Programming Languages (7) Garbage Collection (GC) : A Brief Introduction

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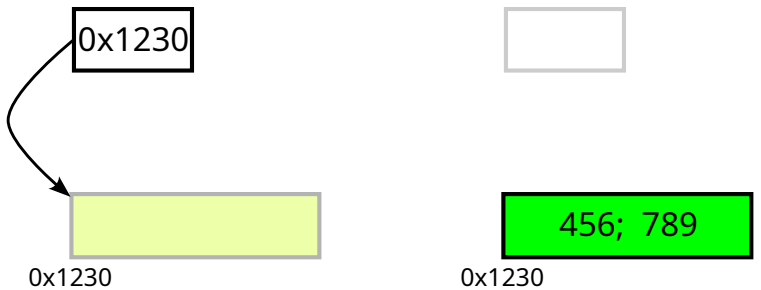
Garbage Collection (GC)

- the fundamental issue is the mismatch between
  - the period in which objects are accessed
  - the period in which the memory block for it is retained



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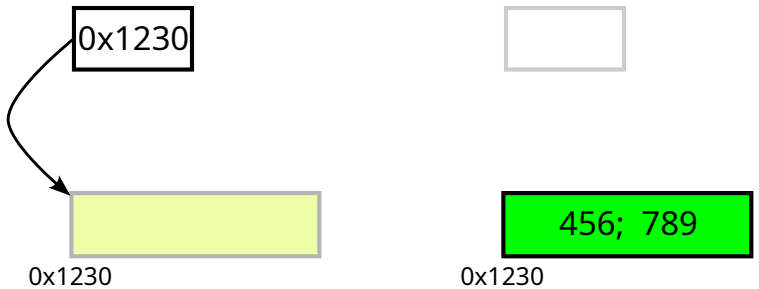

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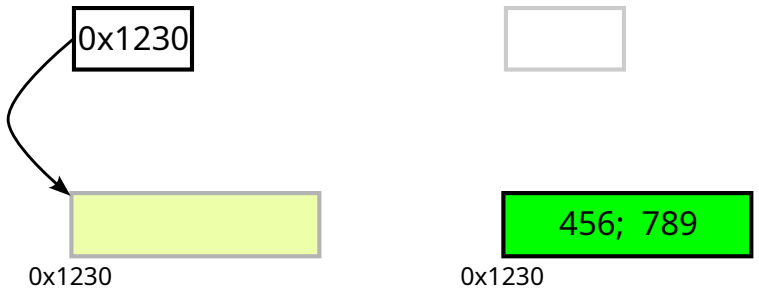

- $\Rightarrow$ Garbage collection (GC)
  - ratain memory block for objects if they could ever be accessed in future and reclaim otherwise
  - the system automatically does that
  - $\Rightarrow$ eliminate memory leak and corruption
- the question: how does the system know *which objects may be accessed in future*?

Objects that may {ever/never} be accessed

- the precise judgment is undecidable
- (at the start of line 2) "the object pointed to by `p` will ever be accessed" $\Longleftrightarrow$ "`f(x)` will terminate and return 0" $\rightarrow$ you need to be able to solve the halting problem...

```
1  int main() {
2    if (f(x) == 0) {
3      printf("%d\n", p->f->x);
4    }
5  }
```

- $\rightarrow$ *conservatively* estimate objects that *may be* accessed in future
  - NEVER reclaim those that are accessed
  - OK not to reclaim those that are in fact never accessed
- in the above example, OK to retain objects pointed to by `p` when the line 2 is about to start

Objects that "may be" accessed

- global variables
- local variables of active function calls (calls that have started but have not finished)

```
1  int * s, * t;
2  void h() { ... }
3  void g() {
4    ...
5    h();
6    ... = p->x ...  }
7  void f() {
8    ...
9    g()
10   ... = q->y ... }
11 int main() {
12   ...
13   f()
14   ... = r->z ... }
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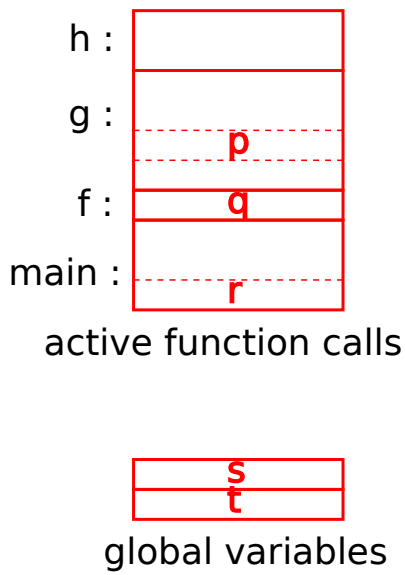

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- global variables
- local variables of active function calls (calls that have started but have not finished)
- objects reachable from them by traversing pointers

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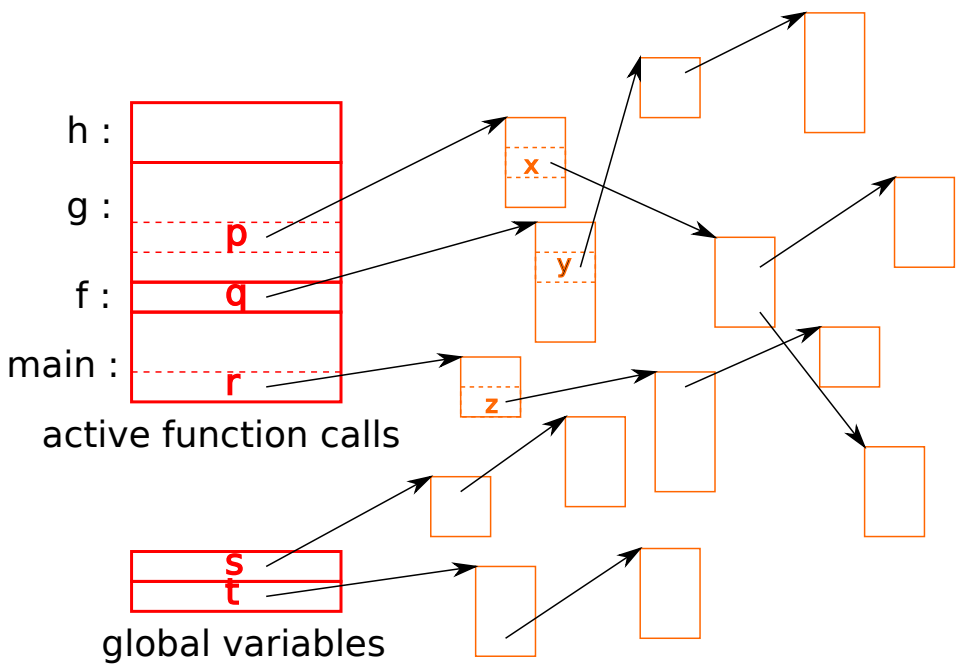

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The basic workings (and terminologies) of GC

- an object: the unit of automatic memory allocation/release (malloc in C; objects in Java; etc.)

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the basic principle of GC:
objects unreachable from the root are dead

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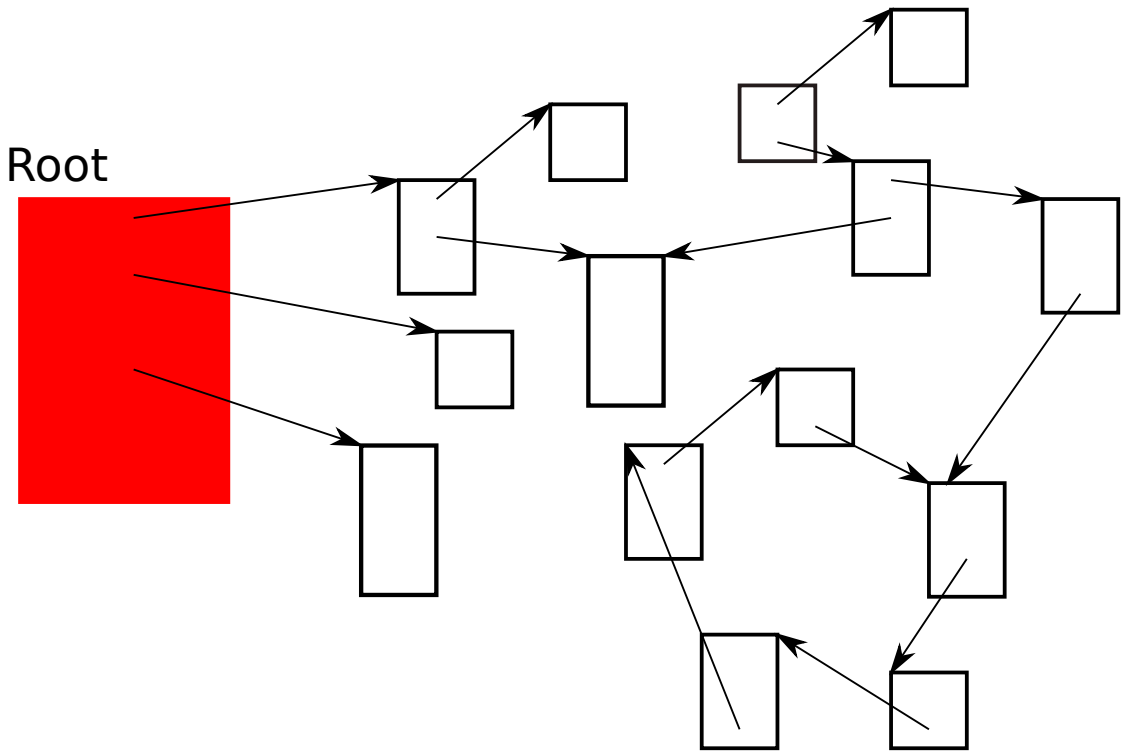
The two major GC methods

- traversing GC:
  - simply traverse pointers from the root, to find (or *visit*) objects reachable from the root
  - reclaim objects not visited
  - two basic traversing methods
    - ⋆ mark&sweep GC
    - ⋆ copying GC
- reference counting GC (or RC):
  - during execution, maintain the number of pointers (reference count) pointing to each object
  - reclaim an object when its reference count drops to zero
  - note: an object's reference count is zero → it's unreachable from the root
- remark: "GC" sometimes narrowly refers to traversing GC

How traversing GC works

- traverse pointers from the root
- once all pointers have been traversed, objects that have not been visited are garbage
- the difference between mark&sweep and copying is covered later



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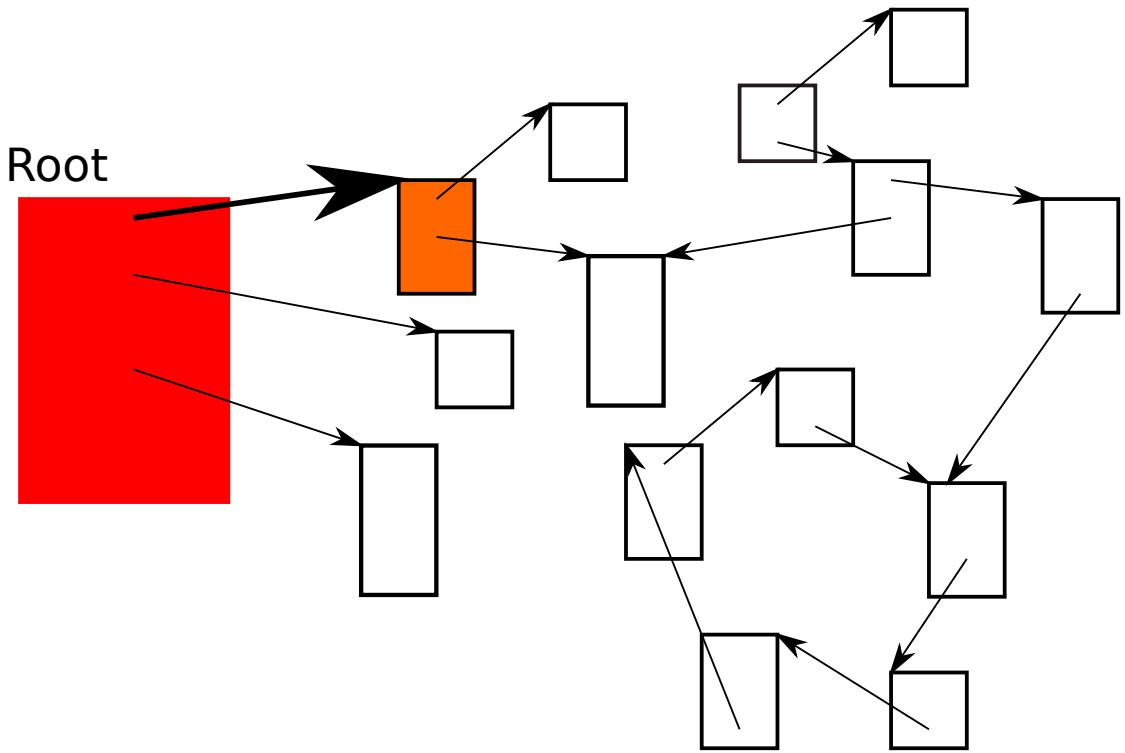

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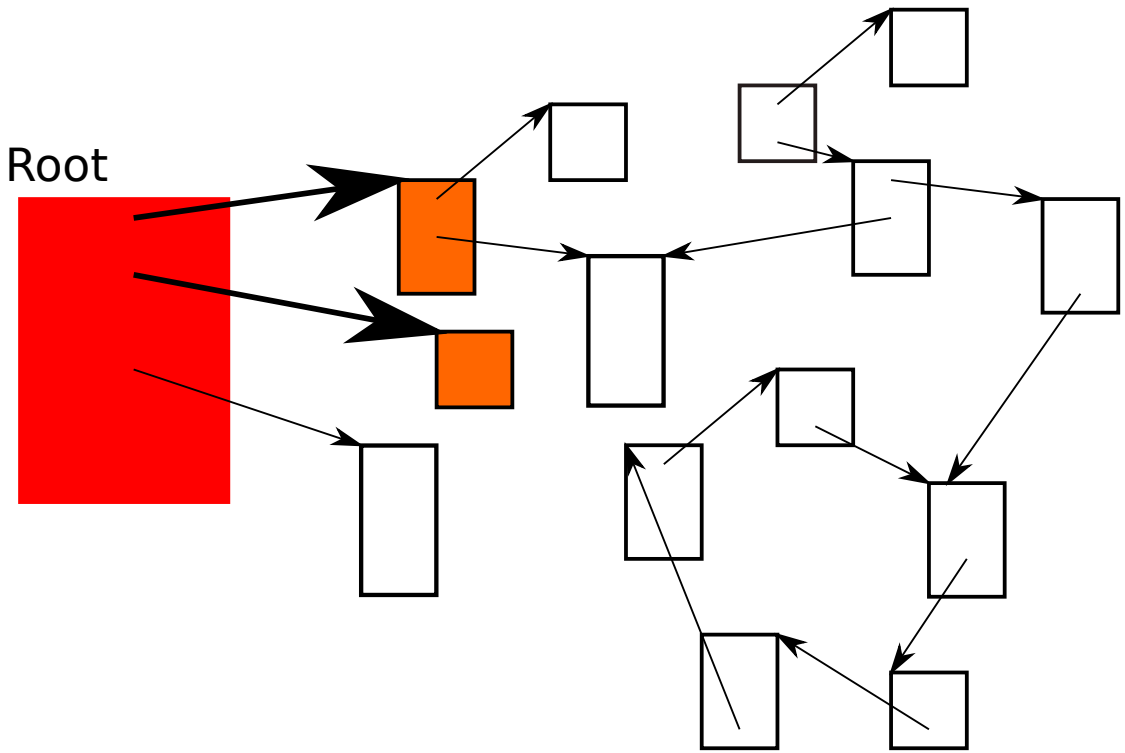

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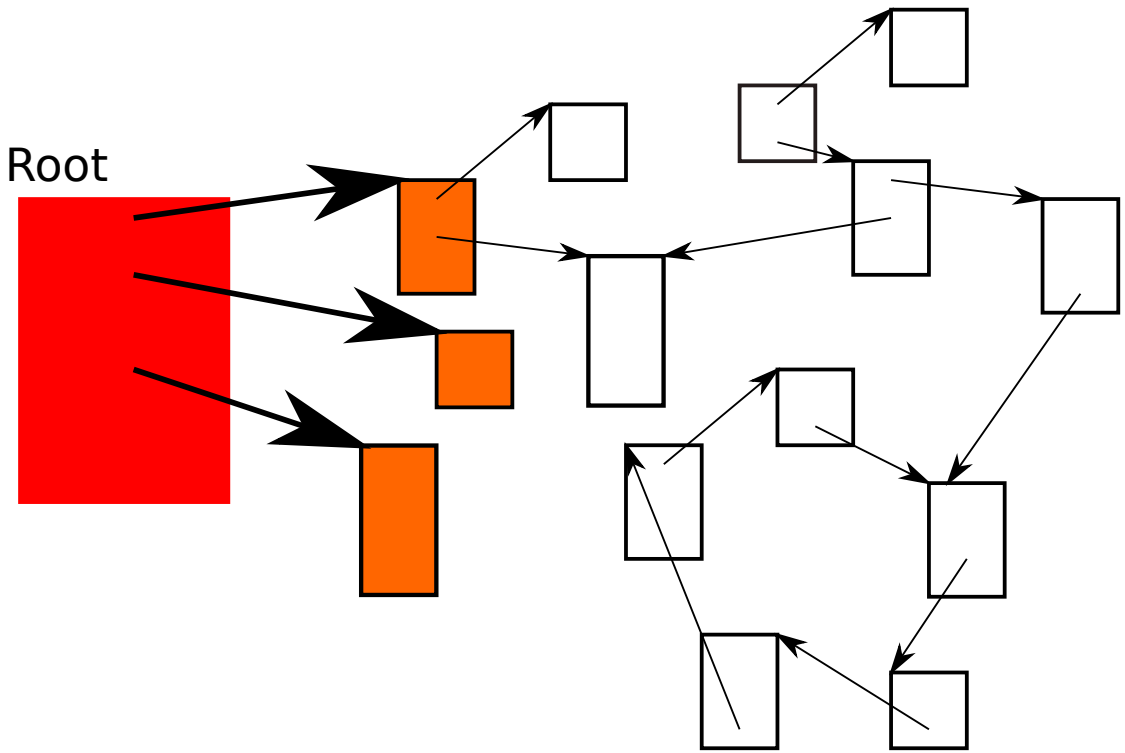

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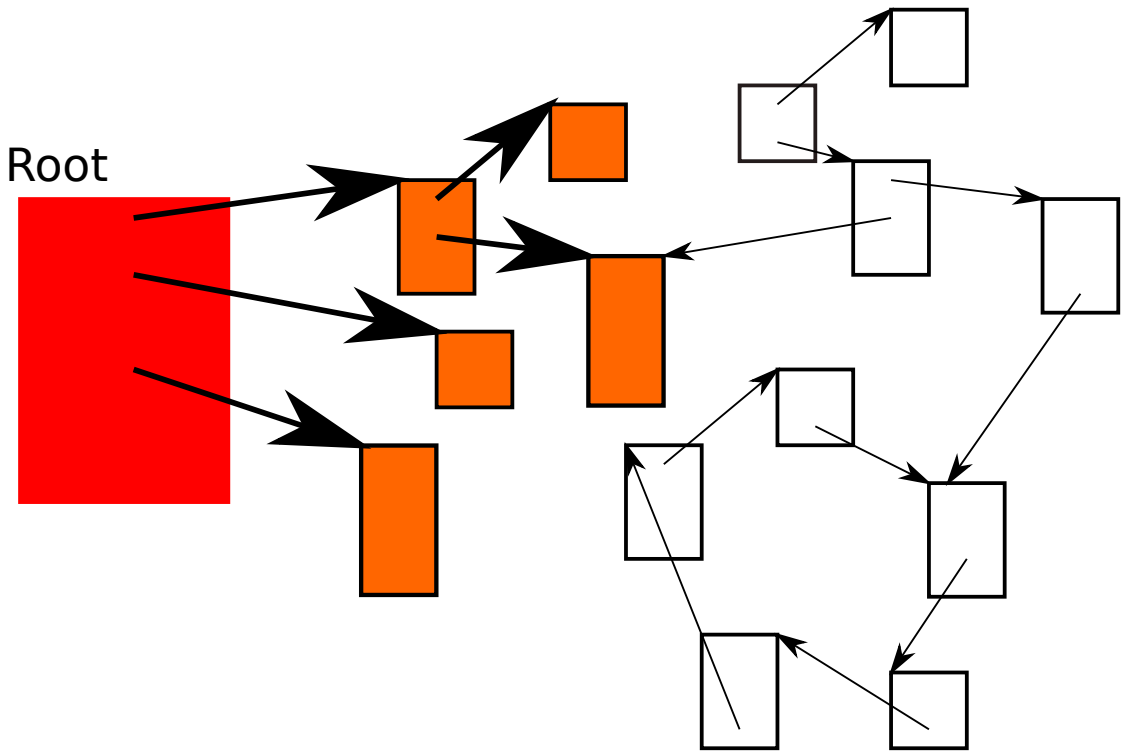

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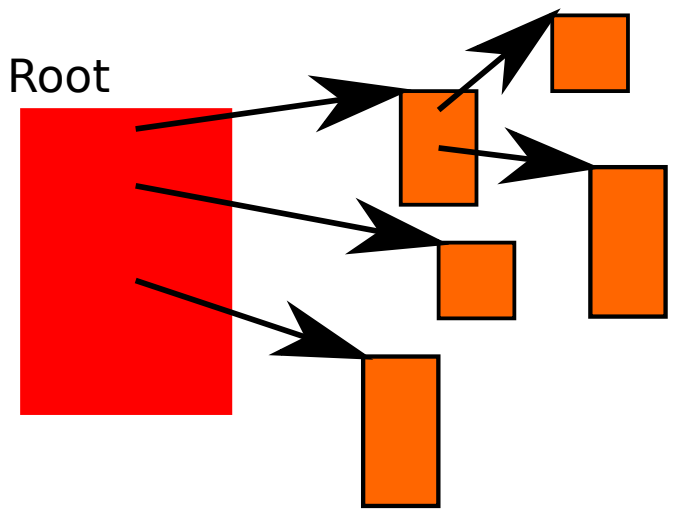
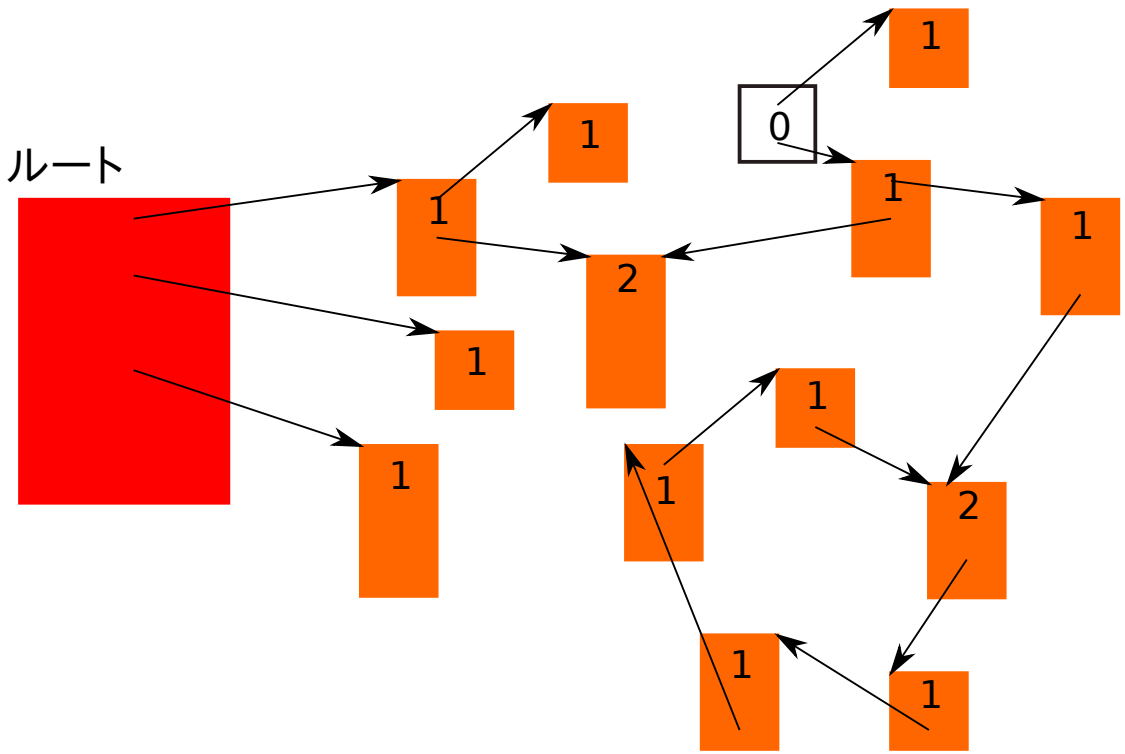


How reference counting works

- each object has a reference count (RC)
- update RCs during execution; e.g., upon `p = q;` →
  - the RC of the object `p` points to `-= 1`
  - the RC of the object `q` points to `+= 1`
- reclaim an object when its RC drops to zero → RCs of objects pointed to by the now reclaimed object decrease



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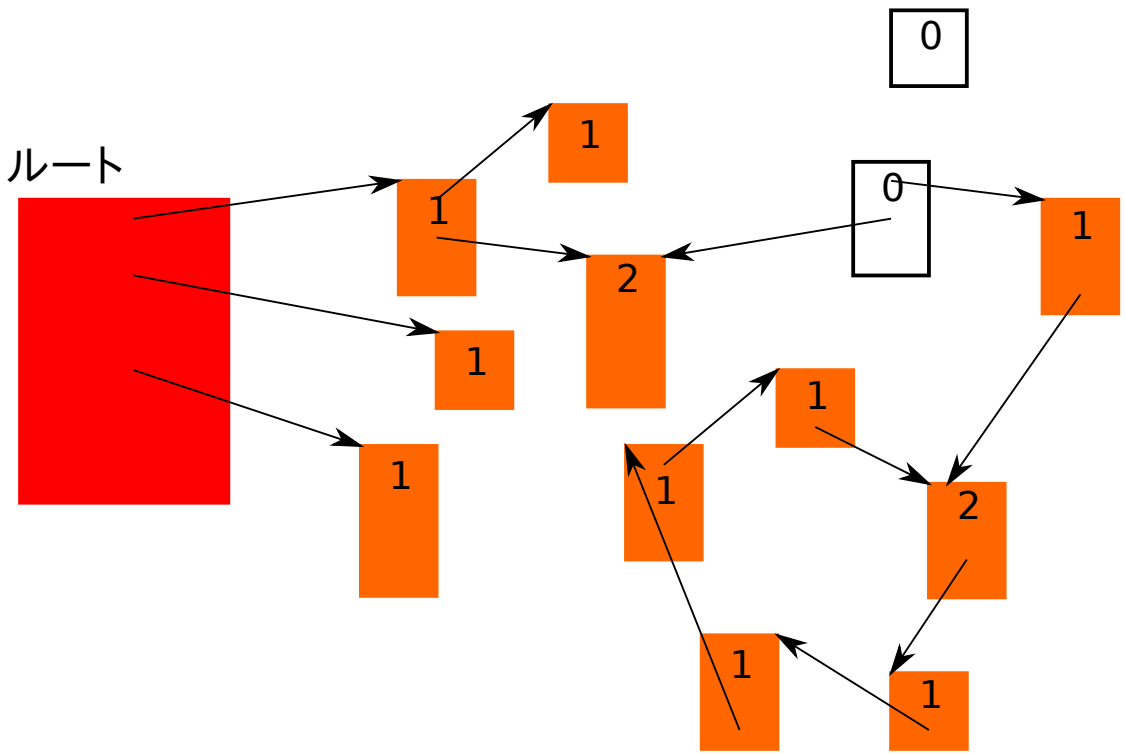

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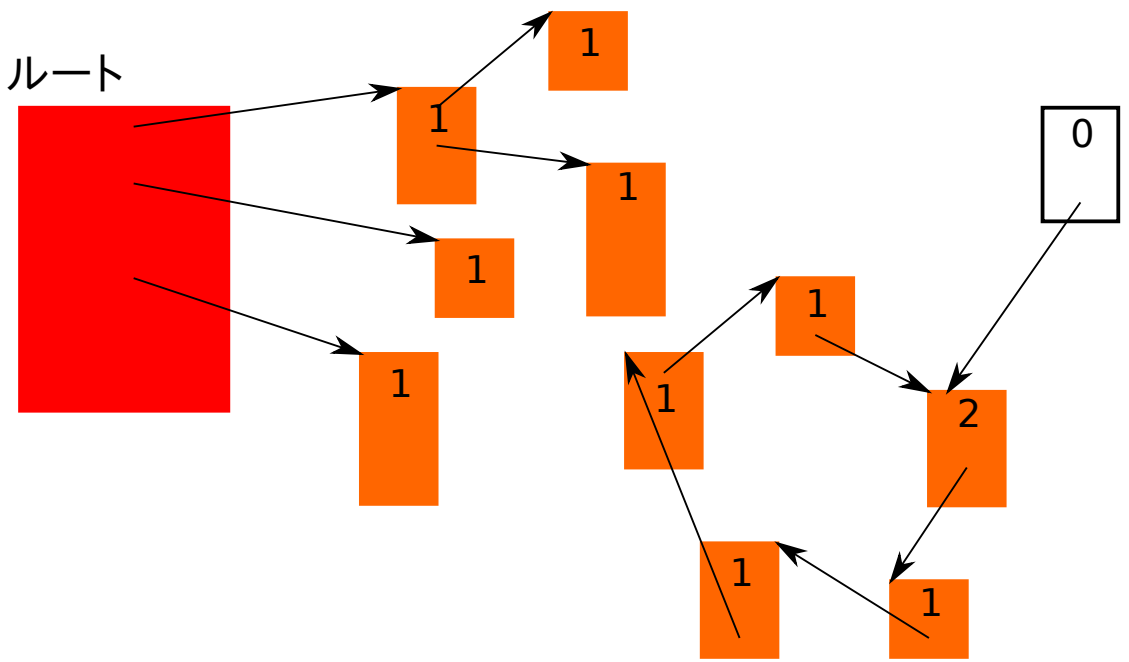

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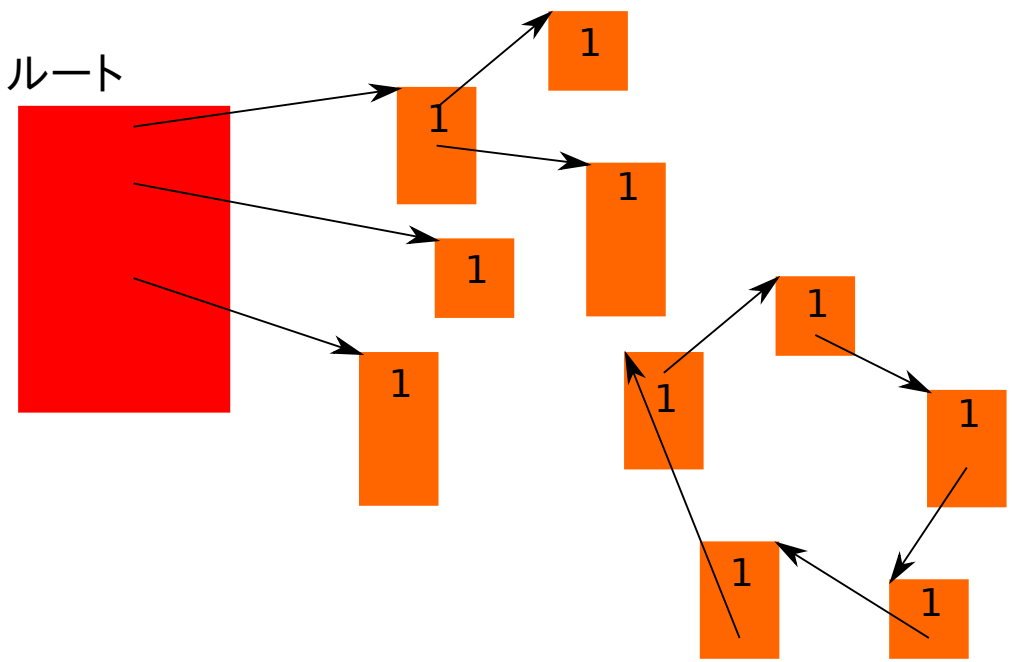

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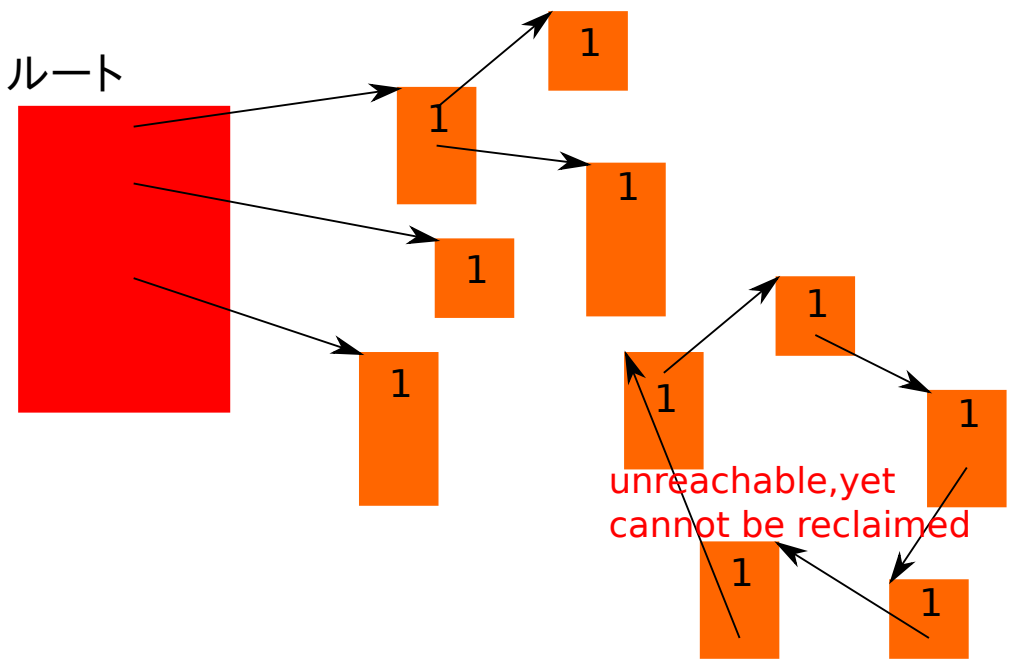

When an RC changes

- a pointer is updated `p = q;` `p->f = q;` etc.
- a function gets called

```
1  int main() {
2    object * q = ...;
3    f(q);
4  }
```

- a variable goes out of scope or a function returns

```
1  f(object * p) {
2    ...
3    {
4      object * r = ...;
5
6    } /* RC of r should decrease */
7    ...
8    return ...; /* RC of p should decrease */
9  }
```

- etc. any point pointer variables get copied / become no longer used

more advanced topics will be convered in later weeks