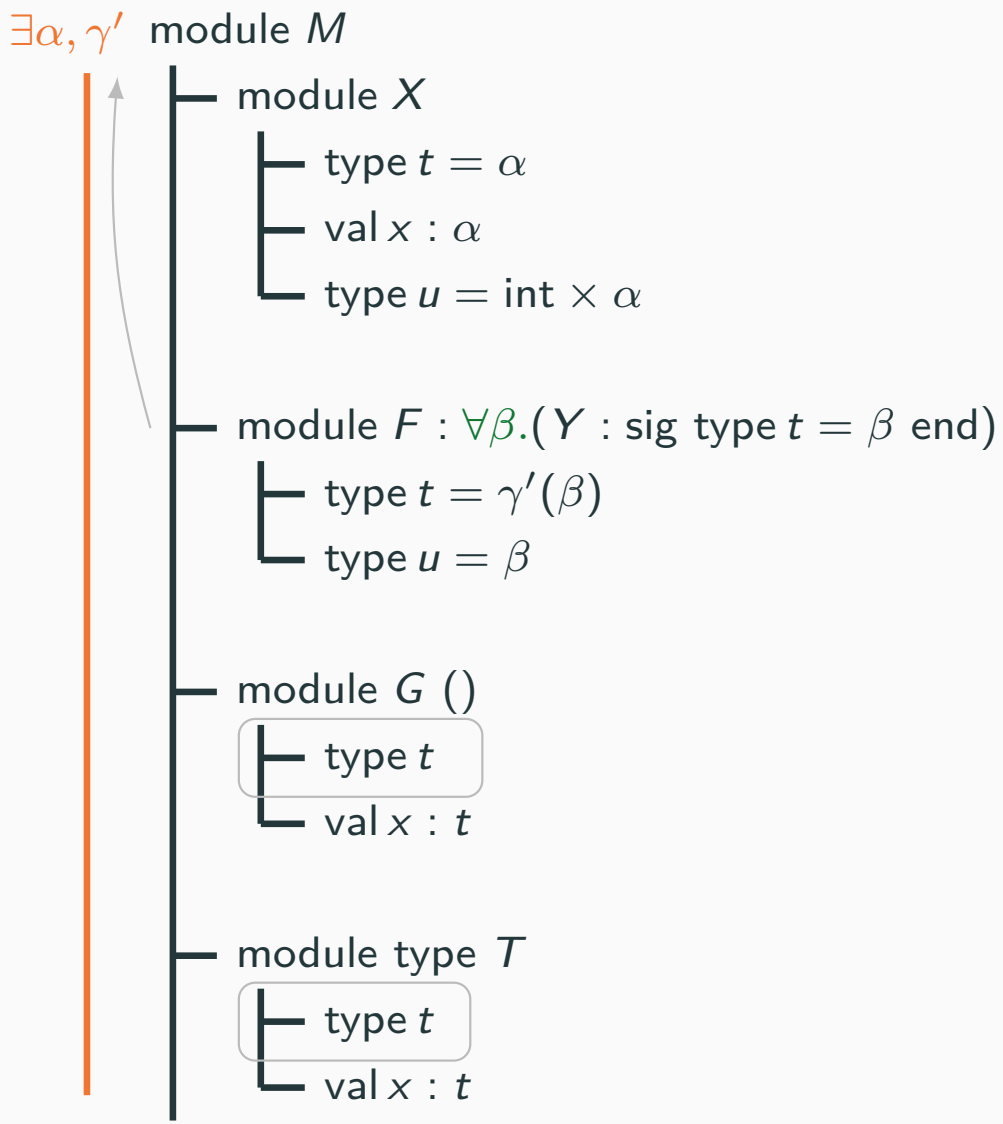

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  - type $t = \gamma'(\beta)$
  - type $u = \beta$
- module G ()
  - $\exists \delta$
    - type $t = \delta$
    - val $x : t$
- module type T
  - type t
  - val $x : t$

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- module G () : $\exists \delta$
  - type $t = \delta$
  - val $x : \delta$
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  - type t
  - val $x : t$

Position-dependent meaning of syntax

Enriched syntax

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- Existential for ascription
- Universal for functors
- Lambda for module types

Key mechanisms

- Existential lifting
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  - type $u = \beta$
- module G () : $\exists \delta$
  - type $t = \delta$
  - val $x : \delta$
- module type T
  - $\lambda \rho$
    - type $t = \rho$
    - val $x : t$

Position-dependent meaning of syntax

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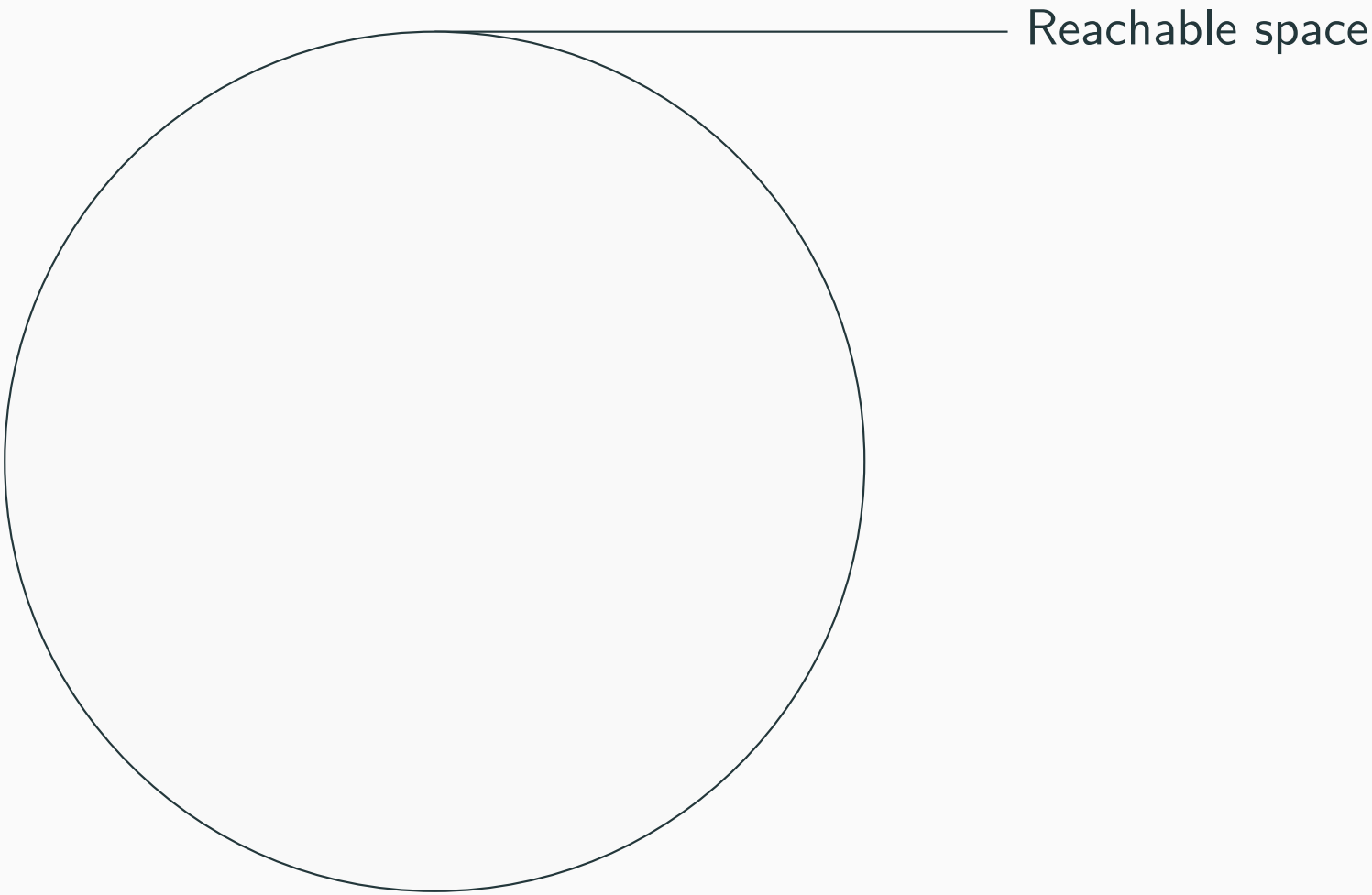
  - type $t = \gamma'(\beta)$
  - type $u = \beta$
- module G () : $\exists \delta$
  - type $t = \delta$
  - val $x : \delta$
- module type $T : \lambda \rho$
  - type $t = \rho$
  - val $x : \rho$

Expressivity mismatch



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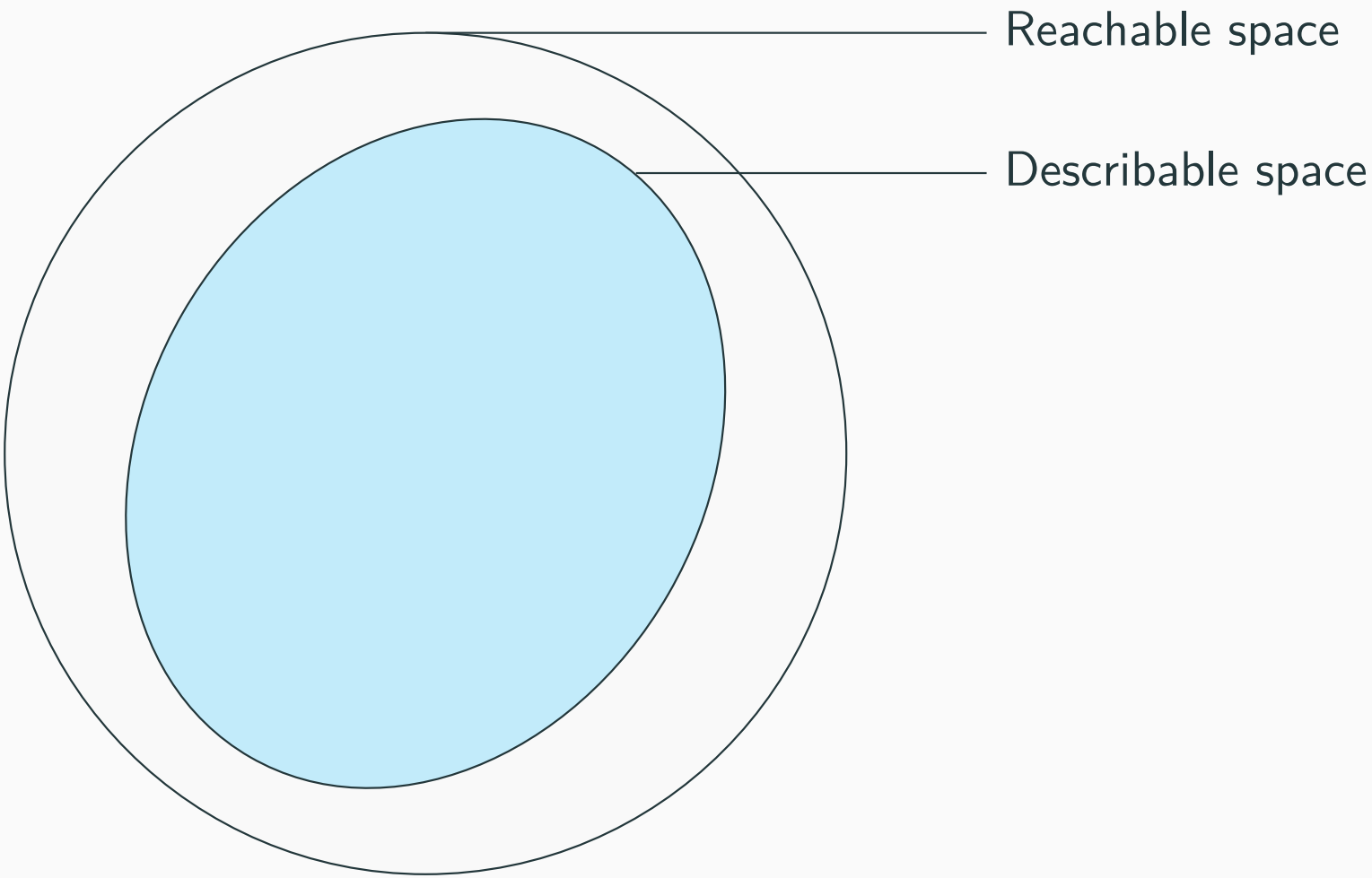

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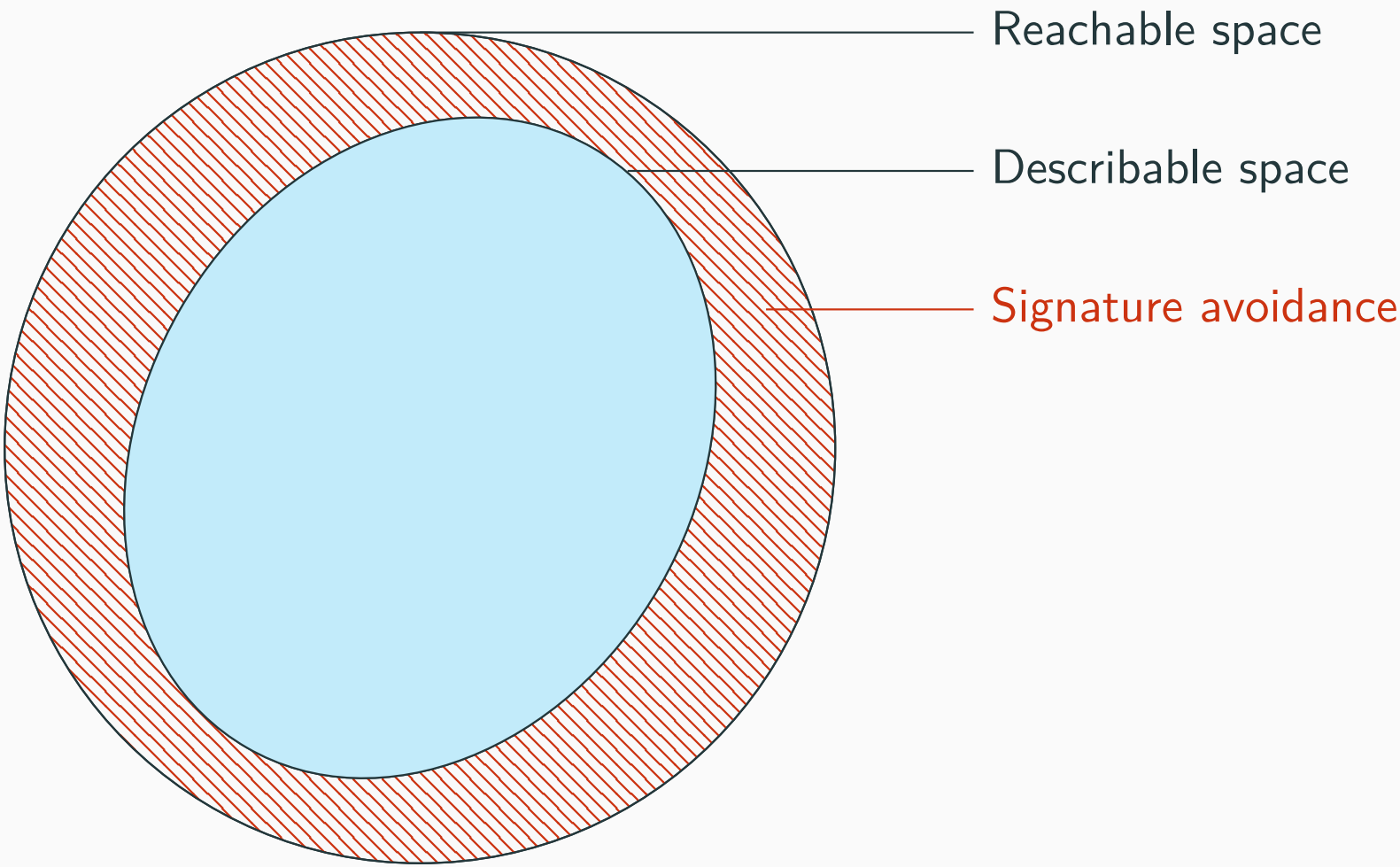

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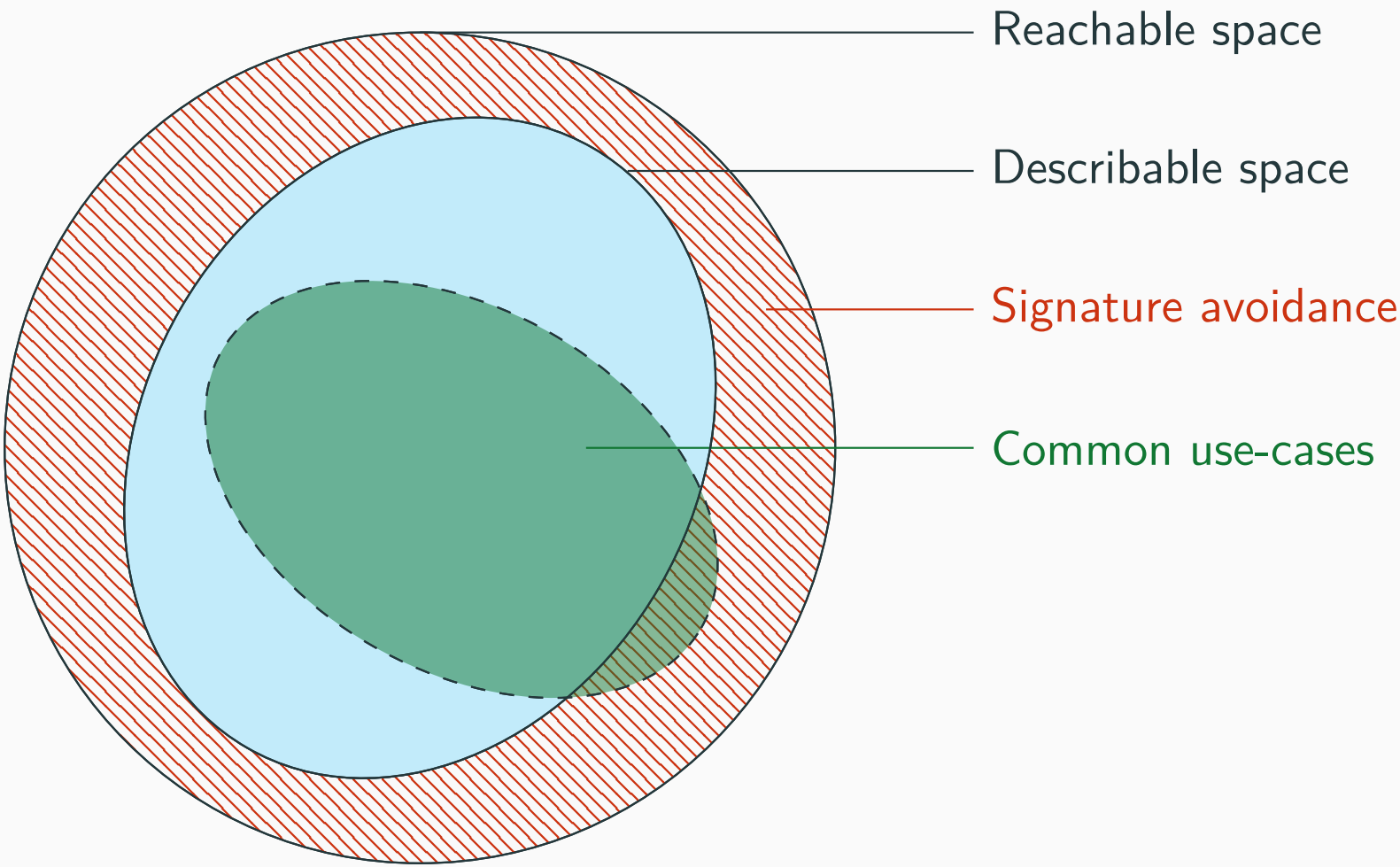

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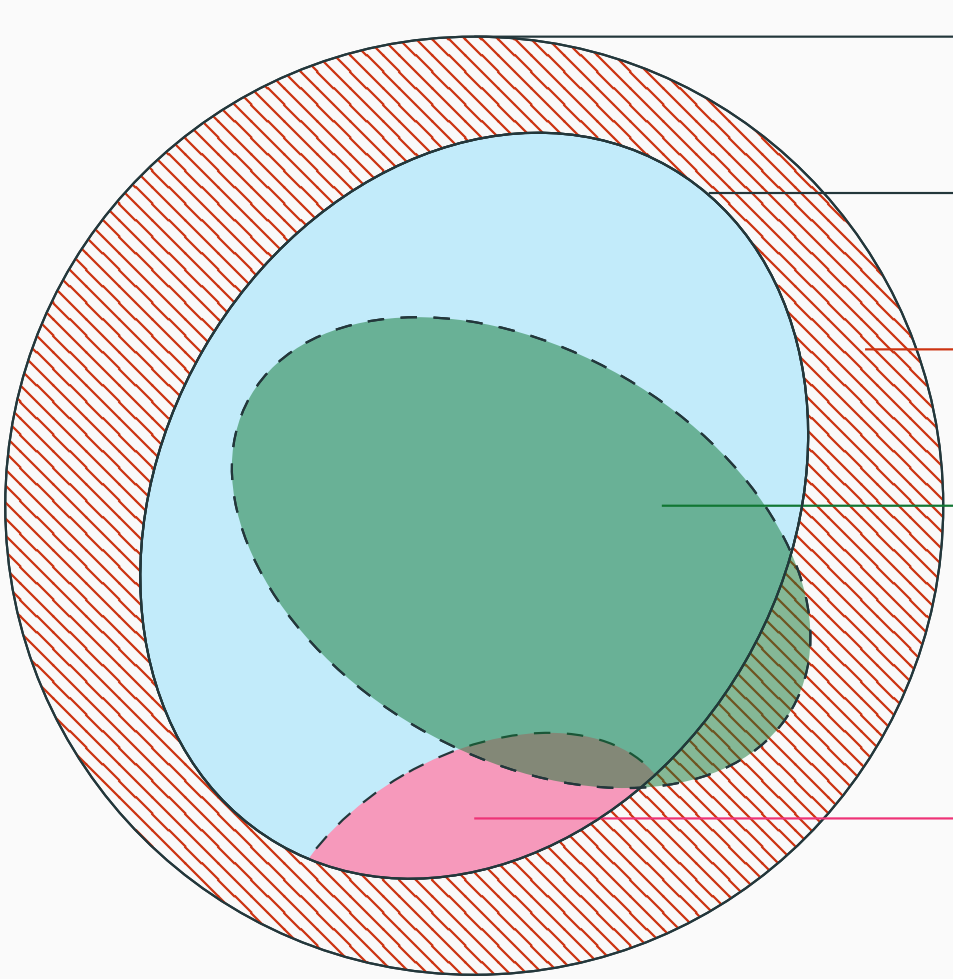

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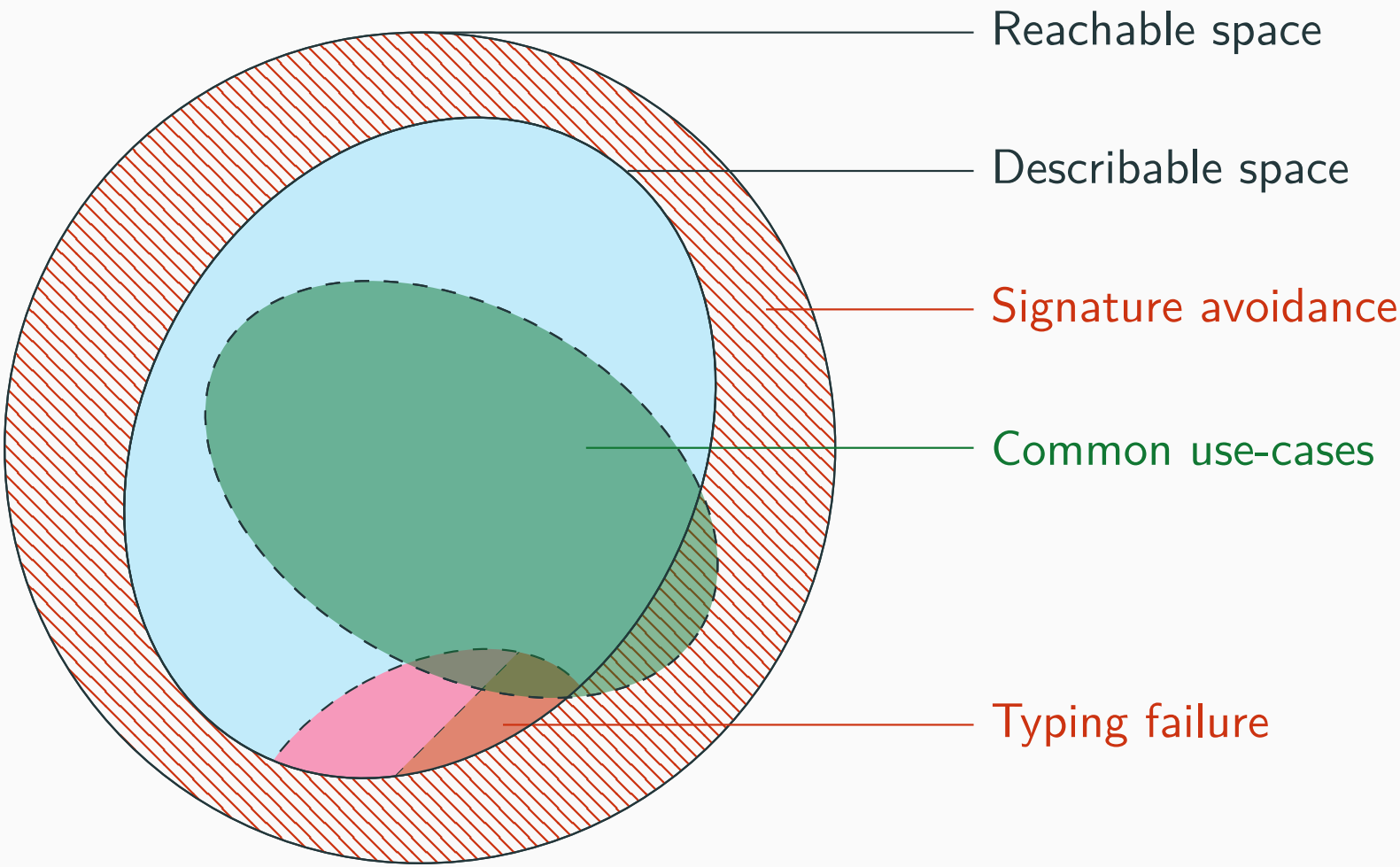

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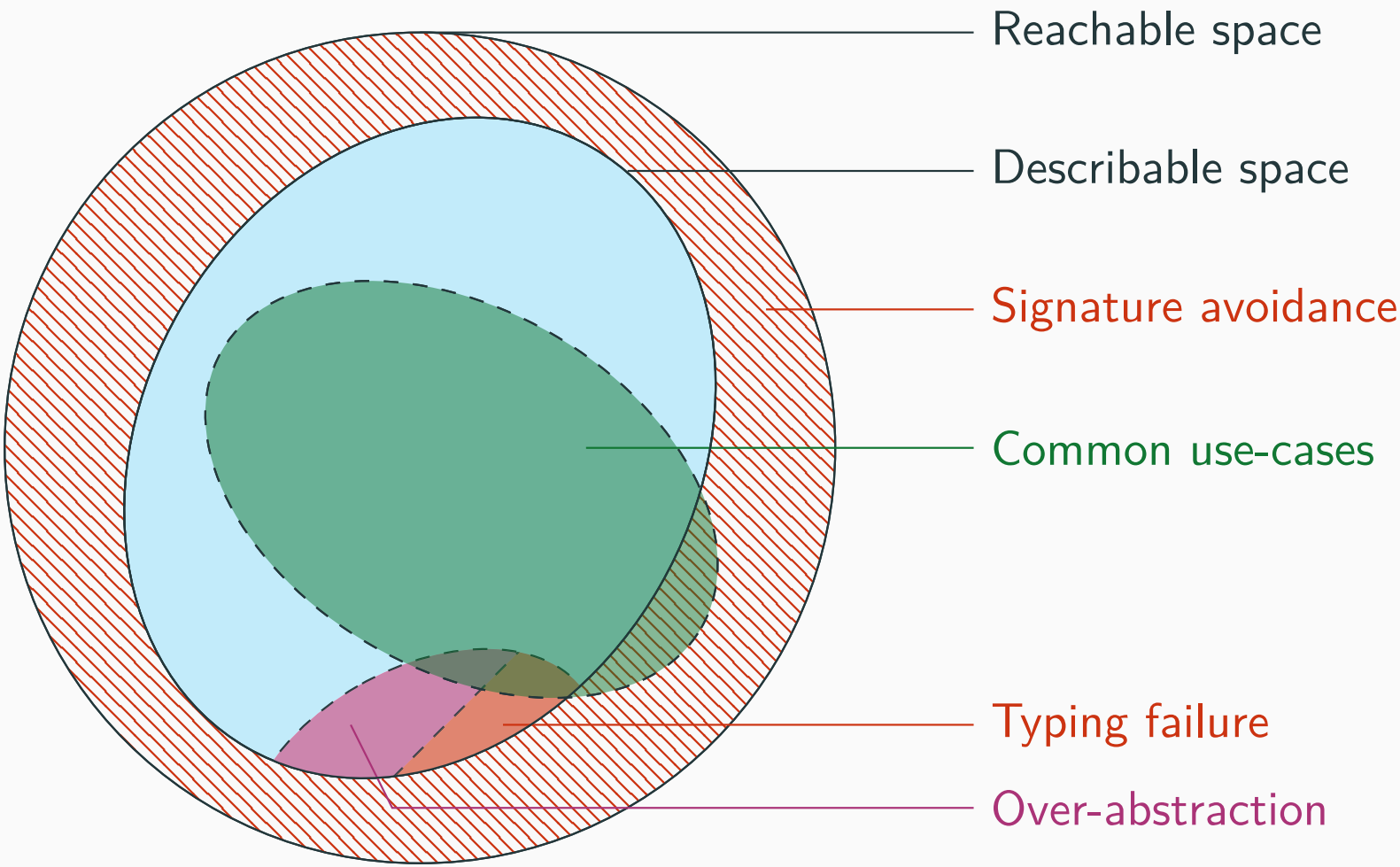

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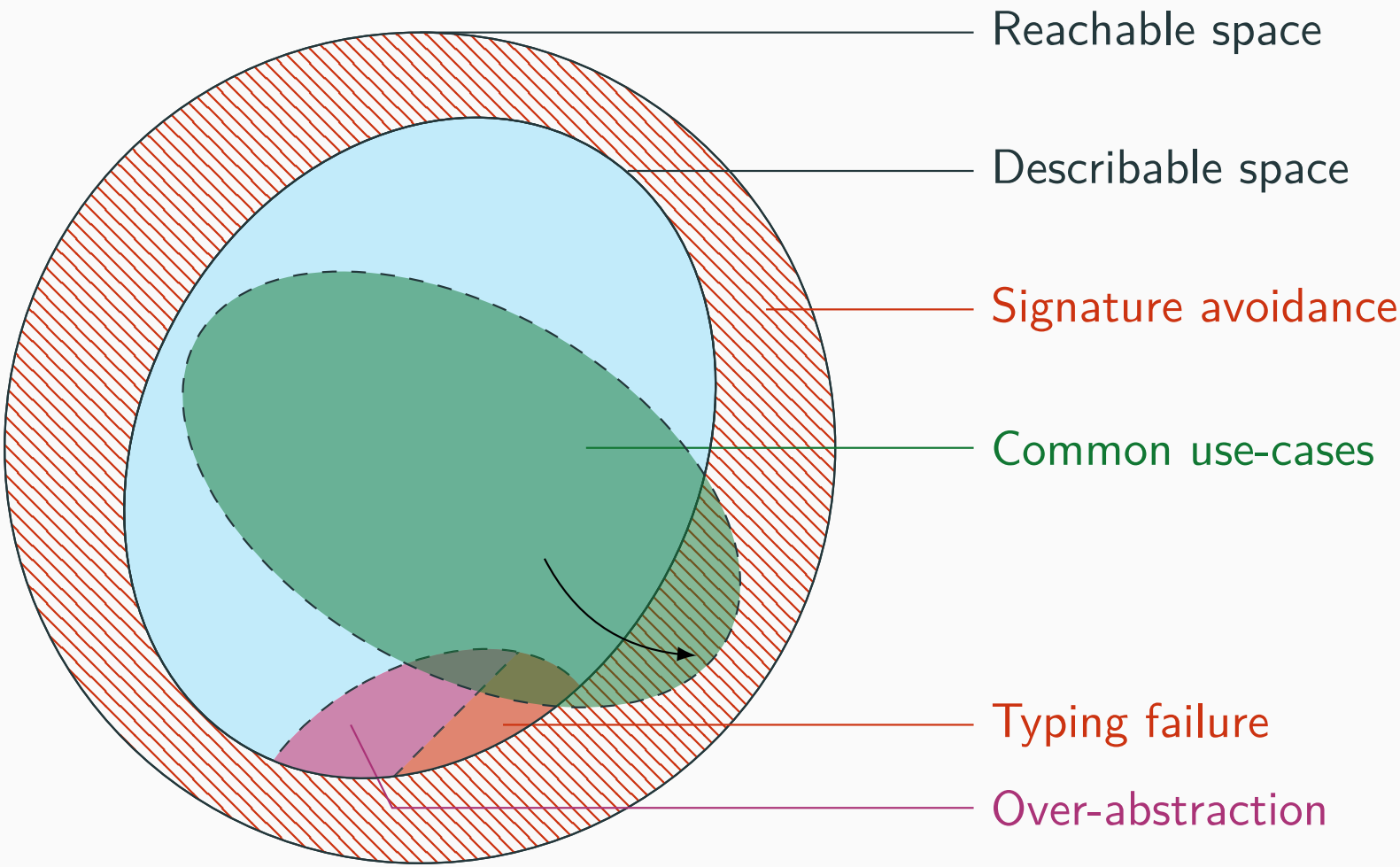

Conclusion

Conclusion

- Specify the OCaml module system via a translation in F^{ω}

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  - ✓ Applicative / Generative functors

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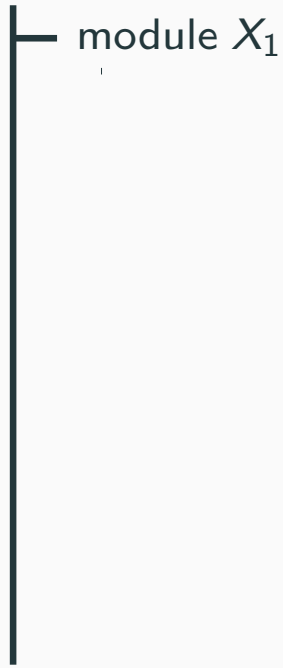
  - Recursive modules
- Rewrite the typechecker
- Implement transparent ascription
- Explore the challenges of having an hybrid syntax with quantifiers

Strengthening

```
module type S = sig
  type t
  val x : t
  type u = int * t
end
```

Strengthening

```
1  module type S = sig
2    type t
3    val x : t
4    type u = int * t
5  end
6
7  module X1      = struct
8
9
10
11
12
13
```



Strengthening

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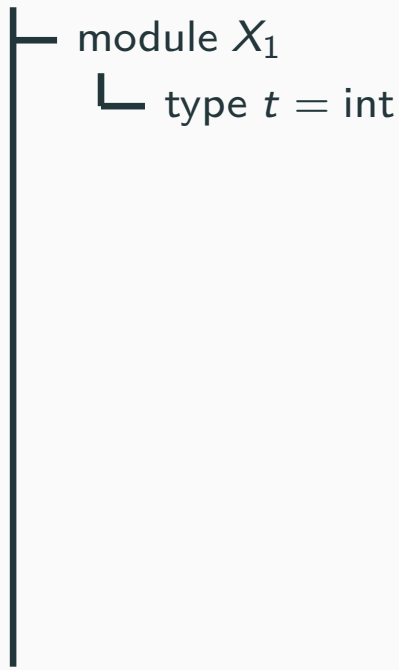

Strengthening

```
1  module type S = sig
2    type t
3    val x : t
4    type u = int * t
5  end
6
7  module X1      = struct
8    type t = int
9    let x : t = 42
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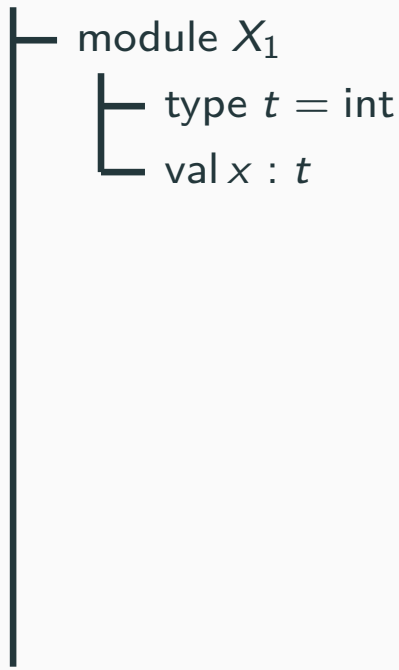
13
```



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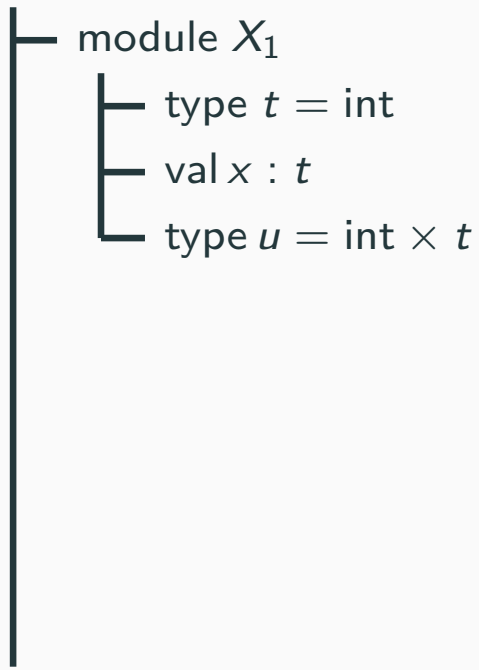

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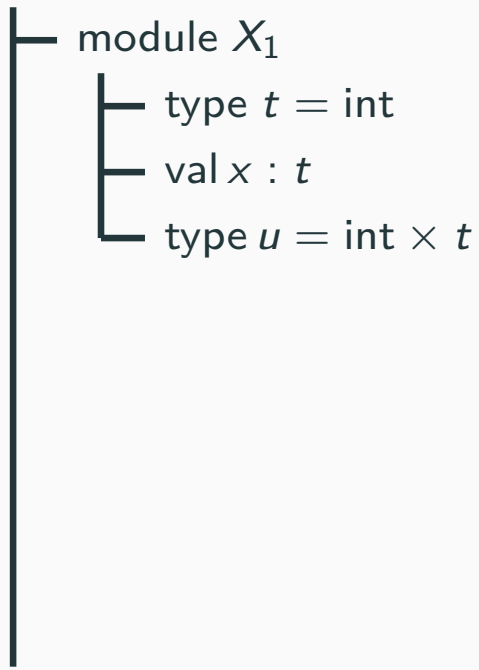

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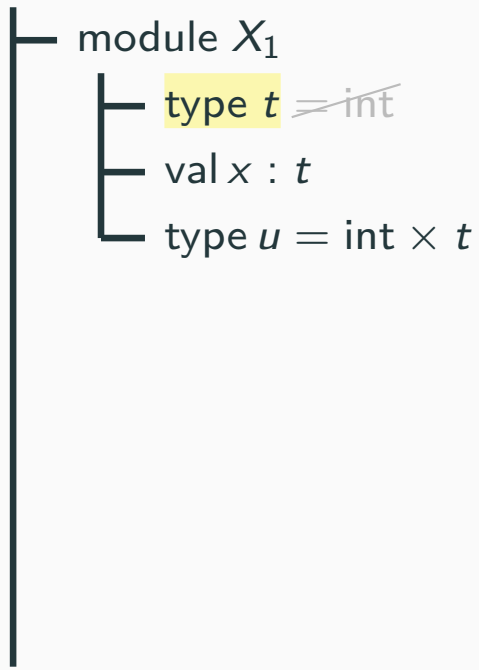

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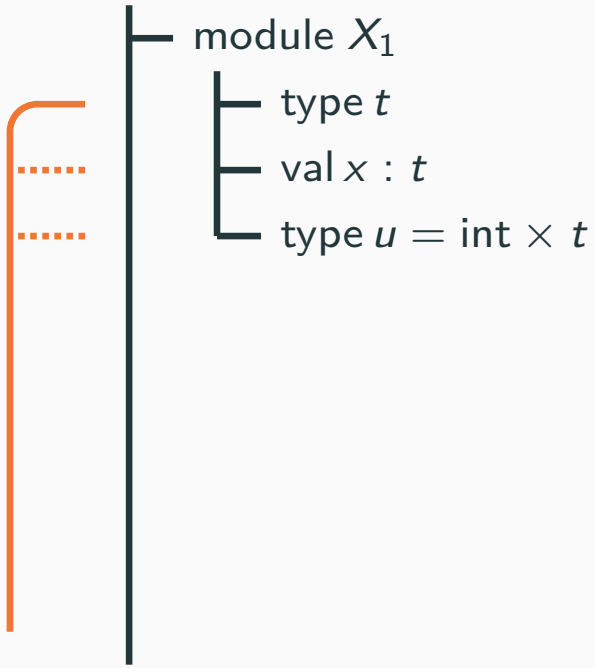

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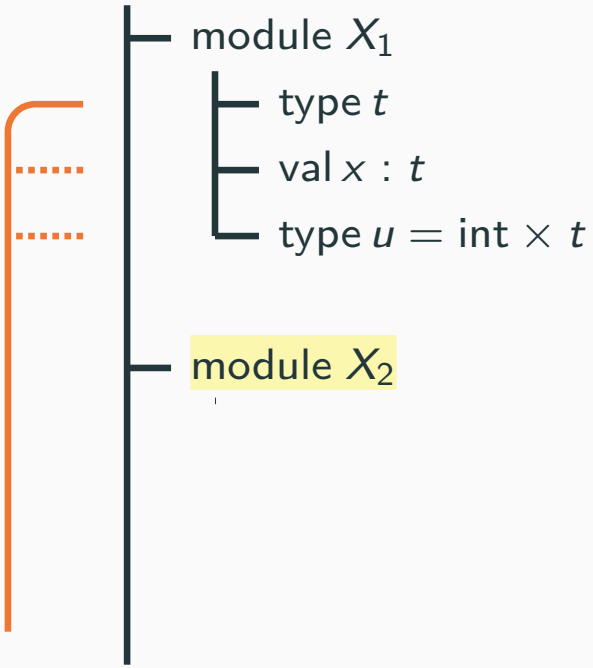

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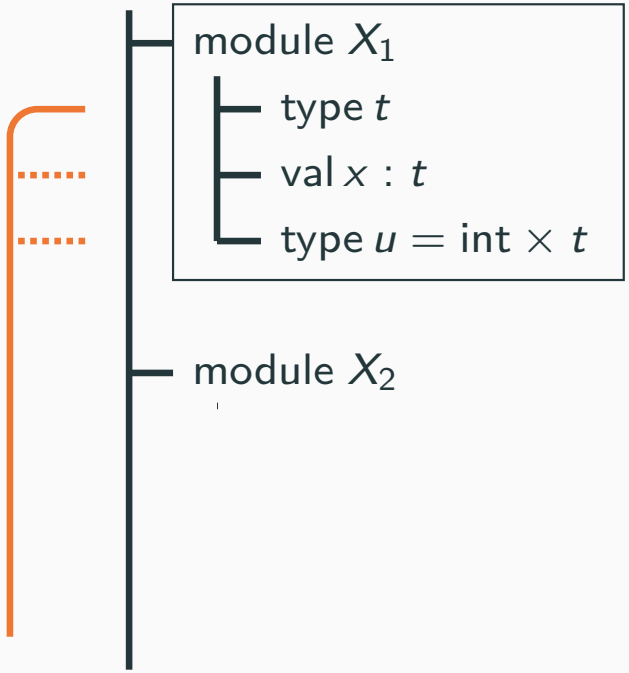

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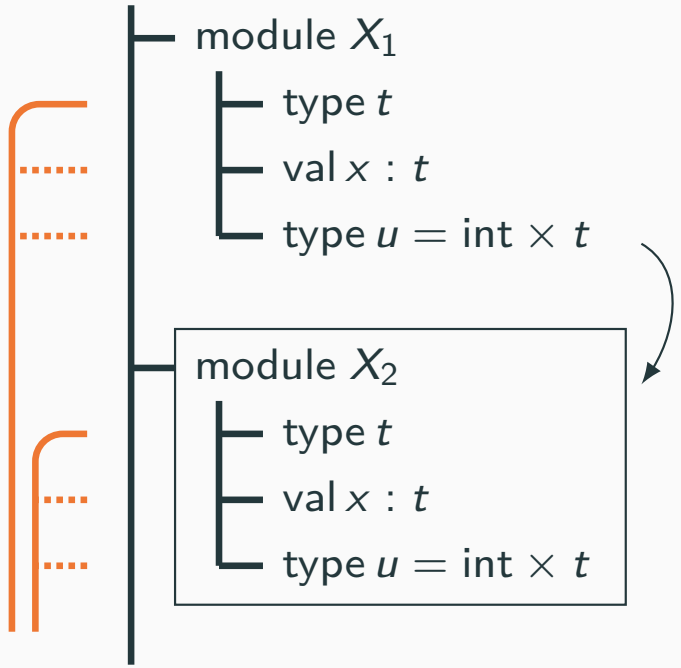

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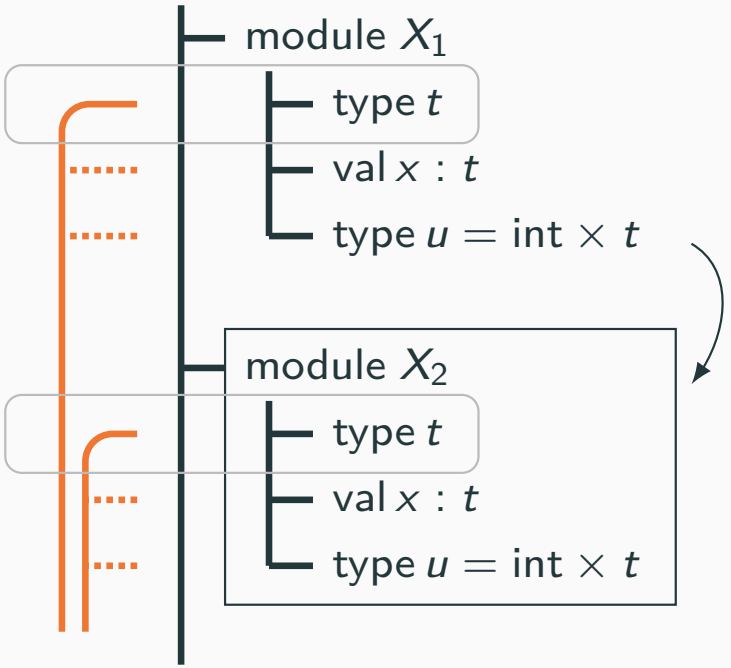
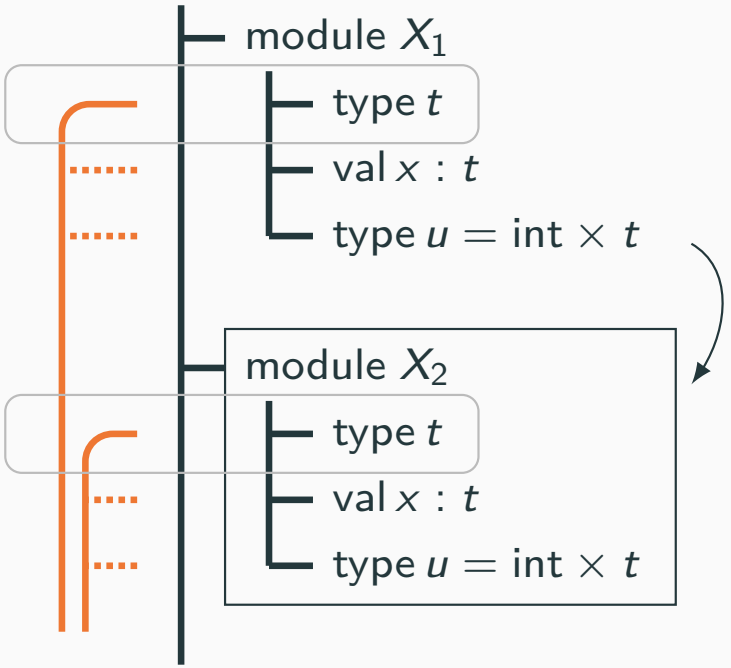


Strengthening

```
1  module type S = sig
2    type t
3    val x : t
4    type u = int * t
5  end
6
7  module X1 : S  = struct
8    type t = int
9    let x : t = 42
10   type u = int * t
11 end
12
13 module X2 = (X1:S)
```



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8    type t = int
9    let x : t = 42
10   type u = int * t
11 end
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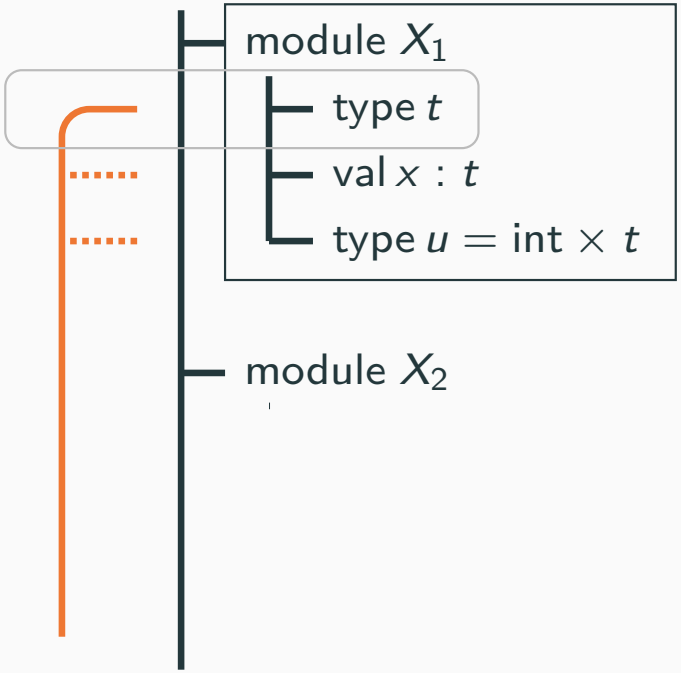

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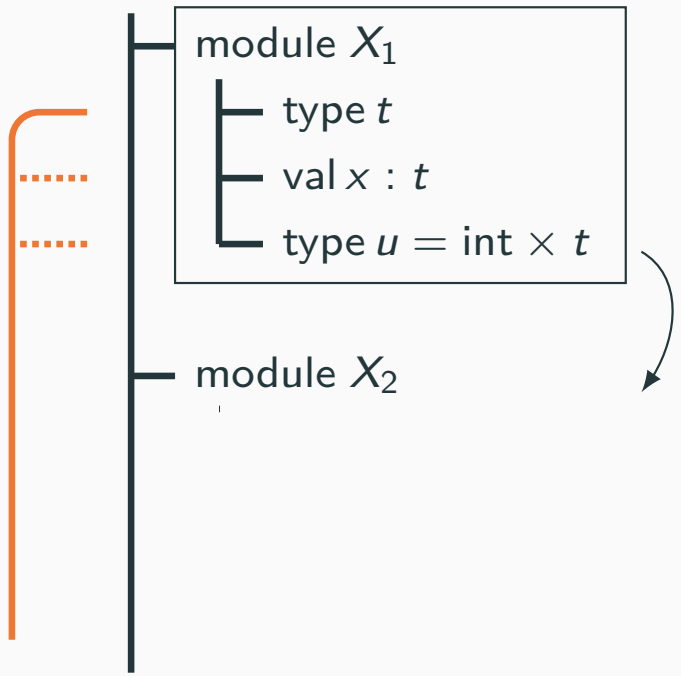

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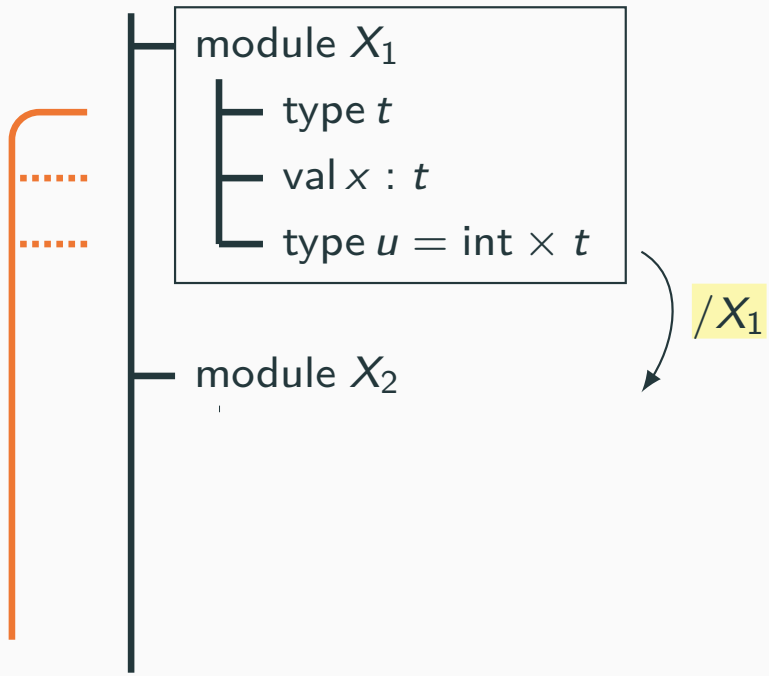

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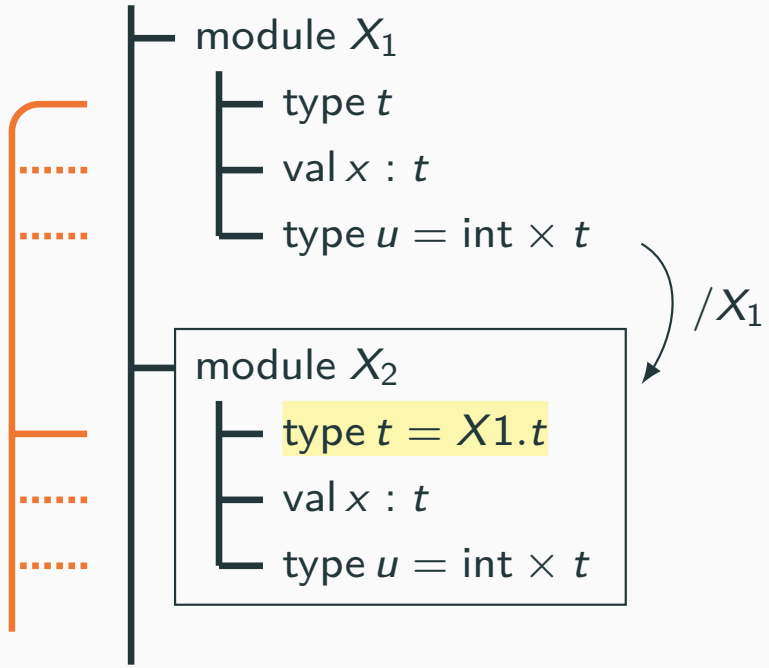
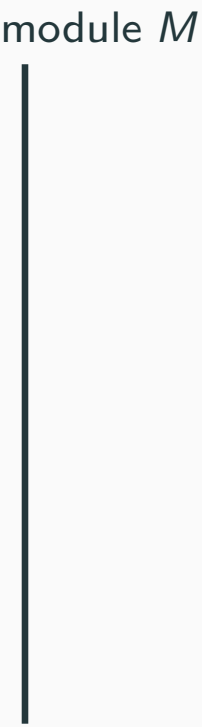


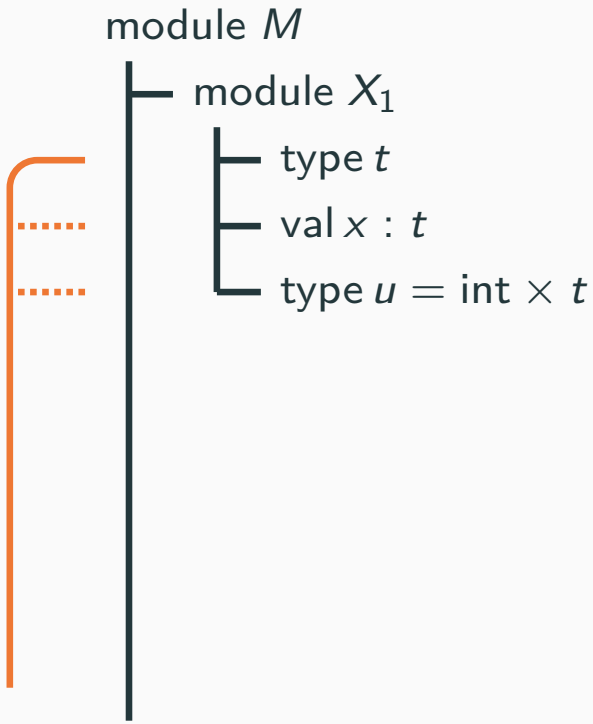
Signature avoidance

```
1 | module M =  struct
2 |
3 |
4 |
5 |
6 |
7 |
8 | end
```



Signature avoidance

```
1  module M =  struct
2    module X1 : S = ...
3
4
5
6
7
8  end
```



Signature avoidance

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1  module M =  struct
2    module X1 : S = ...
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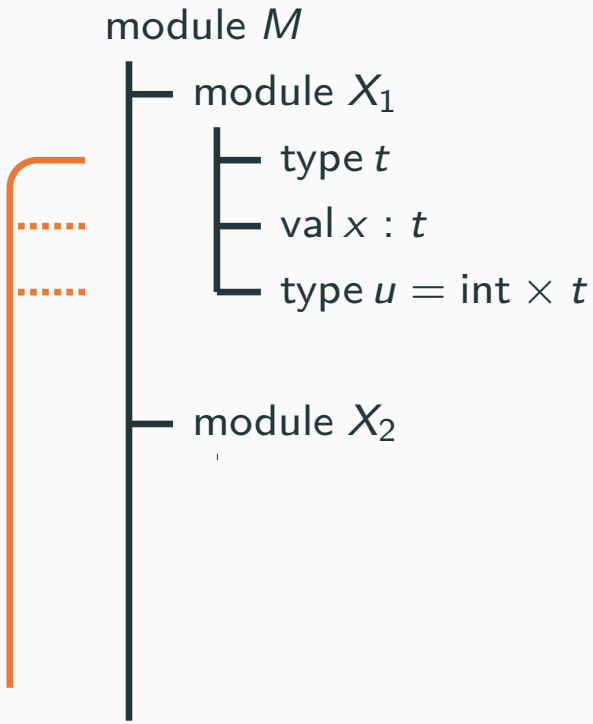
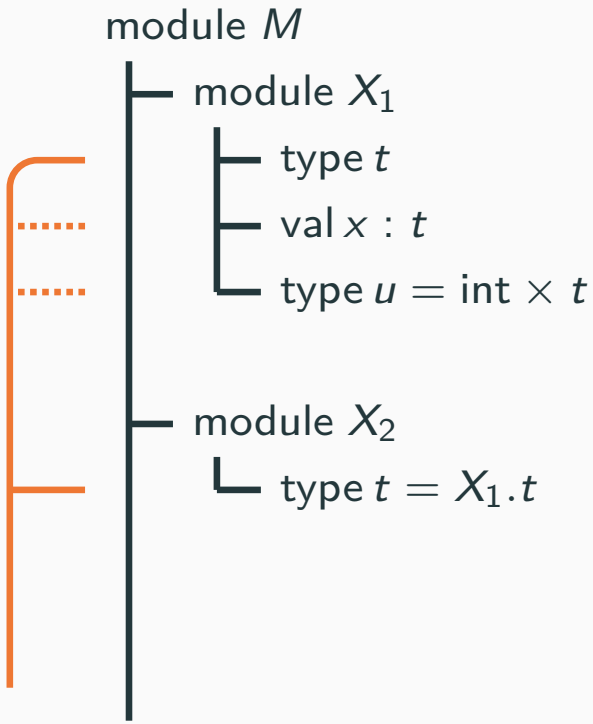


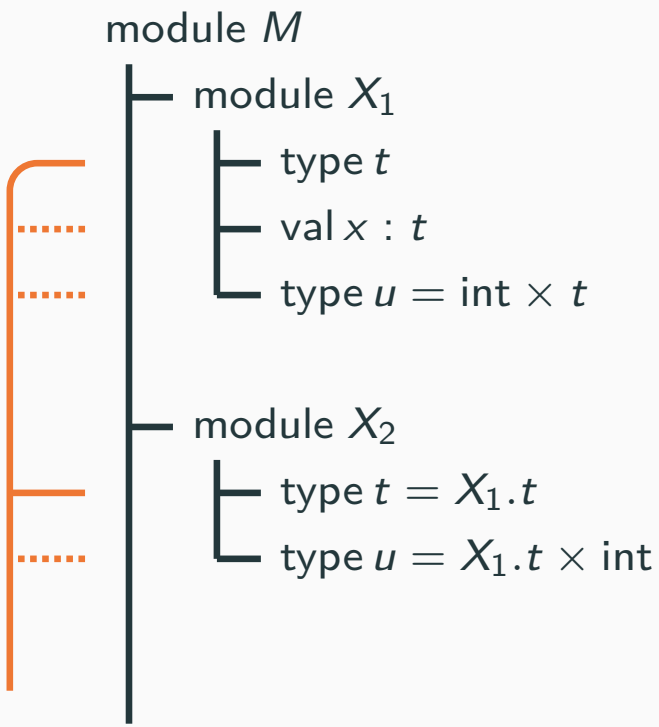
Signature avoidance

```
1  module M =  struct
2    module X1 : S = ...
3
4    module X2 = struct
5      type t = X1.t
6
7
8  end
```



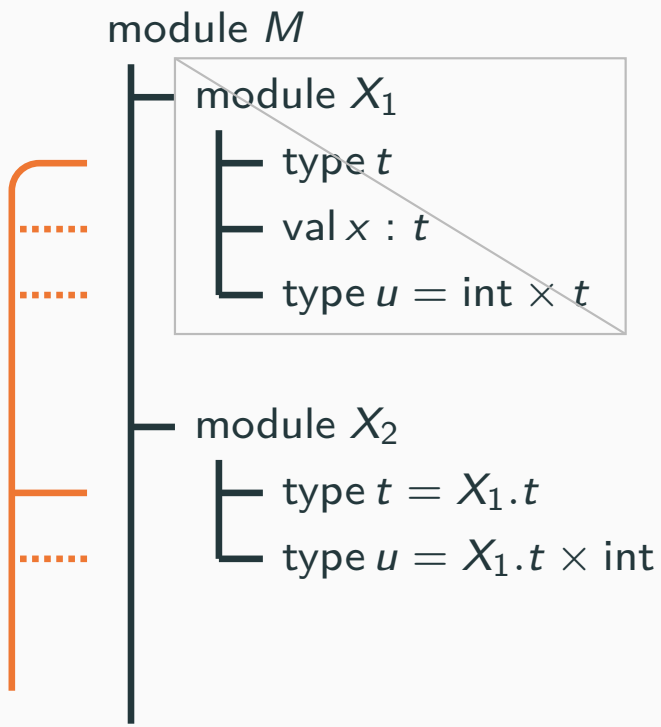
Signature avoidance

```
1  module M =  struct
2    module X1 : S = ...
3
4    module X2 = struct
5      type t = X1.t
6      type u = X1.t * int
7    end
8  end
```



Signature avoidance

```
1  module M = (struct
2    module X1 : S = ...
3
4    module X2 = struct
5      type t = X1.t
6      type u = X1.t * int
7    end
8  end).X2
```



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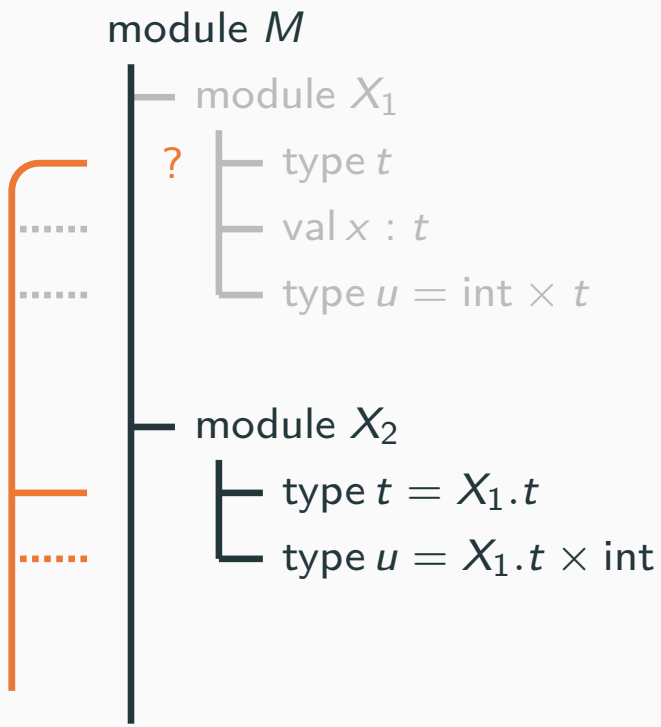

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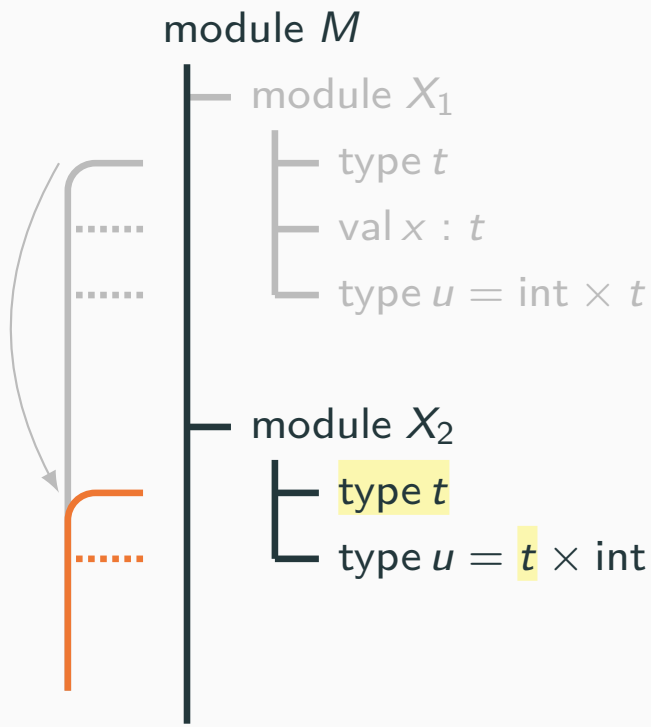
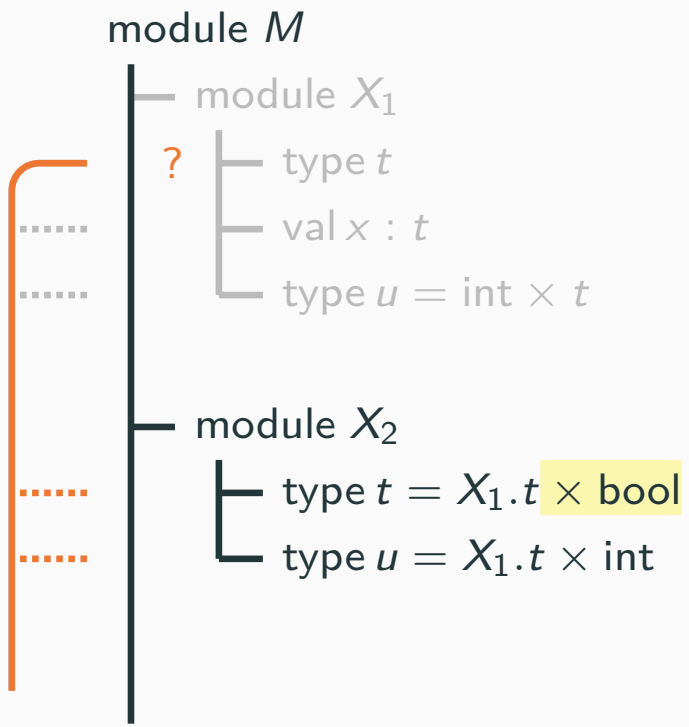


Signature avoidance

```
1  module M = (struct
2    module X1 : S = ...
3
4    module X2 = struct
5      type t = X1.t * bool
6      type u = X1.t * int
7    end
8  end).X2
```



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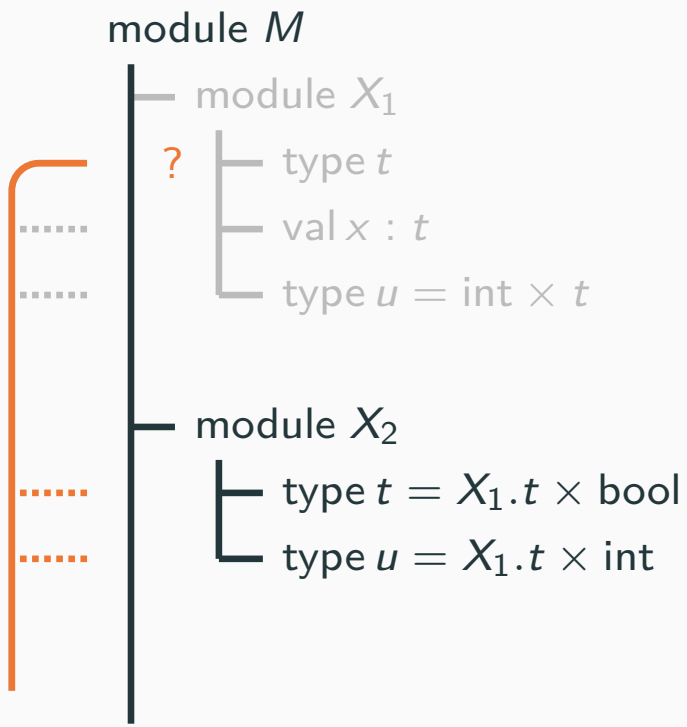

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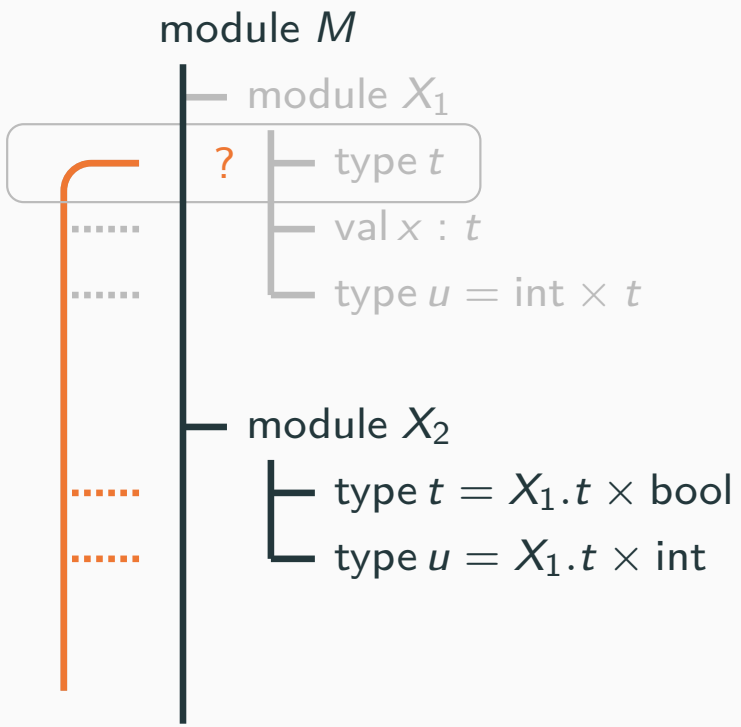

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