Garbage Collection

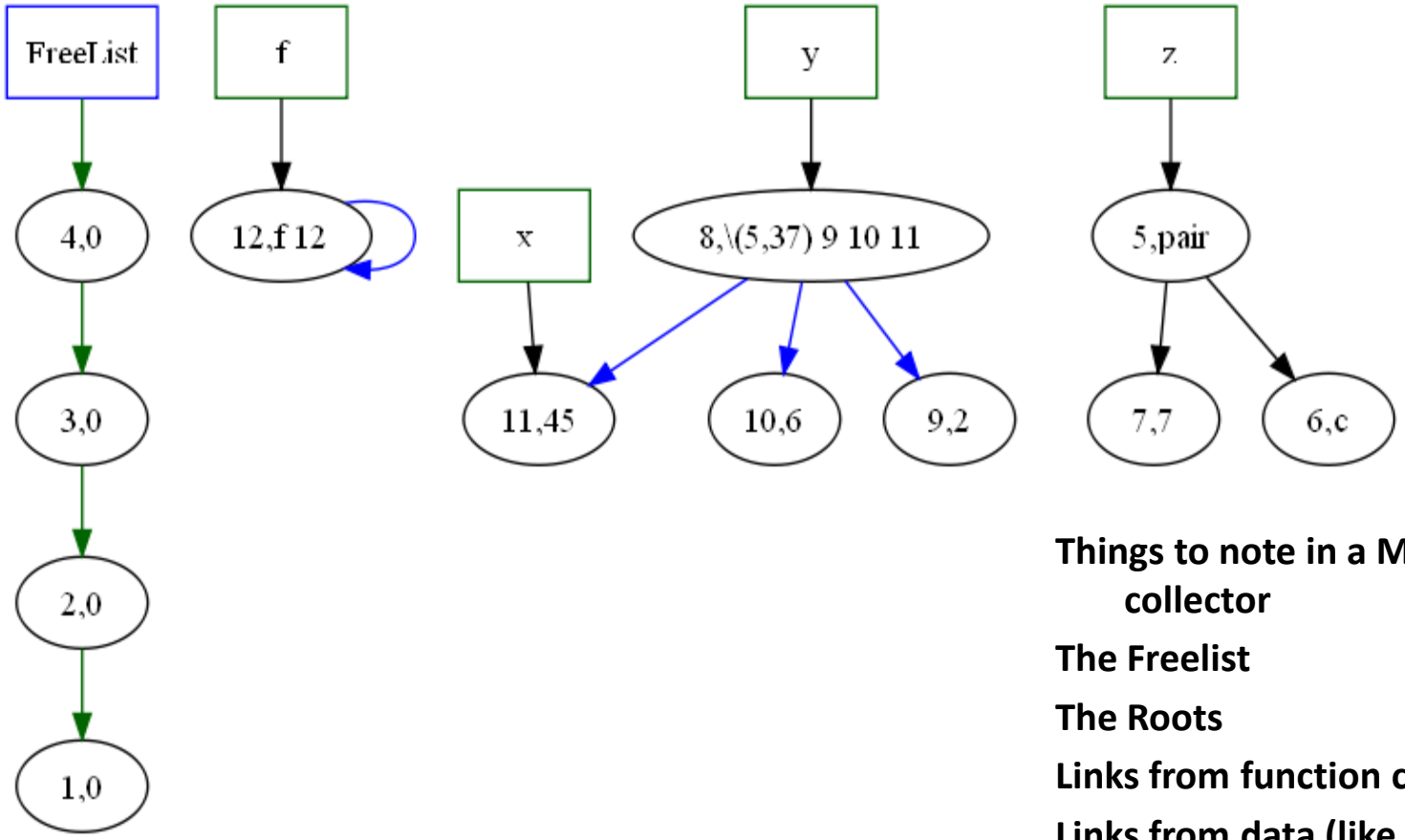
Terminology

- Heap – a finite pool of data cells, can be organized in many ways
- Roots - Pointers from the program into the Heap.
  - We must keep track of these.
  - All pointers from global varaibles
  - All pointers from temporarys (often on the stack)
- Marking – Tracing the live data, starting at the roots. Leave behind a “mark” when we have visited a cell.

Things to keep in mind

- Costs – How much does it cost as function of
  - All data
  - Just the live data
- Overhead – Garbage collection is run when we have little or no space. What space does it require to run the collector?
- Complexity – How can we tell we are doing the right thing?

Structure of the Heap



Things to note in a Mark and sweep collector

The Freelist

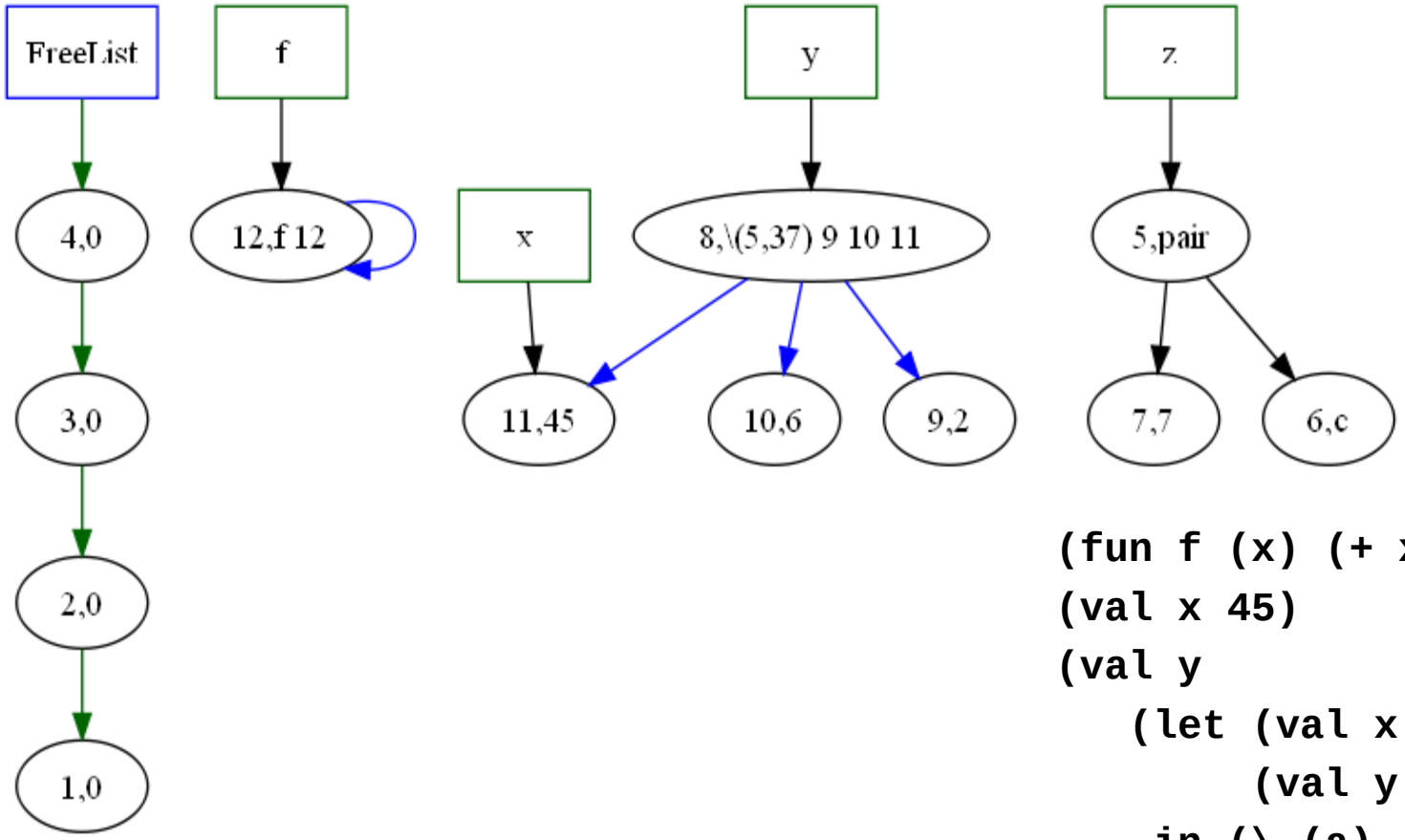
The Roots

Links from function closures

Links from data (like pair or list)

Constants

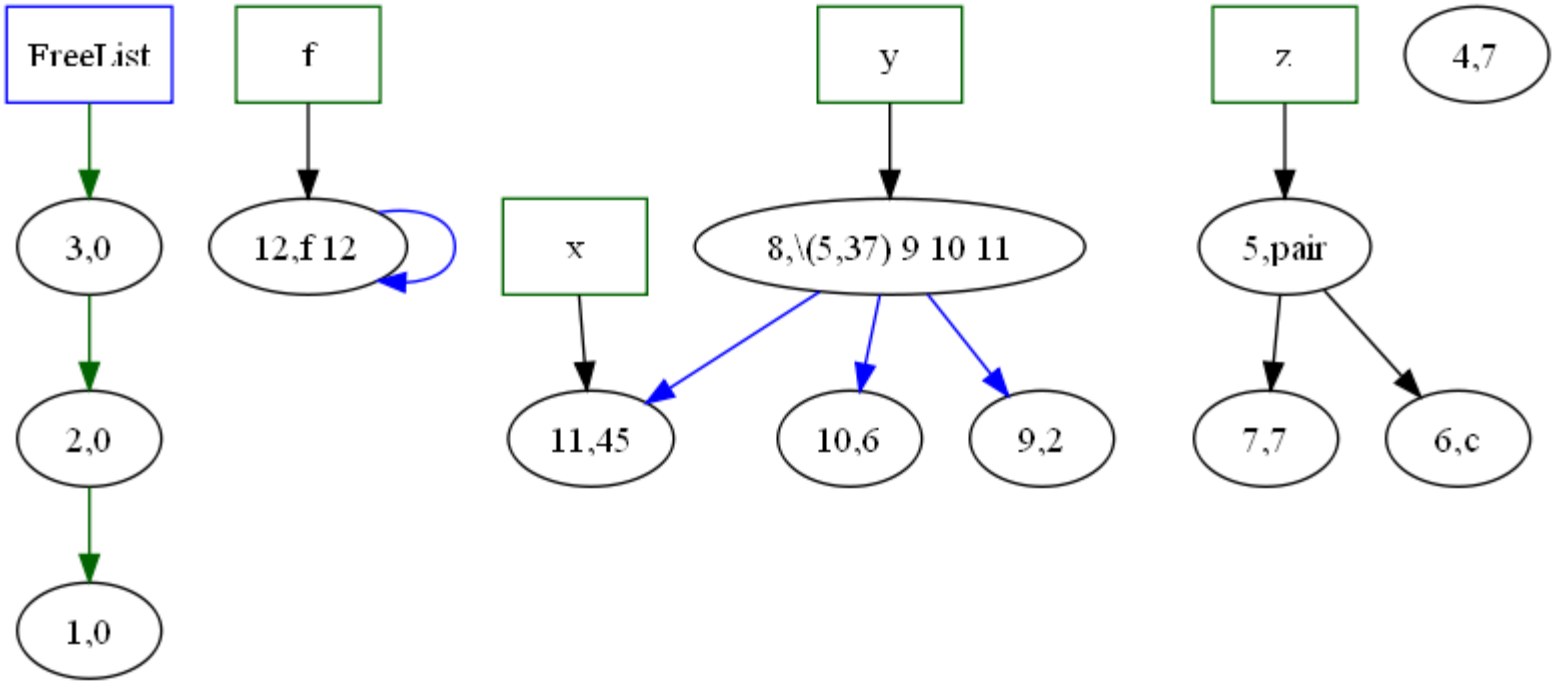
Structure of the Heap



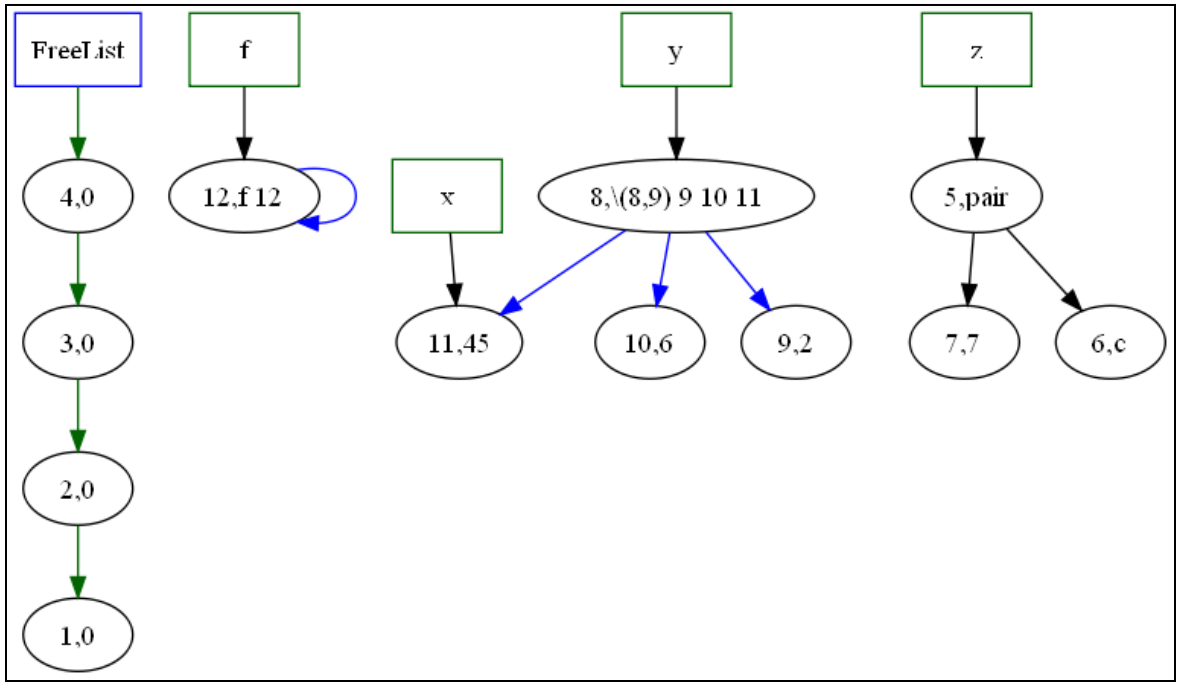

```
(fun f (x) (+ x 7))
(val x 45)
(val y
   (let (val x 6)
        (val y 2)
    in (\ (a)
          (+ x (+ y
   a)))))
(val z (pair 7 'c'))
```

Changes in the heap

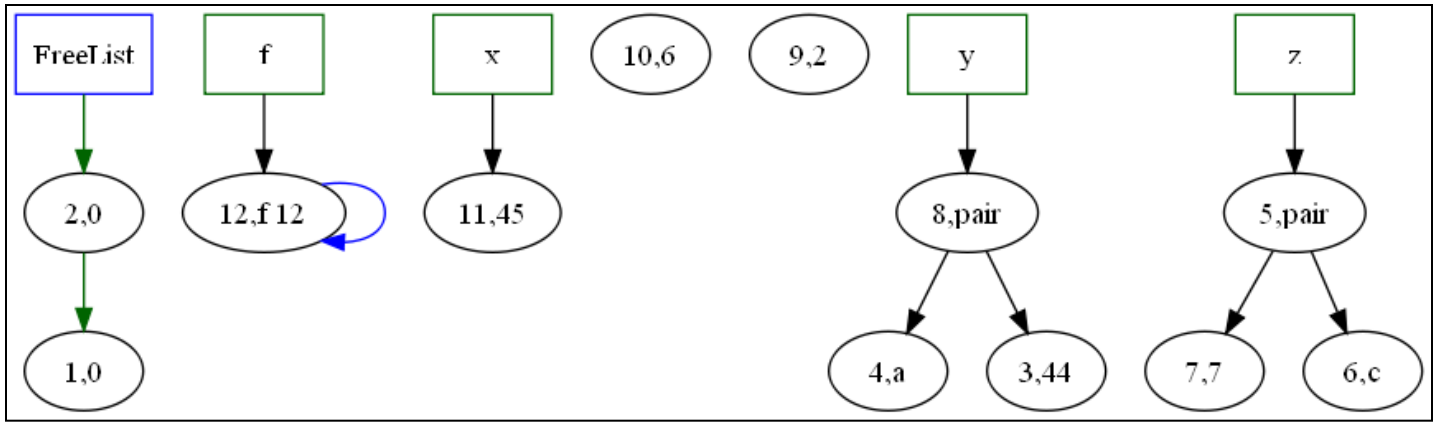
- Intermediate result computation
  - (@ f (fst z))
- Assignment to things
- Garbage collection



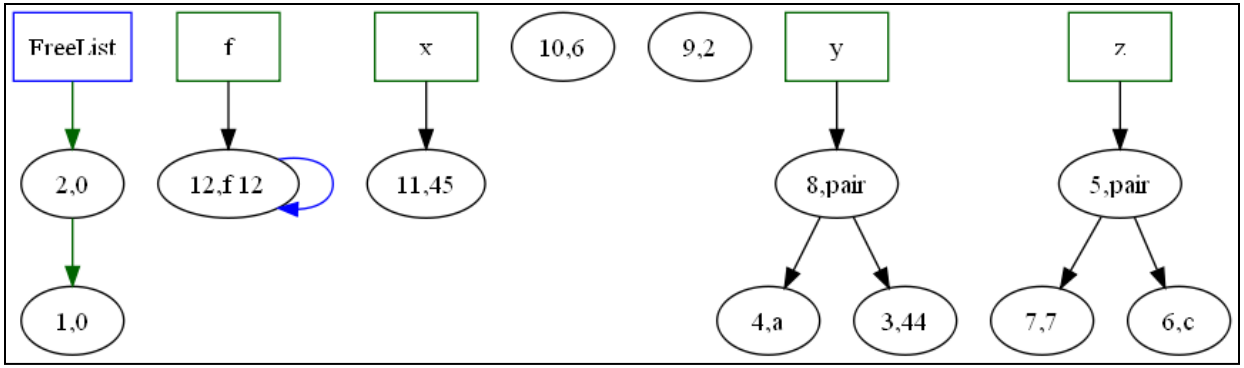
Changes in the heap

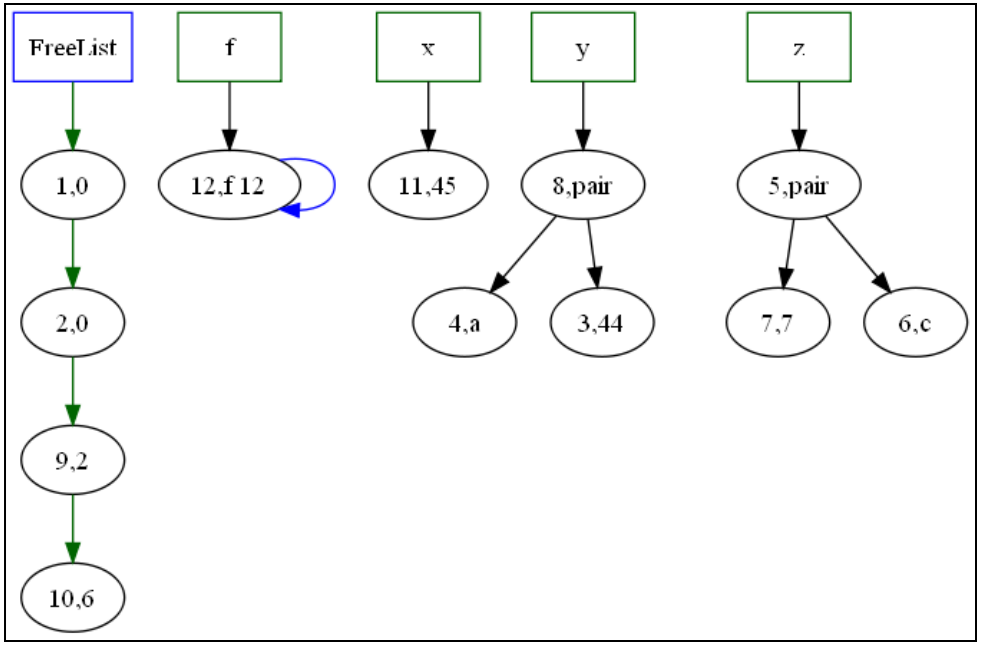


- Intermediate result computation
- Assignment to things
  - **(:= y (pair 7 'c'))**
- Garbage collection



Garbage Collection





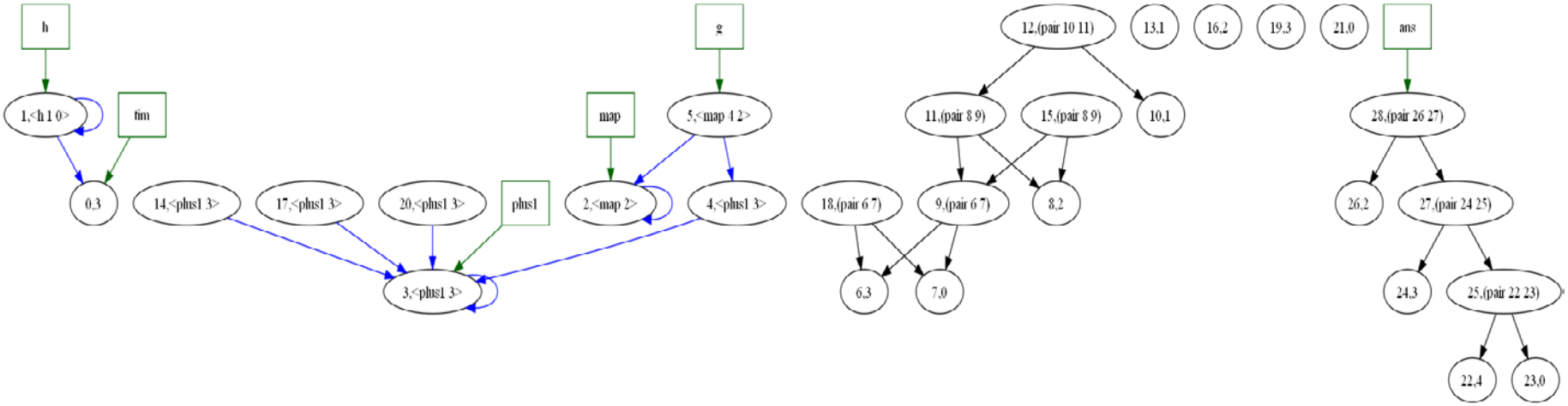
Mark and Sweep

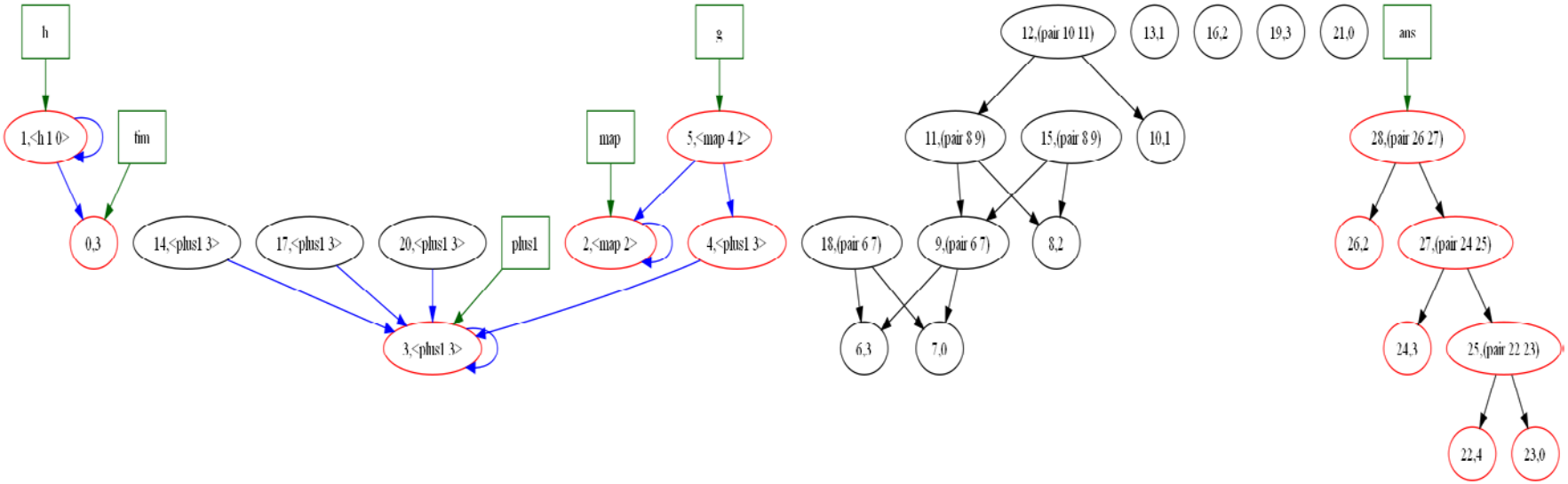
- Cells have room for several things beside data

```
data HCell a = Cell { mark::(IORef Bool)
                    , key :: Int
                    , payload :: IORef a
                    , allocLink:: IORef (HCell a)
                    , allLink:: HCell a }
             | NullCell
```

- All cells start linked together on the free list
- Allocation takes 1 (or more cells) from the free list
- Garbage collection has two phases
  - Mark (trace all live data from the roots)
  - Sweep (visit every cell, and add unmarked cells to free list)

Mark phase (turns cells red in this picture).





Where do links into the heap reside?

- In the environment

```
interpE :: Env (Range Value)        -- the variables in scope
        -> State                    -- the heap
        -> Exp                      -- exp to interpret
        -> IO(Value,State)
```

- Inside data values

```
data Value
  = IntV Int
  | CharV Char
  | ConV String Int (Range Value)
  | FunV Vname (Env (Range Value)) [Vname] Exp
```

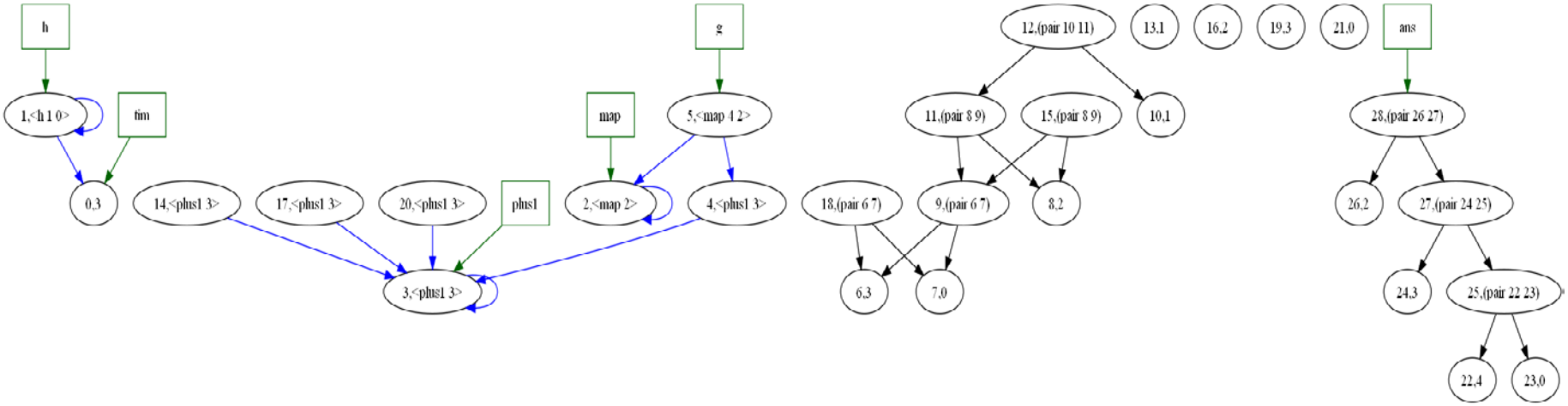
Mark a cell

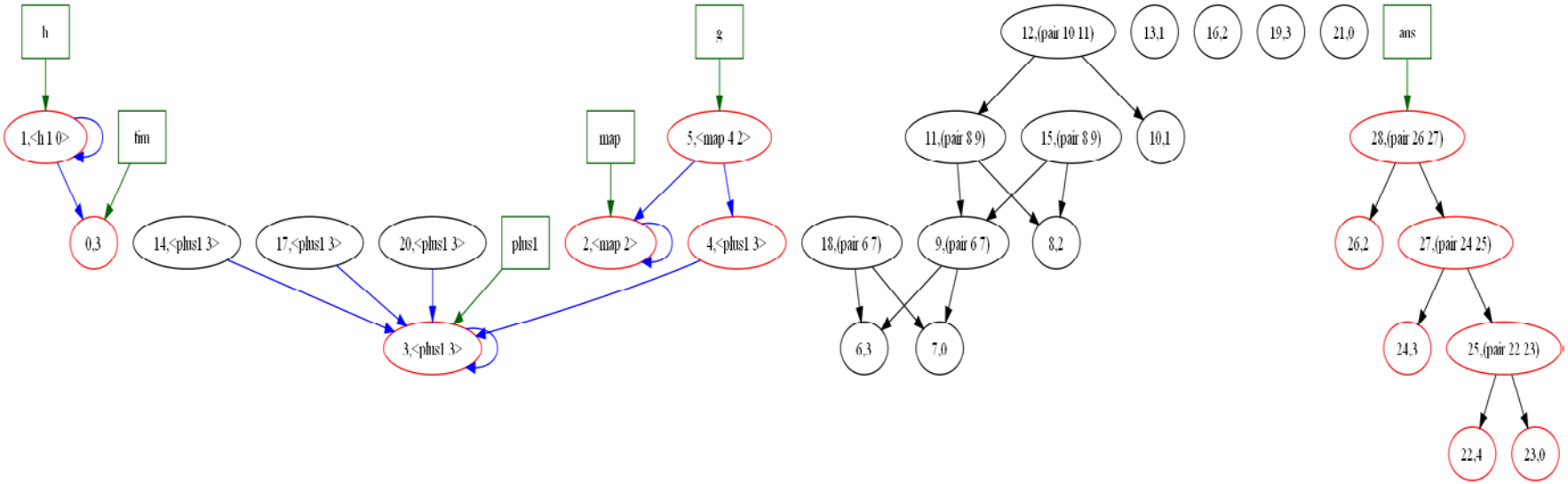
```
markCell markV NullCell = return NullCell
markCell markV (cell@(Cell m id p l1 l2)) =
      do { b <- readIORef m; help b }
  where help True = return cell
        help False =
           do { writeIORef m True
              ; v <- readIORef p
              ; v2 <- markV
                        (markRange markV) v
              ; writeIORef p v2
              ; return cell}
```

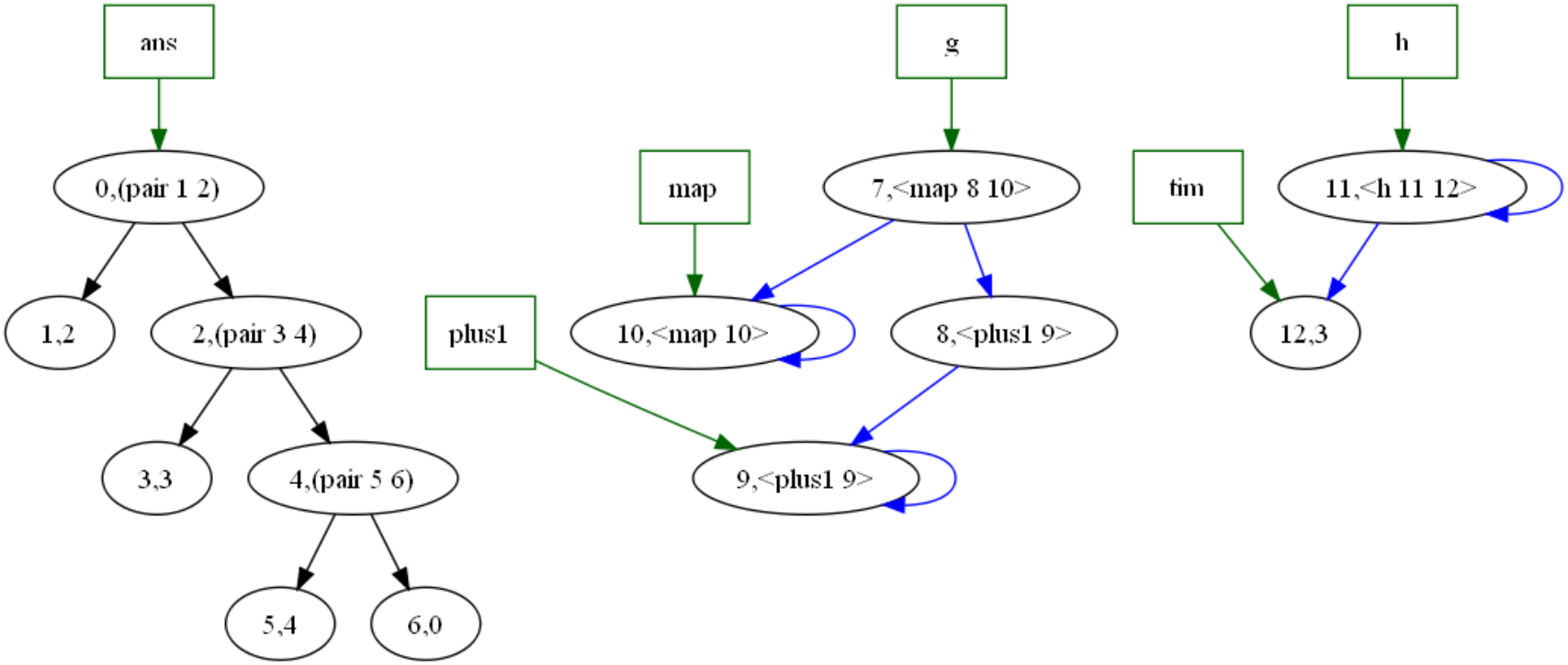
Sweeping through memory

```
sweep (H all free) NullCell = return (H all free)
sweep (H all free) (c@(Cell m id p l more)) =
  do { b <- readIORef m
     ; if b then do { writeIORef m False
                    ; sweep (H all free) more }
            else do { -- link it on the free
                      writeIORef l free
                    ; sweep (H all c) more }}
```

Mark phase (turns cells red in this picture).






ans
0,(pair 1 2)
1,2
2,(pair 3 4)
3,3
4,(pair 5 6)
5,4
6,0
g
map
7,<map 8 10>
plus1
10,<map 10>
8,<plus1 9>
9,<plus1 9>
h
tim
11,<h 11 12>
12,3

Two space collector

- The heap is divided into two equal size regions
- We allocate in the “active” region until no more space is left.
- We trace the roots, creating an internal linked list of just the live data.
- As we trace we compute where the cell will live in the new heap.
- We forward all pointers to point in the new inactive region.
- Flip the active and inactive regions

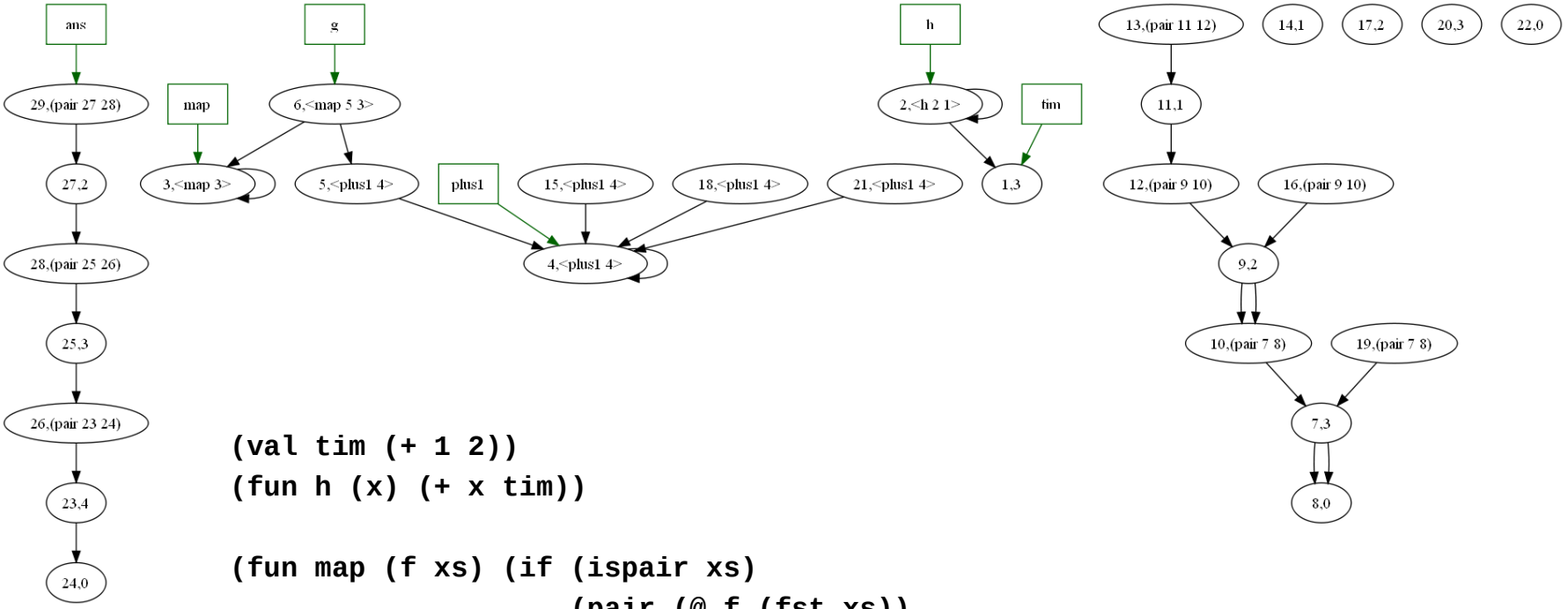
A heap Cell

```
data HCell a =
  Cell { mark :: Mutable Bool
       , payload :: Mutable a
       , forward :: Mutable Addr
       , heaplink:: Mutable Addr
       , showR:: a -> String }
```

The Heap

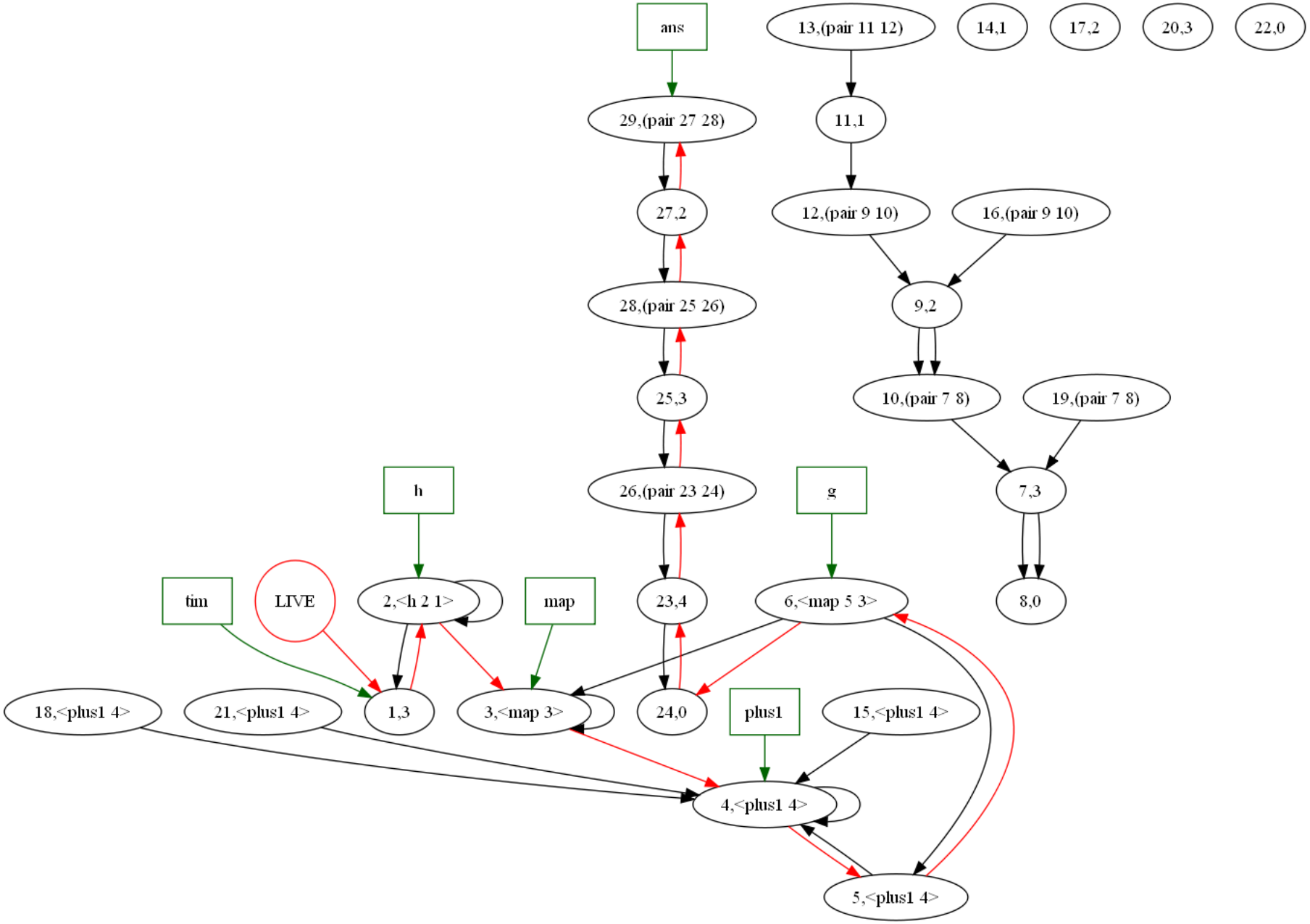
```
data Heap a =
  Heap
    { heapsize    :: Int
    , nextActive :: Addr
    , active  :: (Array Int (HCell a))
    , inactive:: (Array Int (HCell a))
    , nextInActive:: Mutable Addr
    , liveLink:: Mutable Addr }
```

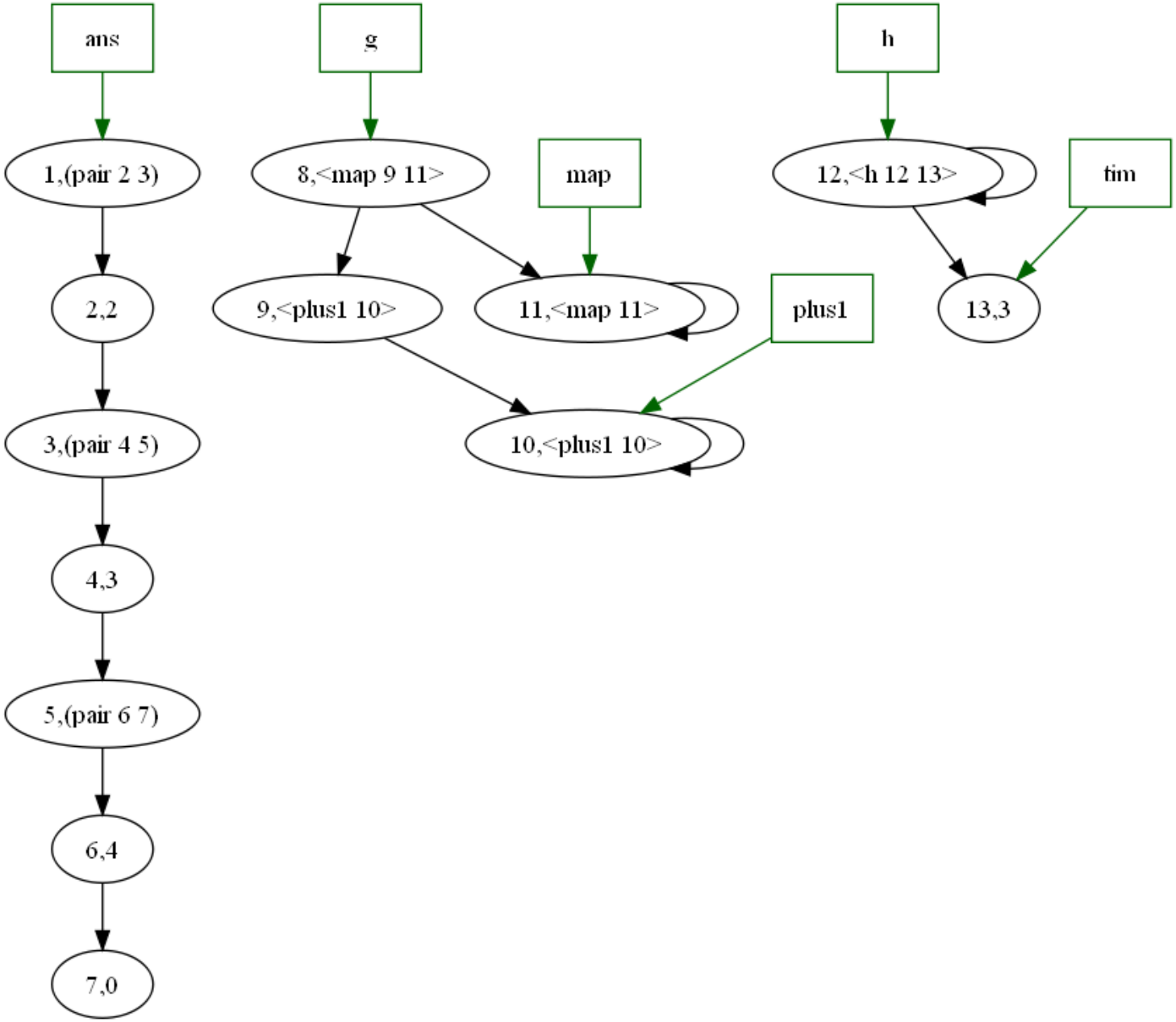
```
(val tim (+ 1 2))
(fun h (x) (+ x tim))

(fun map (f xs) (if (ispair xs)
                    (pair (@ f (fst xs))
                          (@ map f (snd xs)))
                    xs))

(fun plus1 (x) (+ x 1))

(val g (@map plus1))

(val ans (@g (pair 1 (pair 2 (pair 3 0)))) )

in

ans  { should yield (2.(3.(4.0))) }
```




```
(val tim (+ 1 2))
(fun h (x) (+ x tim))

(fun map (f xs) (if (ispair xs)
                    (pair (@ f (fst xs))
                          (@ map f (snd xs)))
                    xs))

(fun plus1 (x) (+ x 1))

(val g (@map plus1))

(val ans (@g (pair 1 (pair 2 (pair 3 0)))) )

in

ans  { should yield (2.(3.(4.0))) }
```

```
markAddr :: (GCRecord a) -> Addr -> IO Addr
markAddr (rec@(GCRec heap markpay showV )) index = mark cell
  where cell = active heap ! index
        nextFreeInNewHeap = nextInActive heap
        markedList = liveLink heap
        mark (Cell m payld forward reachable showr) =
          do { mark <- readIORef m
             ; if mark
                  then do readIORef forward
                  else do {
             -- Set up recursive marking
             ; new <- fetchAndIncrement nextFreeInNewHeap
             ; next <- readIORef markedList
             ; writeIORef markedList index

             -- Update the fields of the cell, showing it is marked
             ; writeIORef m True
             ; writeIORef forward new
             ; writeIORef reachable next

             -- recursively mark the payload
             ; v <- readIORef payld
             ; v2 <- markpay (markRange rec) v

             -- copy payload in the inactive Heap with
             -- all payload pointers relocated .
             ; writeIORef (payload ((inactive heap) ! new)) v2
             -- finally return the Addr where this cell will be relocated to.
             ; return new }}
```


ans
13,(pair 11 12)
14,1
17,2
20,3
22,0
29,(pair 27 28)
11,1
27,2
12,(pair 9 10)
16,(pair 9 10)
28,(pair 25 26)
9,2
25,3
10,(pair 7 8)
19,(pair 7 8)
h
26,(pair 23 24)
g
7,3
tim
LIVE
2,<h 2 1>
map
23,4
6,<map 5 3>
8,0
18,<plus1 4>
21,<plus1 4>
1,3
3,<map 3>
24,0
plus1
15,<plus1 4>
4,<plus1 4>
5,<plus1 4>


ans
g
h
1,(pair 2 3)
8,<map 9 11>
map
12,<h 12 13>
tim
2,2
9,<plus1 10>
11,<map 11>
plus1
13,3
3,(pair 4 5)
10,<plus1 10>
4,3
5,(pair 6 7)
6,4
7,0