COS320: Compiling Techniques

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Compiling object-oriented languages

Objects

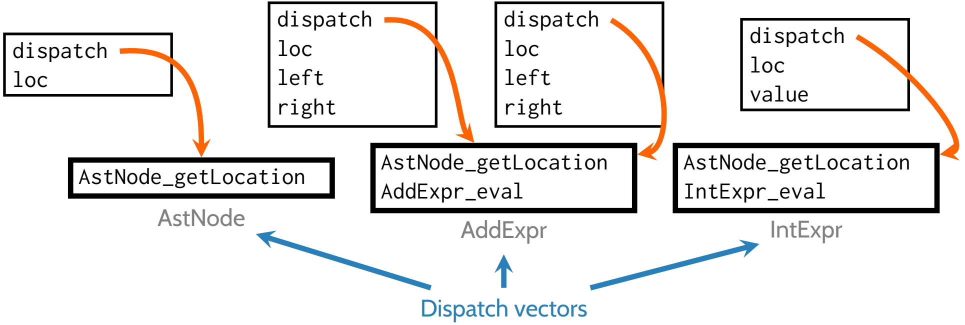
An *object* consists of Data (attributes) and Behavior (methods).

```
public class AstNode {
  location loc;
  public AstNode(location nodeloc)
  {  loc = nodeloc; }
  public location getLocation()
  { return loc; }
}
abstract class Expr extends AstNode {
  public abstract int eval(Env);
  public Expr(location loc) { super(loc); }
}
public class AddExpr extends Expr {
  Expr left, right;
  public AddExpr(int loc, Expr x, Expr y)
  {  super(loc); left = x; right = y; }
  public int eval(Env env)
  {  return left.eval(env) + right.eval(env); }
}
```

```
public class IntExpr extends Expr {
  int value;
  public IntExpr(int loc, int k)
  { super(loc);  value = k; }
  public int eval(int env)
  { return value; }
}
```

Compiling objects

- Compiling OO languages with single inheritance:
  - Each class is associated with a *dispatch vector* (aka virtual table, vtable)
    - dispatch vector = record of function pointers – one for each method
  - Each object is associated with a record, with one field for the dispatch vector of its class, and one field for each attribute



Compiling methods

Each method is extended with an additional parameter for the current object

- Gives the method access to the attributes of the object
- Dispatch vector enables dynamic dispatch

```
location AstNode__getLocation(self) {
    return self.loc;
}
int AddNode__eval(self, env) {
    return self.left.dispatch.eval(self.left, env)
             + self.right.dispatch.eval(self.right, env);
}
int IntNode__eval(self, env) {
     return self.value;
}
```

```
class AstNode { ...
  public location getLocation() { return loc; } }
```

```
public class AddExpr extends Expr { ...
  public int eval(Env env) { return left.eval(env) + right.eval(env); } }
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```
class IntExpr extends Expr { ...
  public int eval(int env) { return value; } }
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Subtyping

- Recall the *Liskov substitution priciple*: if s is a subtype of t, then terms of type s can be used as if they have type t without breaking type safety.
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- This works for the same reason that record width subtyping works:
  - If A has a method *foo*, it appears in the same position in A and B's dispatch vector
  - If A has an attribute *x*, then A objects and B objects place x in the same position in object records

RecordWidth

$$\frac{}{\vdash \{\mathit{lab}_1 : s_1; \ldots; \mathit{lab}_m : s_m\} <: \{\mathit{lab}_1 : s_1; \ldots; \mathit{lab}_n : s_n\}}\ n < m$$

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  - To check `o instanceOf C`, walk up the class hierarchy
    - `o.dispatch = DispatchVector(C)`, or
    - `o.dispatch != DispatchVector(Object)` and `o.dispatch.parent = DispatchVector(C)`, or
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    - ...

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    - `o.dispatch != DispatchVector(Object)` and `o.dispatch.parent != DispatchVector(Object)` and `o.dispatch.parent.parent = DispatchVector(C)`, or
    - ...
  - Checked downcasting: if `o instanceOf c` then bitcast, otherwise throw run-time exception.

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- Previous strategy does not work: base classes have conflicting ideas about where methods are stored in vtable
- Solution: Use hash tables instead of records
- Cost can be reduced with optimizing compiler
  - Perform a conservative analysis to determine the class of (some) objects. If known statically, can replace dynamic dispatch with static dispatch
  - JIT compilation
    - At compile time, we have more precise information about object classes
    - Replace dynamic dispatch with static dispatch, optimize & compile the result.

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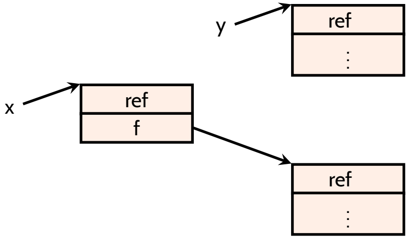
  - *But*, we are happy with a conservative approximation: free memory if it *cannot possibly be used* in the remainder of the program
- Usually not a *static analysis*, but rather a *dynamic analysis*
  - *static analyses* collect information about a program without running it
  - *dynamic analyses* collect information about a program while running it

Reference counting

- Each memory location gets an extra int field to hold the number of active references to that memory
- Collect when count is zero
- Example: compiling a store `x->f = y`



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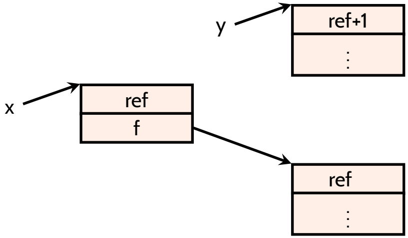

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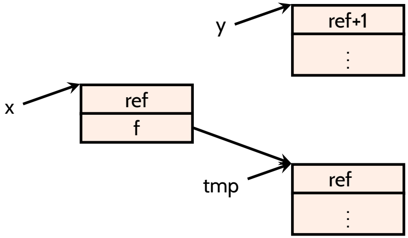

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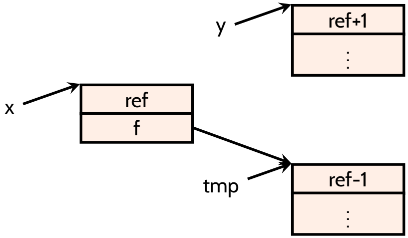

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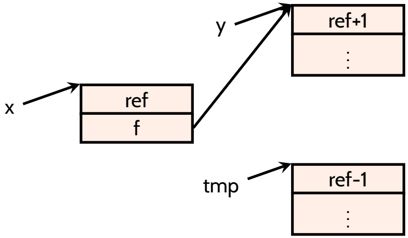

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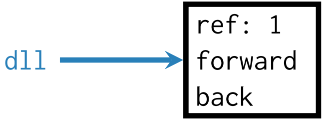

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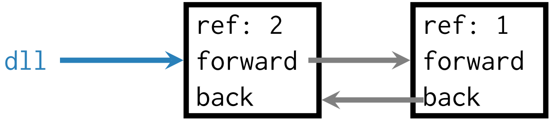

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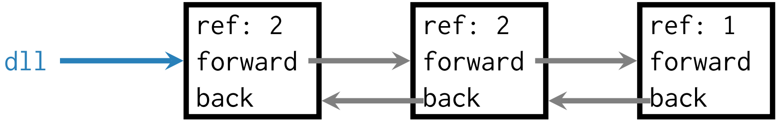

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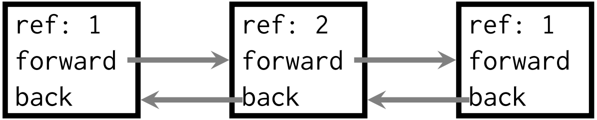

Tracing-based GC

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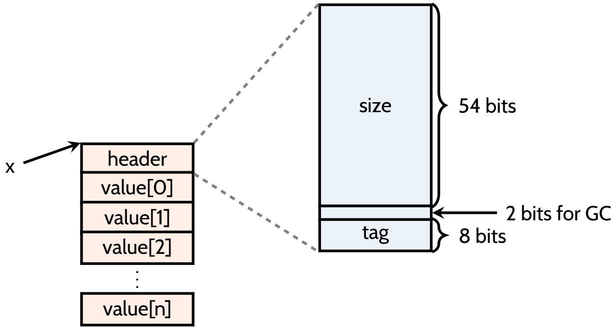
  - *roots* = registers, stack, global static data
- Mark-and-sweep:
  - Each memory location gets an extra bit to hold a "mark"
  - *Mark*: When there is no remaining free memory, run a DFS search from the roots, marking all memory locations
  - *Sweep*: Traverse the entire heap; unmarked nodes are collected; marked nodes are unmarked

Memory layout

- *Boxing*: **every** value is a pointer to a block of memory that begins with metadata. In OCaml:



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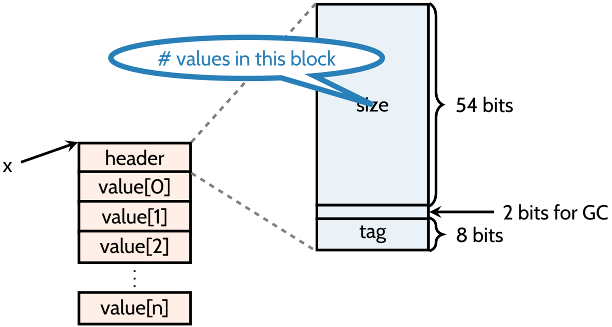

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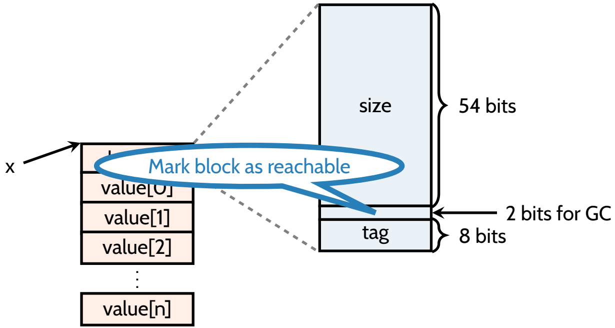

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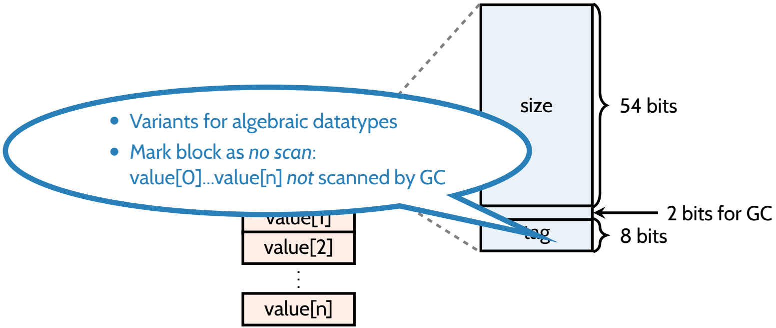
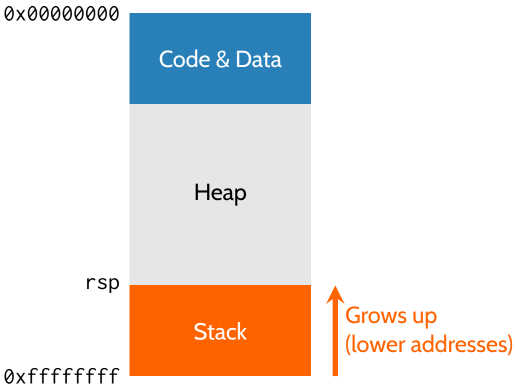


Finding roots

Stack is a sequence of 64-bit values

- Values (pointers in the heap); i.e., roots
- Saved frame pointers (pointers in the stack)
- Saved return addresses (pointers in code)



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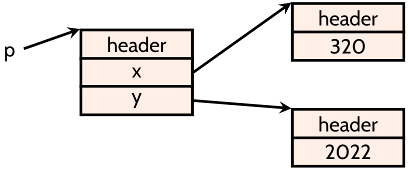


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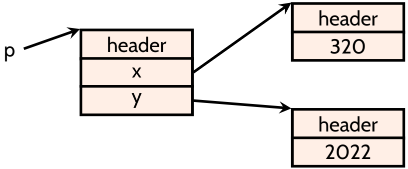


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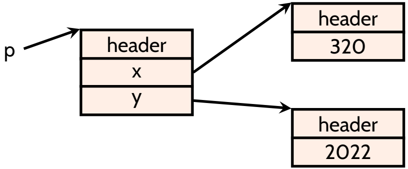

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- Pointers are *quadword aligned* ⇒ last four (low-order) bits are 0
- If values for a type fit into 63 bits, can used *unboxed* value, marked with a last (low-order) bit so GC does not scan
    - Integers are 63 bit: `x` is represented as `x«1 | 1`

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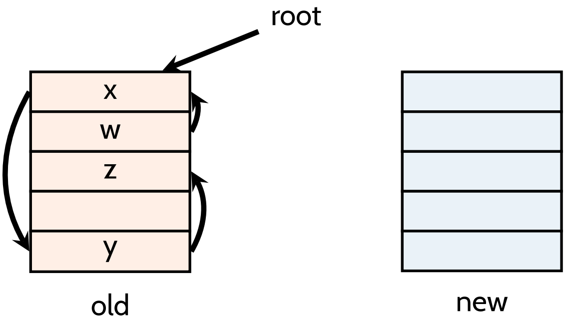
  - Maintain two heaps (roughly equal size), *old* and *new*
  - GC sequentially copies reachable blocks from old heap to new heap



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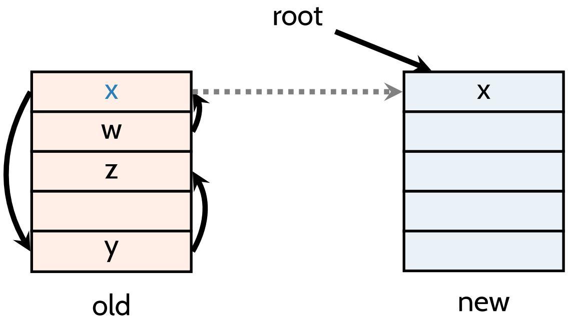

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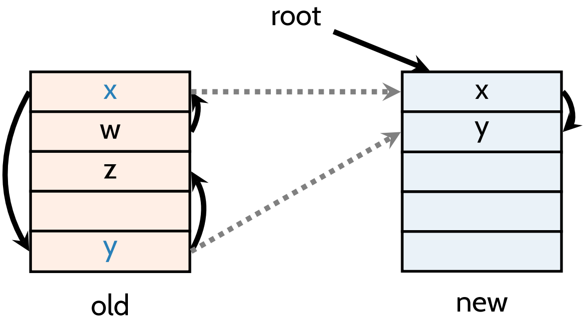

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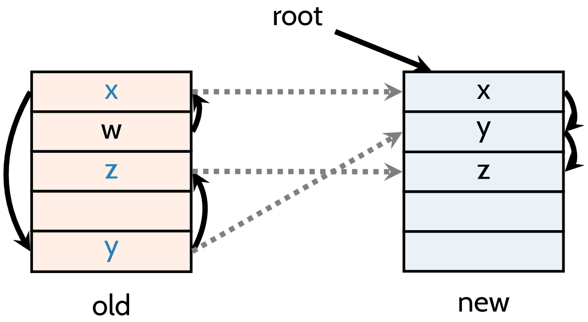

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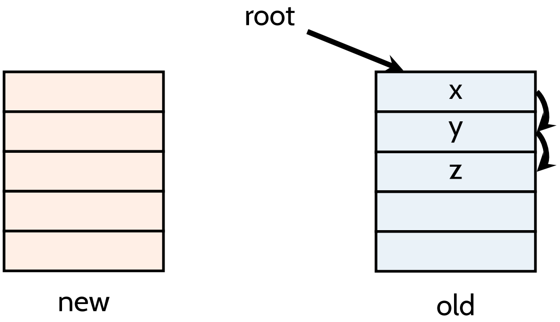

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- Complication: inter-generational pointers (from older to newer generation) are new roots that must be managed

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- Generational GC
  - Shortens average GC pauses; can combine mark-and-sweep & copying GC
  - Relatively complicated, performance penalty for managing intergenerational pointers