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

<u>Goals</u>:

- report as many *distinct* errors as possible
- don't report *same* error multiple times – avoid error cascading

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

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

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
    - control context

Non-local dynamic memory

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

Don't know how much space we'll need

The Heap

- region of memory independent of the stack
- allocated according to calls in the program
- how is memory "given back"?

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

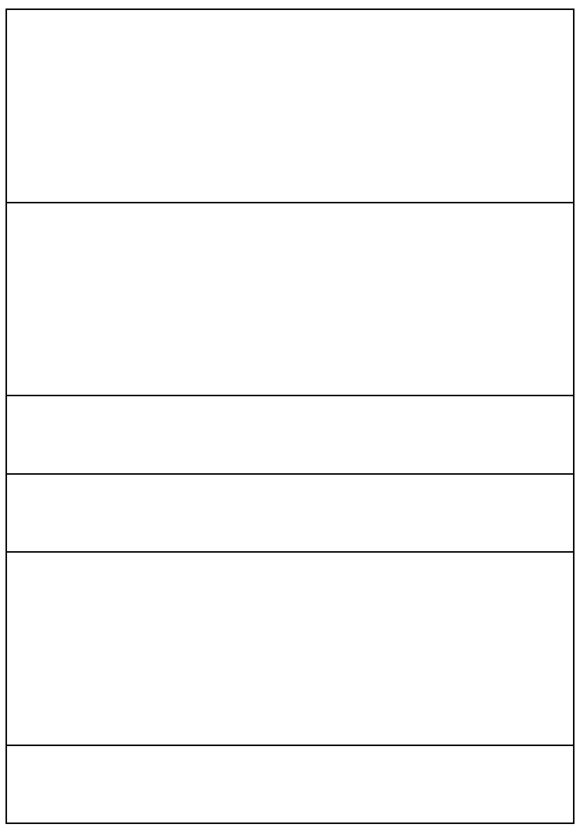
caller = function doing the invocation

callee = function being invoked

$sp (**stack pointer**) – points to top of stack

$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**

Restore *old* **$fp**

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.
]
```