

Question 1 [50 points]: "If it's 'dynamic', it *must* be better."

The following rules define an environment-based semantics for lexically-scoped functions, Lam, and dynamically-scoped functions, Ds-lam.

$env \vdash e \Downarrow v$ Under environment env , expression e evaluates to value v

$$\frac{}{env \vdash (Num\ n) \Downarrow (Num\ n)} \text{Env-num} \qquad \frac{env \vdash e1 \Downarrow (Num\ n1) \quad env \vdash e2 \Downarrow (Num\ n2)}{env \vdash (Add\ e1\ e2) \Downarrow (Num\ n1+n2)} \text{Env-add}$$

$$\frac{env \vdash e1 \Downarrow v1 \quad x=v1, env \vdash e2 \Downarrow v2}{env \vdash (Let\ x\ e1\ e2) \Downarrow v2} \text{Env-let}$$

$$\frac{lookup(env, x) = e}{env \vdash (Id\ x) \Downarrow e} \text{Env-id}$$

$$\frac{lookup(env, x) \text{ undefined}}{env \vdash (Id\ x) \text{ unknown-id-error}} \text{Env-unknown-id}$$

$$\frac{}{env \vdash (Lam\ x\ e1) \Downarrow (Clo\ env\ (Lam\ x\ e1))} \text{Env-lam}$$

$$\frac{env_{old} \vdash e \Downarrow v}{env \vdash (Clo\ env_{old}\ e) \Downarrow v} \text{Env-clo}$$

$$\frac{env \vdash e1 \Downarrow (Clo\ env_{old}\ (Lam\ x\ eB)) \quad env \vdash e2 \Downarrow v2 \quad x=v2, env_{old} \vdash eB \Downarrow v}{env \vdash (App\ e1\ e2) \Downarrow v} \text{Env-app}$$

$$\frac{}{env \vdash (Ds-lam\ x\ e1) \Downarrow (Ds-lam\ x\ e1)} \text{Env-ds-lam} \qquad \frac{env \vdash e1 \Downarrow (Ds-lam\ x\ eB) \quad env \vdash e2 \Downarrow v2 \quad x=v2, env \vdash eB \Downarrow v}{env \vdash (App\ e1\ e2) \Downarrow v} \text{Env-ds-app}$$

Assume that $lookup(env, x)$ returns the **leftmost** binding of x . For example:

$$lookup((x=(Num\ 2), x=(Num\ 1), \emptyset), x) = (Num\ 2)$$

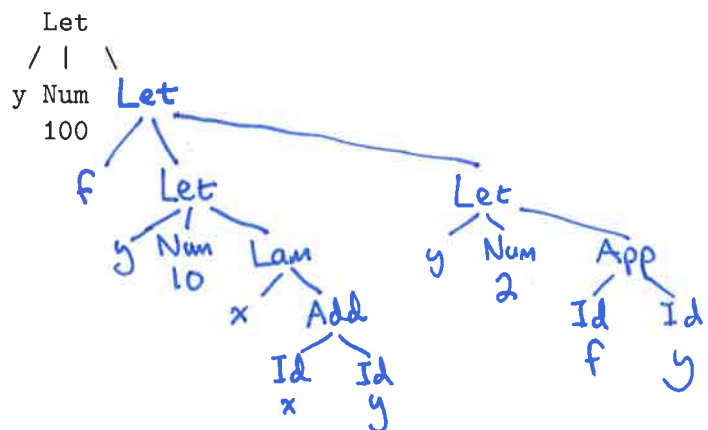
Consider the following expression, shown in concrete syntax (left) and in abstract syntax (right).

```
{Let y 100
  {Let f {Let y 10
          {Lam x {+ x y}}}}
  {Let y 2
    {App f y}}}}
```

```
(Let y (Num 100)
  (Let f (Let y (Num 10)
            (Lam x (Add (Id x) (Id y)))))
  (Let y (Num 2)
    (App (Id f) (Id y)))))
```

Q1a [10 points] Complete the **abstract syntax tree** for the above expression.

\Rightarrow



(Writing ... is also okay) extra lines