Alias Analysis

15-411/15-611 Compiler Design

Seth Copen Goldstein

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Constant Propagation on Memory

$$l_1 : M[q] \leftarrow 4$$
$$l_2 : M[p] \leftarrow 8128$$
$$l_3 : x \leftarrow M[q]$$

- Can we replace l_3 with **x ← 4**?

Constant Propagation on Memory

$$l_1 : M[q] \leftarrow 4$$
$$l_2 : M[p] \leftarrow 8128$$
$$l_3 : x \leftarrow M[q]$$

- Can we replace l_3 with **x ← 4**?
- Only if $p \neq q$
- That is, only if p and q do not alias

CSE

```
foo() {
        int a,k;
        extern int *q;
        ...
        ... // maybe &a or &k
        ...
        k = a+6;
        f(a,&k);
        *q = 13;
        k = a+6
        ...
}
```

Source of Aliases

- Pass by reference parameters
- Address of operator
- Dereferencing pointers
- Array subscripting
- Non-local variables
- Assignment

CSE on Memory

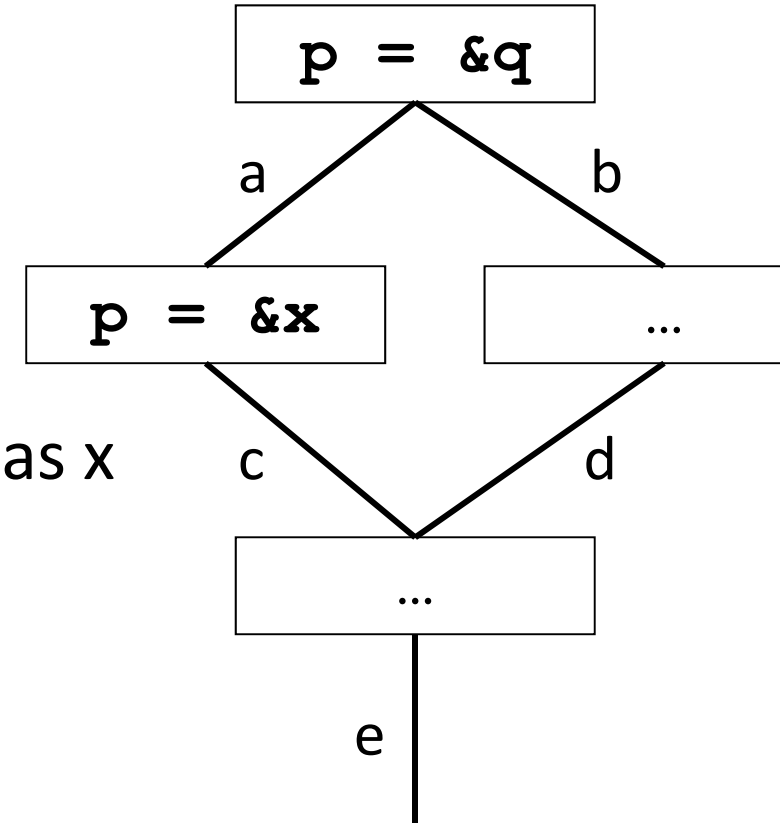
```
struct point {
  int x;
  int y;
};
typedef struct point pt;

void mult(int[] A, pt* p, pt* q) {
  q->x = A[0] * p->x + A[1] * p->y;
  q->y = A[2] * p->x + A[3] * p->y;
  return;
}
```

$\text{mult}(A, p, q):$

$t_0 \leftarrow M[A+0]$
$t_1 \leftarrow M[p+0]$
$t_2 \leftarrow t_0 * t_1$
$t_3 \leftarrow M[A+4]$
$t_4 \leftarrow M[p+4]$
$t_5 \leftarrow t_3 * t_4$
$t_6 \leftarrow t_2 + t_5$
$M[q+0] \leftarrow t_6$
$t_8 \leftarrow M[A+8]$
$t_9 \leftarrow M[p+0]$
$t_{10} \leftarrow t_8 * t_9$
$t_{11} \leftarrow M[A+12]$
$t_{12} \leftarrow M[p+4]$
$t_{13} \leftarrow t_{11} * t_{12}$
$t_{14} \leftarrow t_{10} + t_{13}$
$M[q+4] \leftarrow t_{14}$
return

Alias Information

- must-alias and may-alias
  - a: p must-alias q
  - b: p must-alias q
  - c: p must-alias q
  - d: p must-alias q
  - e: p may-alias q and p may-alias x
- Analysis:
  - flow-insensitive
  - flow-sensitive



What regions?

- Stack based
  - include pointers to stack allocated objects
  - Can use name of locals
- Heap based
  - pointers to heap addresses, e.g., returned from alloc
  - Need way to “name” the objects
  - Will use line number

Flow-based May-Alias

- At each program point a set of tuples:

  (t, d, k)

  - t: variable
  - d: alias class
  - k: offset into alias class
- (t,d,k) means variable t may point to alias class d, or
- t-k points to d

```
struct intlist {
        int val;
        struct intlist* next;
};

struct int foo() {
      struct intlist* p;
      struct intlist* q;
      int a = 1;

      q = alloc(struct intlist);
      q->val = 0;
      q->next NULL;
      p = alloc(struct intlist);
      p->val = 0;
      p->next = q;
      q->val = 5;
      a = p->val;
      return a;
}
```

```
1:  MOVE   t2        <- 0                          p
2:  MOVE   t3        <- 0                          q
3:  MOVE   t4        <- 1                          a
4:  CALL   t5        <- malloc(8)    (t5,4,0)      q <- alloc
5:  PLUS   u1        <- t5,    0
6:  STORE  MEM[u1]   <-  0                         q->val = 0
7:  PLUS   u2        <- t5,    4
8:  STORE  MEM[u2]   <-  0                         q->next = 0
9:  MOVE   t3        <- t5                         q
10: CALL   t6        <- malloc(8)                  p <- alloc
11: PLUS   u3        <- t6,    0
12: STORE  MEM[u3]   <-  0                         p->val = 0
13: PLUS   u4        <- t6,    4
14: STORE  MEM[u4]   <- t3                         p->next = q
15: MOVE   t2        <- t6                         p
16: PLUS   u5        <- t3,    0
17: STORE  MEM[u5]   <-  5                         q->val = 5
18: PLUS   u6        <- t2,    0                   p
19: LOAD   t4        <- MEM[u6]                    a
20: RET              t4
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14: STORE  MEM[u4]   <- t3                         p->next = q
15: MOVE   t2        <- t6           (t2,10,0)     p
16: PLUS   u5        <- t3,     0    (u5,4,0)
17: STORE  MEM[u5]   <-  5                         q->val = 5
18: PLUS   u6        <  t2,     0    (u6,10,0)     p
19: MOVE   t4        <  0                          a
20: RET              0
```

```
struct intlist* foo() {
      struct intlist* p;
      struct intlist* q;
      int a = 1;

      p = alloc(struct intlist);
      p->val = 0;
      p->next = 0;

      q = alloc(struct intlist);
      q->val = 6;
      q->next = p;

      if (a == 0) p = q;
      p->val = 4;
      return p;
}
```

```
1:  CALL   t2      <- malloc(8)              p
2:  PLUS   u1      <- t2,0
3:  STR    MEM[u1] <-  0                     p->val = 0
4:  PLUS   u2      <- t2, 4
5:  STR    MEM[u2] <- 0                      p->next = 0
6:  MOVE   t3      <- t2                     x=p
7:  CALL   t4      <- malloc(8)              q
8:  PLUS   u3      <- t4,0
9:  STR    MEM[u3] <- 6                      q->val = 6
10: PLUS   u4      <- t4,0
11: STR    MEM[u4] <- t3                     q->next = p
12: MOVE   t5      <- t4                     q
13: MOVE   t6      <- 1                      a
14: CJUMP  t6 == 0, ifT0,ifF1                a == 0 ?
ifT0:
16: MOVE   t3'     <- t5                     x=q
ifF1:
18: PHI    t3''    <- ϕ(t3,t3')
19: PLUS   u5      <- t3'', 0
20: STR    MEM[u5] <- 4
21: RET    t2
```

```
1:  CALL   t2      <- malloc(8) (t2,1,0)     p
2:  PLUS   u1      <- t2,0
3:  STR    MEM[u1] <-  0                     p->val = 0
4:  PLUS   u2      <- t2, 4
5:  STR    MEM[u2] <- 0                      p->next = 0
6:  MOVE   t3      <- t2                     x=p
7:  CALL   t4      <- malloc(8)              q
8:  PLUS   u3      <- t4,0
9:  STR    MEM[u3] <- 6                      q->val = 6
10: PLUS   u4      <- t4,0
11: STR    MEM[u4] <- t3                     q->next = p
12: MOVE   t5      <- t4                     q
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1:  CALL   t2      <- malloc(8) (t2,1,0)     p
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6:  MOVE   t3      <- t2        (t3,1,0)     x=p
7:  CALL   t4      <- malloc(8) (t4,7,0)     q
8:  PLUS   u3      <- t4,0      (u3,7,0)
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13: MOVE   t6      <- 1                      a
14: CJUMP  t6 == 0, ifT0,ifF1                a == 0 ?
ifT0:
16: MOVE   t3'     <- t5                     x=q
ifF1:
18: PHI    t3''    <- ϕ(t3,t3')
19: PLUS   u5      <- t3'', 0
20: STR    MEM[u5] <- 4
21: RET    t2
```

```
1:  CALL   t2      <- malloc(8) (t2,1,0)     p
2:  PLUS   u1      <- t2,0      (u1,1,0)
3:  STR    MEM[u1] <-  0                     p->val = 0
4:  PLUS   u2      <- t2, 4     (u2,1,4)
5:  STR    MEM[u2] <- 0                      p->next = 0
6:  MOVE   t3      <- t2        (t3,1,0)     x=p
7:  CALL   t4      <- malloc(8) (t4,7,0)     q
8:  PLUS   u3      <- t4,0      (u3,7,0)
9:  STR    MEM[u3] <- 6                      q->val = 6
10: PLUS   u4      <- t4,0      (u4,7,0)
11: STR    MEM[u4] <- t3                     q->next = p
12: MOVE   t5      <- t4        (t5,7,0)     q
13: MOVE   t6      <- 1                      a
14: CJUMP  t6 == 0, ifT0,ifF1                a == 0 ?
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16: MOVE   t3'     <- t5        (t3',7,0)    x=q
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9:  STR    MEM[u3] <- 6                      q->val = 6
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```

Dependence Information

```
foo(int[] a, int[] b, int n) {
    int i;
    for (i=1; i<n; i++) {
        a[i] = b[i-1]+a[i]
    }
}
```

- What are the dependence distances?