

# Efficient Elaboration with Controlled Definition Unfolding

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# Overview

- ① We want to fill holes during elaboration with nice terms.
- ② We want to present nice terms to users in interaction.

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Not unfolding anything can be also bad...

...but we want to preserve unfoldings until we can make a good decision.

# Unfolding can be explosive

Classic Hindley-Milner example:

```
let x1 = (True, True) in
let x2 = (x1, x1) in
let x3 = (x2, x2) in
...
xN
```

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Quadratic elaboration is surprisingly common with fancy types!

```
cons : (n :  $\mathbb{N}$ )  $\rightarrow$  Bool  $\rightarrow$  Vec Bool n  $\rightarrow$  Vec Bool (suc n)
myvec = cons _ True (cons _ True (cons _ True nil))
```

Also in GHC: <https://well-typed.com/blog/2021/12/type-level-sharing-now/>

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```
cons : (n : ℕ) → Bool → Vec Bool n → Vec Bool (suc n)
myvec = cons (suc (suc zero)) True (cons (suc zero) True (cons zero Tru
```

Also in GHC: <https://well-typed.com/blog/2021/12/type-level-sharing-now/>



# Hash consing is insufficient

Hash consing doesn't know about beta-expansions.

```
data Nat = Zero | Suc Nat
```

```
oneMillion : Nat
```

```
oneMillion = ...
```

The `oneMillion` definition may be tiny, but the end result is big and incompressible by hash consing!

Hash consing also doesn't help with unfolding in user interaction.

But: hash-consing/CSE can be crucial to clean up very bad input.

# Basic setup

- **Core terms** are viewed as immutable program code.
- Terms get **evaluated** into **semantic values**.
- Expensive computation (reduction, conversion, unification) is implemented only on values.
- There is a **quotation** operation which turns values back to terms.

Interleaving of normalization-by-evaluation and elaboration.<sup>1</sup>

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<sup>1</sup>Originally by Thierry Coquand, 1996, “An algorithm for checking dependent types”

## Minimal NbE with top-level unfolding control (1)

```
{-# language Strict #-}
```

```
data Tm = TopVar TopName  
        | LocalVar LocName  
        | App Tm Tm  
        | Lam LocName Tm
```

```
type Spine = [Val]
```

```
type Env   = [(LocName, Val)]
```

```
data Val   = VNe LocName Spine | VLam LocName (Val -> Val)  
           | VUnfold (TopName, Spine) ~Val
```

## Minimal NbE with top-level unfolding control (2)

**eval** :: Env -> Tm -> Val

**eval** env t = case t of

TopVar x     -> VUnfold (x, []) (lookupTop x)

LocalVar x -> lookup x env

App t u       -> vApp (eval env t) (eval env u)

Lam x t       -> VLam x ( $\lambda v \rightarrow \text{eval } ((x, v):e) \text{ } t$ )

**vApp** :: Val -> Val -> Val

**vApp** v v' = case v of

VLam \_ f                   -> f v'

VUnfold (x, sp) v -> VUnfold (x, (v':sp)) (vApp v v')

VNe x sp                   -> VNe x (v':sp)

## Minimal NbE with top-level unfolding control (3)

```
quoteSp :: [LocalName] -> Bool -> Tm -> Spine -> Tm
```

```
quoteSp ns unfold t sp =
```

```
  foldl' (\t v -> App t (quote ns unfold v)) t sp
```

```
quote :: [LocalName] -> Bool -> Val -> Tm
```

```
quote ns unfold v = case v of
```

```
  VNe x sp          -> quoteSp ns unfold (LocalVar x) sp
```

```
  VLam x f          -> let x' = fresh ns x in
```

```
    Lam x' (quote (x':ns) (f (VNe x' [])))
```

```
  VUnfold (x, sp) v -> if unfold then quote ns unfold v
```

```
    else quoteSp ns unfold (TopVar x)
```

## Glued values

One value in the pair is *minimally* unfolded, the other is *maximally* unfolded.

```
type GVal = (Val, Val)
```

During elaboration/unification, we often force values to whnf, but don't want to throw away the original value!

```
whnf :: Val -> Val
```

```
whnf (VUnfold _ v) = whnf v
```

```
whnf v              = v
```

```
type VTy = Val
```

```
type GTy = GVal
```

```
check :: Context -> RawTm -> GTy -> M Tm
```

```
infer :: Context -> RawTm -> M (Tm, GTy)
```

```
unify :: Context -> GVal -> GVal -> M ()
```

## When unfolding is needed

Elaboration input:

```
map2 : ∀ A B C : Type → (B → C) → (A → B) → List A → List B  
map2 f g as = map f (map g as)
```

# When unfolding is needed

Elaboration input:

```
map2 : ∀ A B C : Type → (B → C) → (A → B) → List A → List B  
map2 f g as = map f (map g as)
```

Un-optimized output:

```
m1 = λ A B C f g as. B  
m2 = λ A B C f g as. C  
m3 = λ A B C f g as. A  
m4 = λ A B C f g as. B
```

```
map2 : ∀ {A B C : Type} → (B → C) → (A → B) → List A → List B  
map2 = λ {A}{B}{C} f g as.  
  map {m1 A B C f g as}{m2 A B C f g as} f  
    (map {m3 A B C f g as}{m3 A B C f g as} g as)
```



## When unfolding is needed

Desired output:

```
map2 : ∀ {A B C : Type} → (B → C) → (A → B) → List A → List B  
map2 = λ {A}{B}{C} f g as. map {B}{C} f (map {A}{B} g as)
```

# Early code optimization

User-written code should be **preserved**.

Code from elaboration/tactics should be **optimized** soon after it's generated.

- Already in elaboration, we don't want to compute with poor-quality code.
- Simple and fast optimization (basic inlining, let-motion) makes a big difference.

Human-readable elaboration output is important for debugging/optimization!

- A major issue in Agda right now.

# Local unfolding control

```
topdef =  
  let bigDef1 = ...  
      bigDef2 = ...  
      bigDef3 = ...  
      ...  
  in ?
```

We split the local Env to two parts:

- ① Visible let-s in elaboration scope.
- ② Non-visible bindings arising from evaluation.

## Local unfolding control

```
data Tm  = ... | Let LocName Val Val
data Val = ... | VLet LocName Val (Val -> Val) ~Val
           | VUnfoldLoc (LocName, Spine) ~Val
```

```
eval :: Env -> Env -> Tm -> Val
```

```
eval env env' t = case t of
  LocalVar x -> if x is in env' then lookup x env'
                else VUnfoldLet (x, []) (lookup x env)
  Let x t u   -> let v = eval env env' t in
                VLet x v (\v -> eval env ((x, v):env') u) v
  ...
```

```
vApp v v' = case v of
```

```
  VLet x t f v          -> VLet x t ((`vApp` v') . f) (vApp v v')
  VUnfoldLoc (x, sp) v -> VUnfoldLoc (x, (v':sp)) (vApp v v')
  ...
```

## Local unfolding control

```
quote ns unfold v = case v of
```

```
  VUnfoldLoc (x, sp) v
```

```
    | unfold      -> quote ns unfold v
```

```
    | otherwise -> quoteSp ns unfold (LocVar x)
```

```
  VLet x v f v'
```

```
    | unfold      -> quote ns unfold v'
```

```
    | otherwise -> let x' = fresh ns x in
```

```
                  Let x' (quote ns unfold v)
```

```
                  (quote (x':ns) unfold (f (VNe x' [])))
```

```
  ...
```

# Metavars and local let-s

How can meta solutions refer to local let-s? Two ways:

- ① Metas are top-level only, but abstract over let-s too.
  - -: More overhead during elaboration.
  - +: Relatively simple.
- ② Use metas in arbitrary local scope.
  - +: More efficient during elaboration.
  - +: The only sensible way to do let-generalization.
  - -: A lot more complex.
  - -: We still need to optimize its output.

# Non-explosive record construction

What's wrong with this in Agda and elsewhere?

```
foo = record {  
  field1 = bigDef1;  
  field2 = bigDef2;  
  ...  
  fieldN = bigDefN }
```

There's no way to share field definitions in elaboration!

*Fix: each field definition binds the field name like a local let, in the rest of the record construction.*

## Related Implementations

- Sixten: <https://github.com/ollef/sixten>
- Sixty: <https://github.com/ollef/sixty>
- smalltt: <https://github.com/AndrasKovacs/smalltt>
- sett: <https://github.com/AndrasKovacs/sett>
- cctt: <https://github.com/AndrasKovacs/cctt>
- Idris 2: <https://github.com/idris-lang/Idris2>