CS 536 Announcements for Monday, April 1, 2024

Last Time

- type checking
- type-system concepts
- type-system vocabulary
- base
    - type rules
    - how to apply type rules

Today

- runtime environments
- runtime storage layout
- activation records
- static allocation
- stack allocation
- what happens on function call, entry, return

Next Time

- parameter passing

Type checking in base

base's type system

- primitive types: `integer` `logical` `void`
- type constructors: `tuple`
- coercion: a `logical` cannot be used as an `integer` is expected and vice versa

Type errors in base

- operators applied to operands of wrong type
- expressions that, because of context, must be a particular type but are not
- related to function calls

Type checking

- Recursively walks the AST to
    - determine the type of each expression and sub-expression using the type rules of the language
    - find type errors
- Add a `typeCheck` method to AST nodes

Type checking (cont.)

Type checking: errors

Goals:

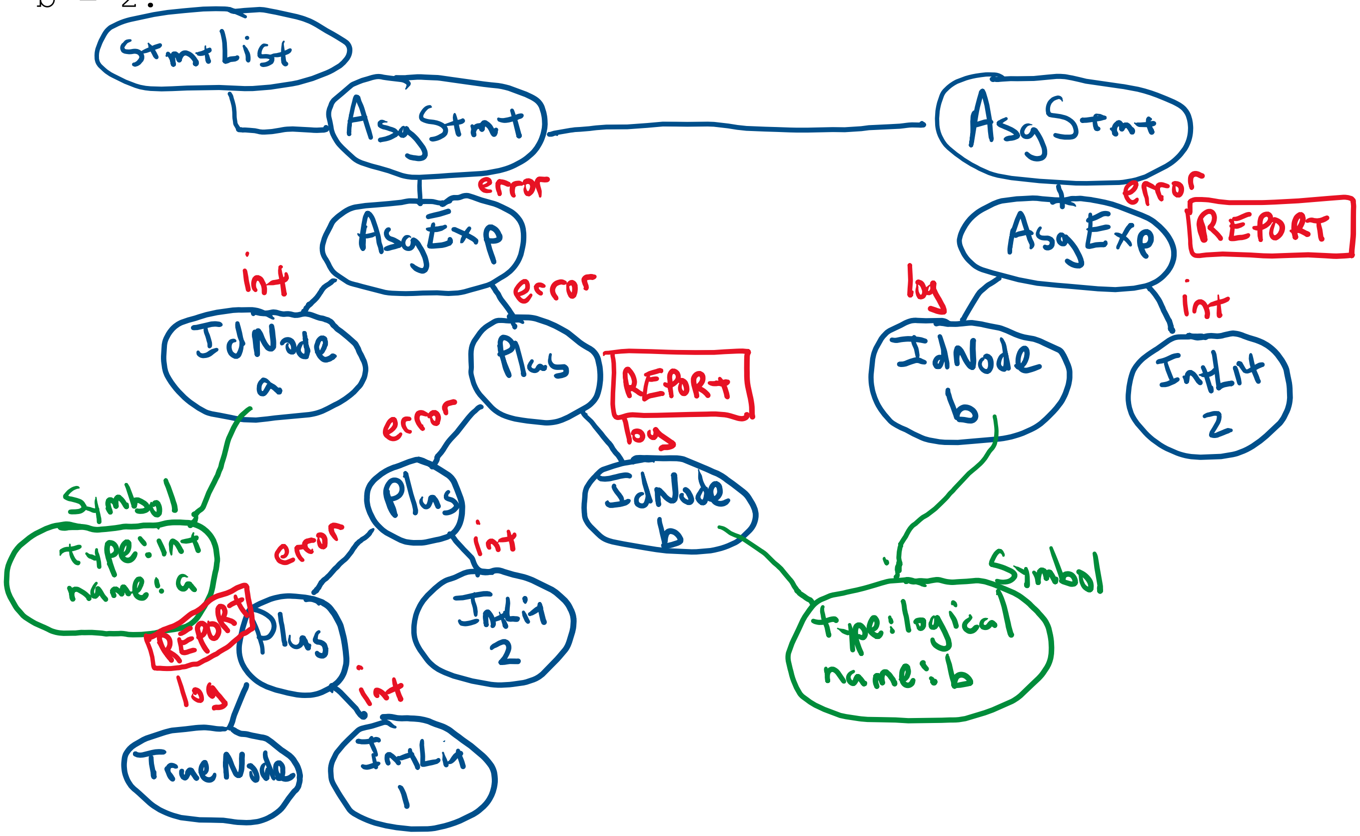
- report as many *distinct* errors as possible – don't give up after 1st error
- don't report *same* error multiple times – avoid error cascading – internally need to know if an error has already been reported

Introduce internal `error` type

- when type incompatibility is discovered
  - report the error
  - pass `error` up the tree
- when a type check gets `error` as an operand
  - don't (re)report an error
  - pass `error` up the tree

Example:

```
integer a.
logical b.
a = (((True + 1) + 2) + b).
b = 2.
```



Back to the big picture

Before code generation, we need to consider the ***runtime environment***:
= underlying software & hardware configuration assumed by the program

Program piggybacks on the operating system (OS)

- provides functions access to hardware
- provides illusion of uniqueness
- enforces some boundaries on what is allowed

Compiler must use runtime environment as best it can

- limited # of very fast registers to do computation
- comparatively large region of memory to hold data
- some basic instructions from which to build more complex behaviors

We need to create/impose conventions on the way our program accesses memory

- assembly code enforces very few rules
- conventions help to guarantee separately developed code works together

- allows modularity
- increases programmer efficiency

Issues to consider

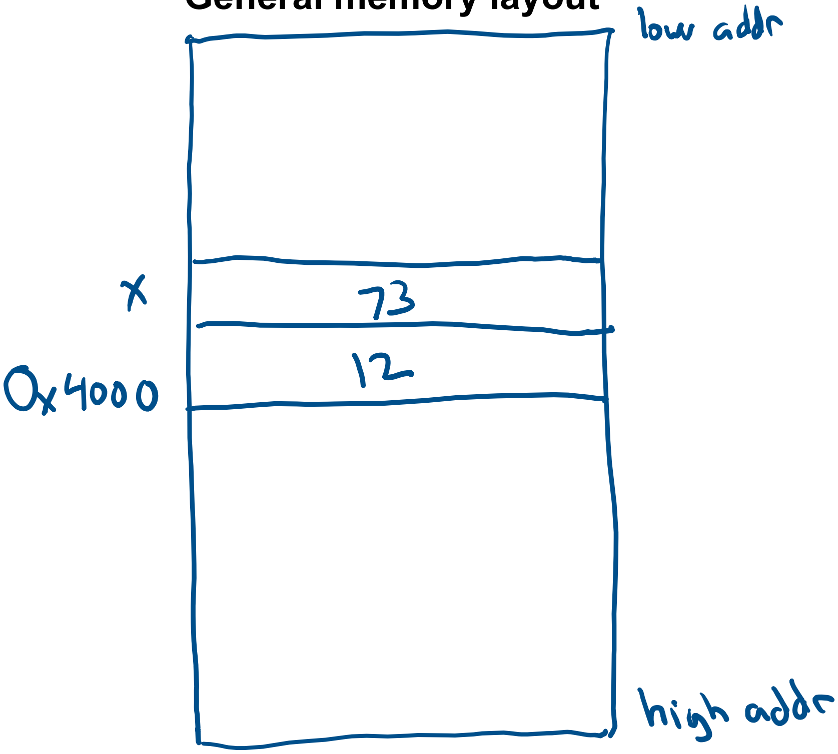
Variables

- How are they stored?
- What happens when a variable's value is needed?

How do functions work?

- What information should be stored for each function?
- What should happen when client code calls a function?
- What should happen when a function is entered?
- What should happened when a function returns?

General memory layout



Memory layout: static allocation

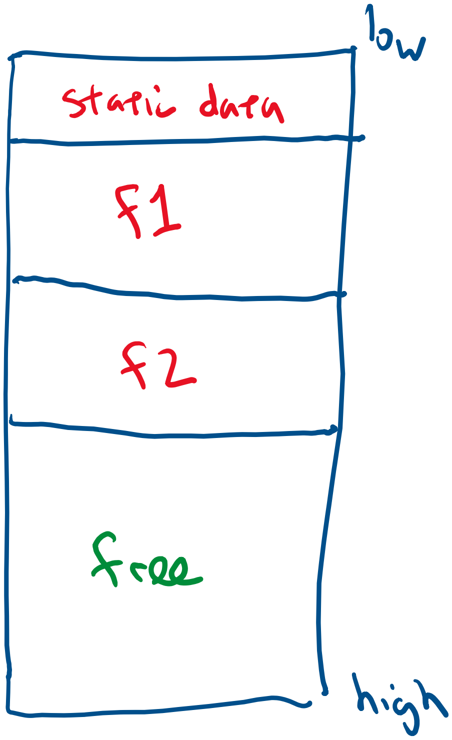
Region for global memory

One "frame" for each procedure

- memory "slot" for each local, parameter
- memory "slot" for caller

Every time a function is called,
its names (local varibles & parameters)
refer to the *same* location in memory

+ fast access to all names
+ no overhead for stack manipulations
- no recursion
- no dynamic memory allocation
  (eg, linked lists)

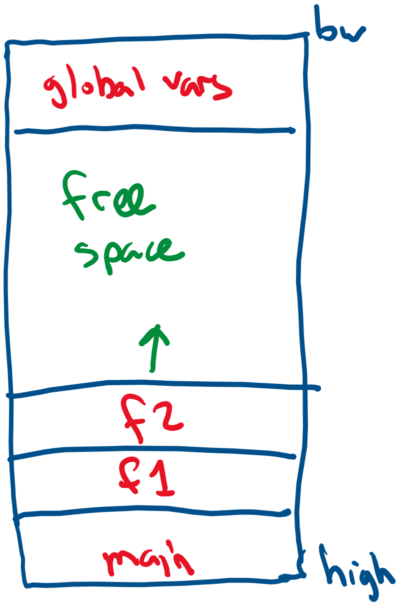


frame

Memory layout: stack allocation

Allocate one ***activation record*** (AR) per invocation

- use the stack
- push a new AR on function entry
- pop AR on function exit
- to reduce the size, put static data in the global area



Stack size not known at compile time

- don't know (at compile-time) how many ARs there will be
- size of local variables may not be known
- each AR keeps track of the previous AR's boundaries

Activation record keeps track of

- local variables
- info about the call made by the caller
    - data context
      enough info to determine boundaries of AR in use when curr fctn was called
    - control context
      enough info to know code that invoked curr fctn

Non-local dynamic memory

Don't always want all data allocated in a function call to disappear on return

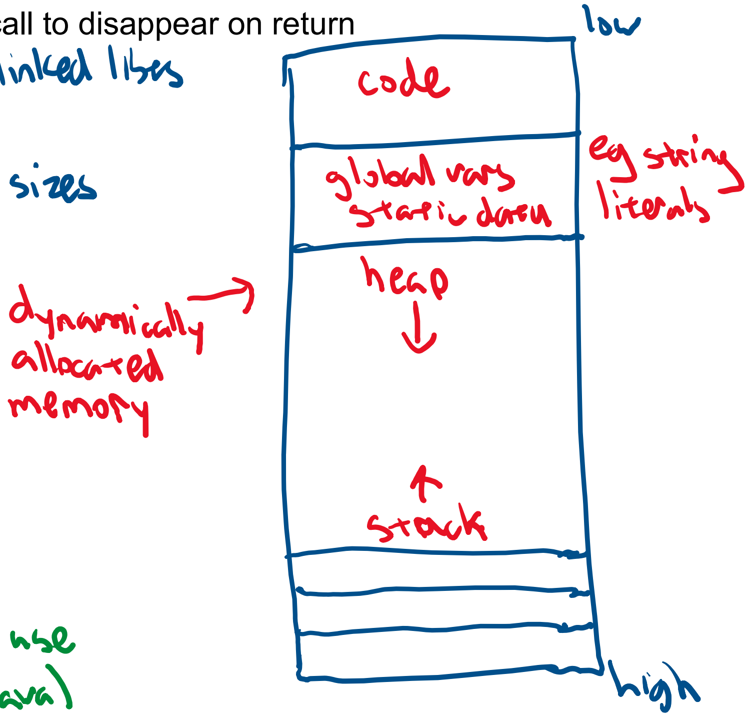
want to be able to create, eg, linked lists

Don't know how much space we'll need

allocate many such obj's of various sizes

The Heap

- region of memory independent of the stack
- allocated according to calls in the program
- how is memory "given back"?
  - programmer specifies when no longer in use (C)
  - runtime environment determines automatically when no longer in use (Java)



Function calls

Instruction pointer (**$ip**) tracks the line (address) of code that it is executing

- if **$ip** points to code generated for some function, we'll say we are ***in*** that function

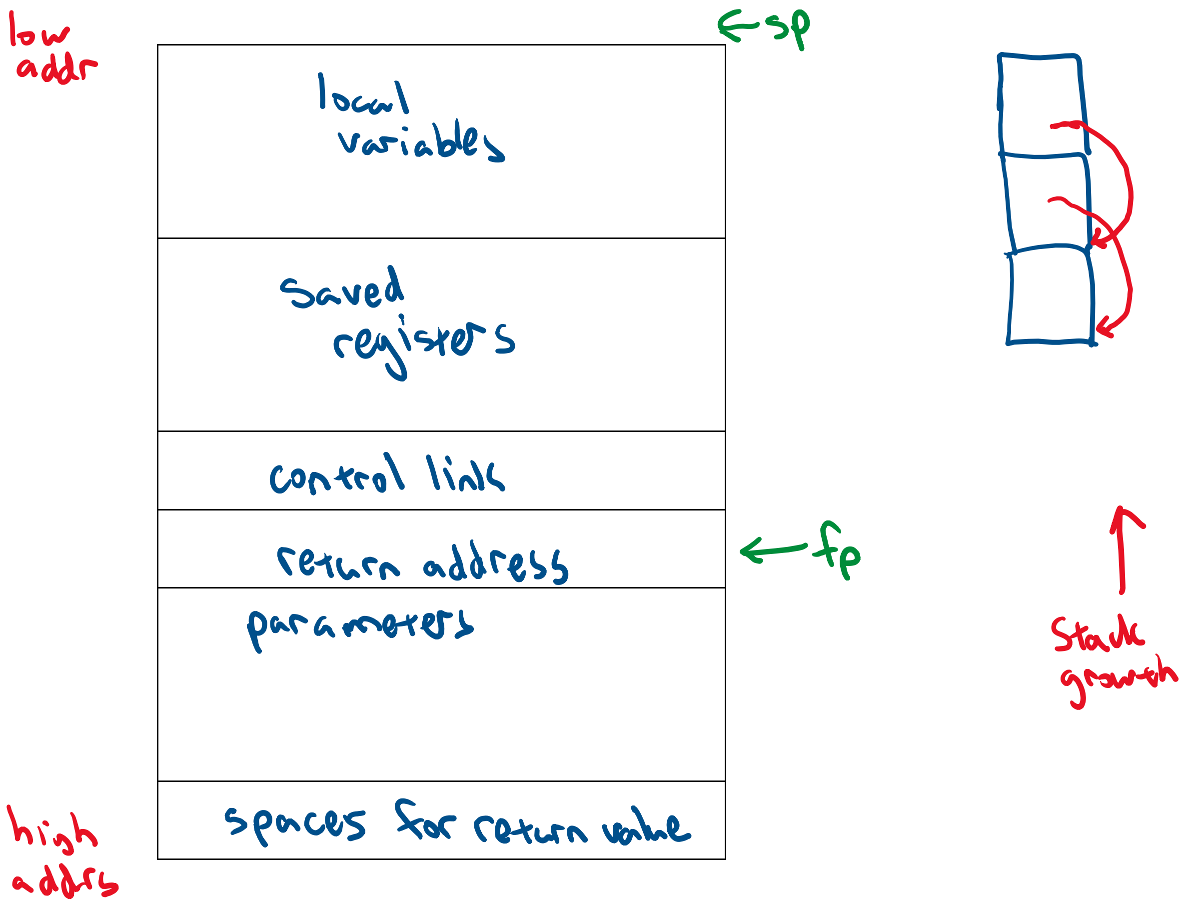
caller = function doing the invocation

callee = function being invoked

$sp (**stack pointer**) – points to top of stack (1st unused location)

$fp (**frame pointer**) – points to bottom of current AR

Activation records revisited



Function entry: caller responsibilities

Store the *caller-saved* registers in it's own AR

Set up the actual parameters
- set aside slot for the return value
- push parameters onto the stack

Copy return address out of **$ip**

Jump to first instruction of the callee

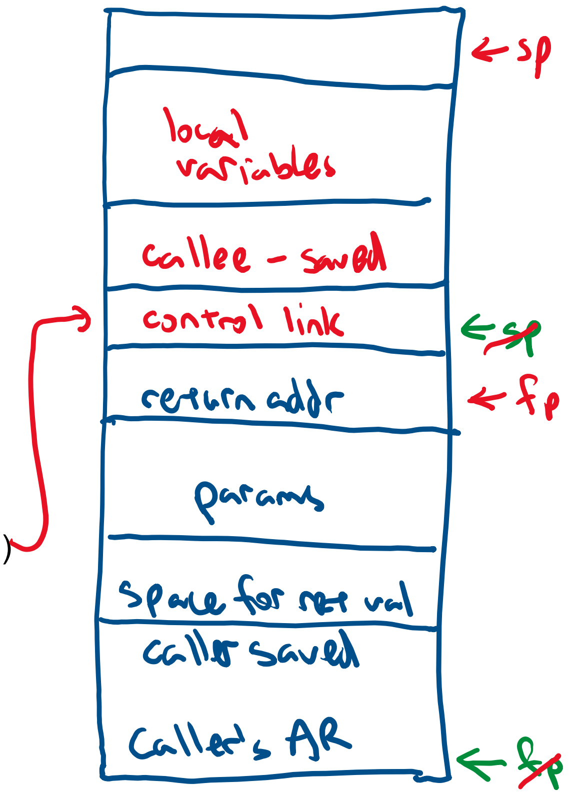
Function entry: callee responsibilities

Save **$fp** (it will need to be restored when the callee returns)

Update the base of the new AR to be the end of the old AR

Save *callee-saved* registers (if necessary)

Make space for locals



Function exit: callee responsibilities

Set the return value

Restore callee-saved registers

Grab stored return address

Restore *old* **$sp** calc based on fp

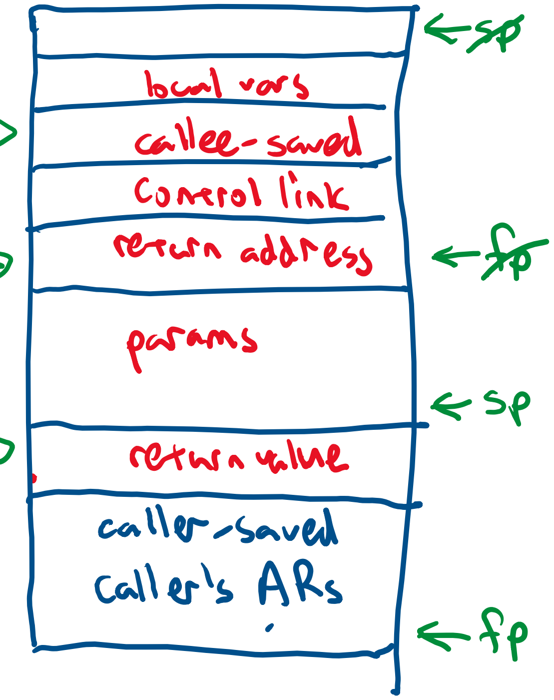
Restore *old* **$fp** from control link

Jump to the stored return address

Function exit: caller responsibilities

Pop the return value (or copy from register)

Restore caller-saved registers



Example

```
integer summation{integer max} [
   integer sum.
   integer k.
   sum = 0.
   k = 1.
   while k <= max [
      sum = sum + k.
      k++.
   ]
   return sum.
]
void main{} [
   integer x.
   x = summation(4).
   write << x.
]
```