



软件科学基础

TYPECHECKING: A Typechecker for STLC

熊英飞
北京大学

Type-Checking Extended STLC



- Extended STLC仍然具有类型唯一性并可以把 `has_type` 关系转换成函数

Theorem `unique_types` : `forall` Gamma e T T',
Gamma |- e `\in` T ->
Gamma |- e `\in` T' ->
T = T'.



复习：判断类型等价

```
Fixpoint eqb_ty (T1 T2:ty) : bool :=
  match T1,T2 with
  | <{ Bool }> , <{ Bool }> =>
    true
  | <{ T11->T12 }>, <{ T21->T22 }> =>
    andb (eqb_ty T11 T21) (eqb_ty T12 T22)
  | _,_ =>
    false
  end.
```



复习：类型检查函数

```
Fixpoint type_check (Gamma : context) (t : tm) : option ty :=
  match t with
  | tm_var x =>
    Gamma x
  | <{\x:T2, t1}> =>
    match type_check (x |-> T2 ; Gamma) t1 with
    | Some T1 => Some <{T2->T1}>
    | _ => None
    end
  | <{t1 t2}> =>
    match type_check Gamma t1, type_check Gamma t2 with
    | Some <{T11->T12}>, Some T2 =>
      if eqb_ty T11 T2 then Some T12 else None
    | _,_ => None
    end
  end
```



复习：类型检查函数

```
| <{true}> =>  
  Some <{Bool}>  
| <{false}> =>  
  Some <{Bool}>  
| <{if guard then t else f}> =>  
  match type_check Gamma guard with  
  | Some <{Bool}> =>  
    match type_check Gamma t, type_check Gamma f with  
    | Some T1, Some T2 =>  
      if eqb_ty T1 T2 then Some T1 else None  
    | _, _ => None  
    end  
  | _ => None  
  end  
end.
```



改进符号



大量嵌套的match不好书写，引入类似命令式语言的符号

```
Notation " x <- e1 ;; e2" := (match e1 with
                              | Some x => e2
                              | None => None
                              end)
      (right associativity, at level 60).
```

```
Notation " 'return' e "
      := (Some e) (at level 60).
```

```
Notation " 'fail' "
      := None.
```

即定义函数式语言中的Monad支撑机制在option上的的特化版本



改进符号

```
| <{\x:T2, t1}> =>  
  match type_check (x |-> T2 ; Gamma) t1 with  
  | Some T1 => Some <{T2->T1}>  
  | _ => None  
end
```



```
| <{\x:T2, t1}> =>  
  T1 <- type_check (x |-> T2 ; Gamma) t1 ;;  
  return <{T2->T1}>
```



改进符号

```
| <{t1 t2}> =>  
  match type_check Gamma t1, type_check Gamma t2 with  
  | Some <{T11->T12}>, Some T2 =>  
    if eqb_ty T11 T2 then Some T12 else None  
  | _,_ => None  
end
```



```
| <{t1 t2}> =>  
  T1 <- type_check Gamma t1 ;;  
  T2 <- type_check Gamma t2 ;;  
  match T1 with  
  | <{T11->T12}> =>  
    if eqb_ty T11 T2 then return T12 else fail  
  | _ => fail  
end
```




扩展eqb_ty

```
Fixpoint eqb_ty (T1 T2 : ty) : bool :=
  match T1,T2 with
  | <{{Nat}}>, <{{Nat}}> =>
    true
  | <{{Unit}}>, <{{Unit}}> =>
    true
  | <{{T11 -> T12}}>, <{{T21 -> T22}}> =>
    andb (eqb_ty T11 T21) (eqb_ty T12 T22)
  | <{{T11 * T12}}>, <{{T21 * T22}}> =>
    andb (eqb_ty T11 T21) (eqb_ty T12 T22)
  | <{{T11 + T12}}>, <{{T21 + T22}}> =>
    andb (eqb_ty T11 T21) (eqb_ty T12 T22)
  | <{{List T11}}>, <{{List T21}}> =>
    eqb_ty T11 T21
  | _,_ =>
    false
  end.
```



eqb_ty的性质

```
Lemma eqb_ty_refl : forall T,  
  eqb_ty T T = true.
```

```
Lemma eqb_ty__eq : forall T1 T2,  
  eqb_ty T1 T2 = true -> T1 = T2.
```

注意：在递归类型、精化类型等复杂类型系统中，语法上不等的类型也有可能等价，上述Lemma就不再成立。



复习：在Coq中定义STLC

- $\langle \{ \dots \} \rangle$ 定义项
- $\langle \{ \{ \dots \} \} \rangle$ 定义类型



练习：定义Sum的类型检查分支

```
Fixpoint type_check (Gamma : context) (t : tm) : option ty :=
  match t with
  (* Complete the following cases. *)
  (* sums *)
  | ... =>
    ...
  | ...
```



答案：定义Sum的类型检查分支

```
Fixpoint type_check (Gamma : context) (t : tm) : option ty :=
  match t with
  (* Complete the following cases. *)
  (* sums *)
  | <{inl Tr t}> =>
    T1 <- type_check Gamma t ;;
    return <{{T1 + Tr}}>
  | <{inr T1 t}> =>
    Tr <- type_check Gamma t ;;
    return <{{T1 + Tr}}>
  | <{case t0 of | inl x1 => t1 | inr x2 => t2}> =>
    T0 <- type_check Gamma t0 ;;
    match T0 with
    | <{{T1 + Tr}}> =>
      T1 <- type_check (x1 |-> T1 ; Gamma) t1 ;;
      T2 <- type_check (x2 |-> Tr ; Gamma) t2 ;;
      if eqb_ty T1 T2 then return T1 else fail
    | _ => fail
  end
```



证明Sum的类型检查正确性

Theorem `type_checking_sound` : forall Gamma t T,
type_check Gamma t = Some T ->
has_type Gamma t T.



复习： solve_by_invert

- 定义策略在任意命题上反复应用n次inversion



```
Ltac solve_by_inverts n :=  
  match goal with | H : ?T |- _ =>  
  match type of T with Prop =>  
    solve [  
      inversion H;  
      match n with S (S (?n')) =>  
        subst; solve_by_inverts (S n')  
      end ]  
  end end.
```

```
Ltac solve_by_invert :=  
  solve_by_inverts 1.
```

|- : 匹配目标 (复习)
match type of X with
Type: 匹配类型
solve [策略]: 如果策略
没有完成当前目标证明,
就报错
(避免进入执行完策略
但没有证明目标的情况)



复习： type_checking_sound中 app的证明

在证明工具中演示



定义一系列的证明策略

```
Ltac invert_typecheck Gamma t T :=  
  remember (type_check Gamma t) as T0;  
  destruct T0 as [T|];  
  try solve_by_invert; try (inversion H0; eauto); try (subst; eauto).
```

用于消除 $T \leftarrow \text{type_check } \Gamma t$ 的运算

```
Ltac analyze T T1 T2 :=  
  destruct T as [T1 T2 | |T1 T2|T1| |T1 T2]; try solve_by_invert.
```

用于消除以下运算:

```
match T1 with  
  | ... => fail  
  | <{ ... }> => return ...  
end
```



定义一系列的证明策略

```
Ltac case_equality S T :=  
  destruct (eqb_ty S T) eqn: Heqb;  
  inversion H0; apply eqb_ty__eq in Heqb; subst; subst; eauto.
```

用于消除如下运算

```
if eqb_ty S T then return ... else fail
```



重写 `type_checking_sound` 中 `app` 的证明

在证明工具中演示

练习：定义Sum的类型检查 证明分支



```
Theorem type_checking_sound : forall Gamma t T,  
  type_check Gamma t = Some T ->  
  has_type Gamma t T.
```

```
Proof with eauto.
```

```
  intros Gamma t. generalize dependent Gamma.  
  induction t; intros Gamma T Htc; inversion Htc.
```

```
  ...
```

```
(* sums *)
```

```
- invert_typecheck Gamma t0 T1.  
- invert_typecheck Gamma t0 Tr.  
- invert_typecheck Gamma t1 T0.  
  analyze T0 T1 Tr.  
  remember (s |-> T1; Gamma) as Gamma1.  
  invert_typecheck Gamma1 t2 T1.  
  remember (s0 |-> Tr; Gamma) as Gamma2.  
  invert_typecheck Gamma2 t3 T2.  
  case_equality T1 T2.
```



作业

- 完成TypeChecking中
 - `type_check_defn`和`ext_type_checking_sound`的
 - Sums
 - Lists
 - Fix