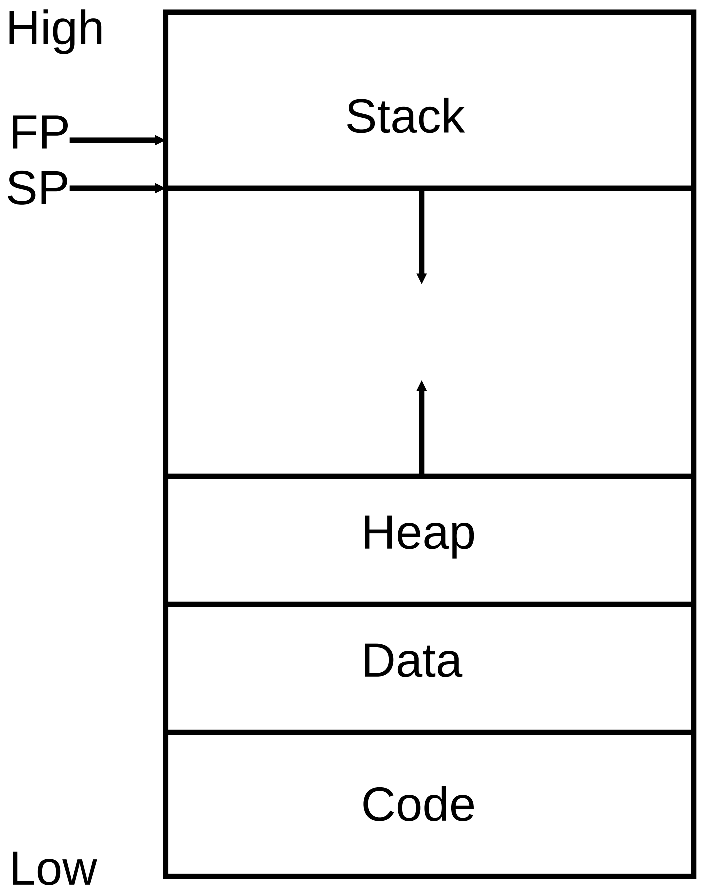
Session Plan

- Session 6: ***Activation records (stack frames)***
  - memory model
  - local variables
  - stack frames
    - layout
    - frame pointer and stack pointer
    - parameter passing
    - calling conventions
  - static links
  - frames implementation

Layout in memory ('memory model')



possible format of a code file before it is loaded into memory:

header [magic number,sizes,entry point]
text [the code]
data [global variable space]

symbol table
[variable & method names etc]
string table
[the text of names in symbol table]

Local variables

- functions/methods may have *local* variables
- several invocations at same time each with own instantiations of local variables
- e.g. recursive calls
- local variables destroyed on method return
- LIFO behaviour (implemented with stack data structure)

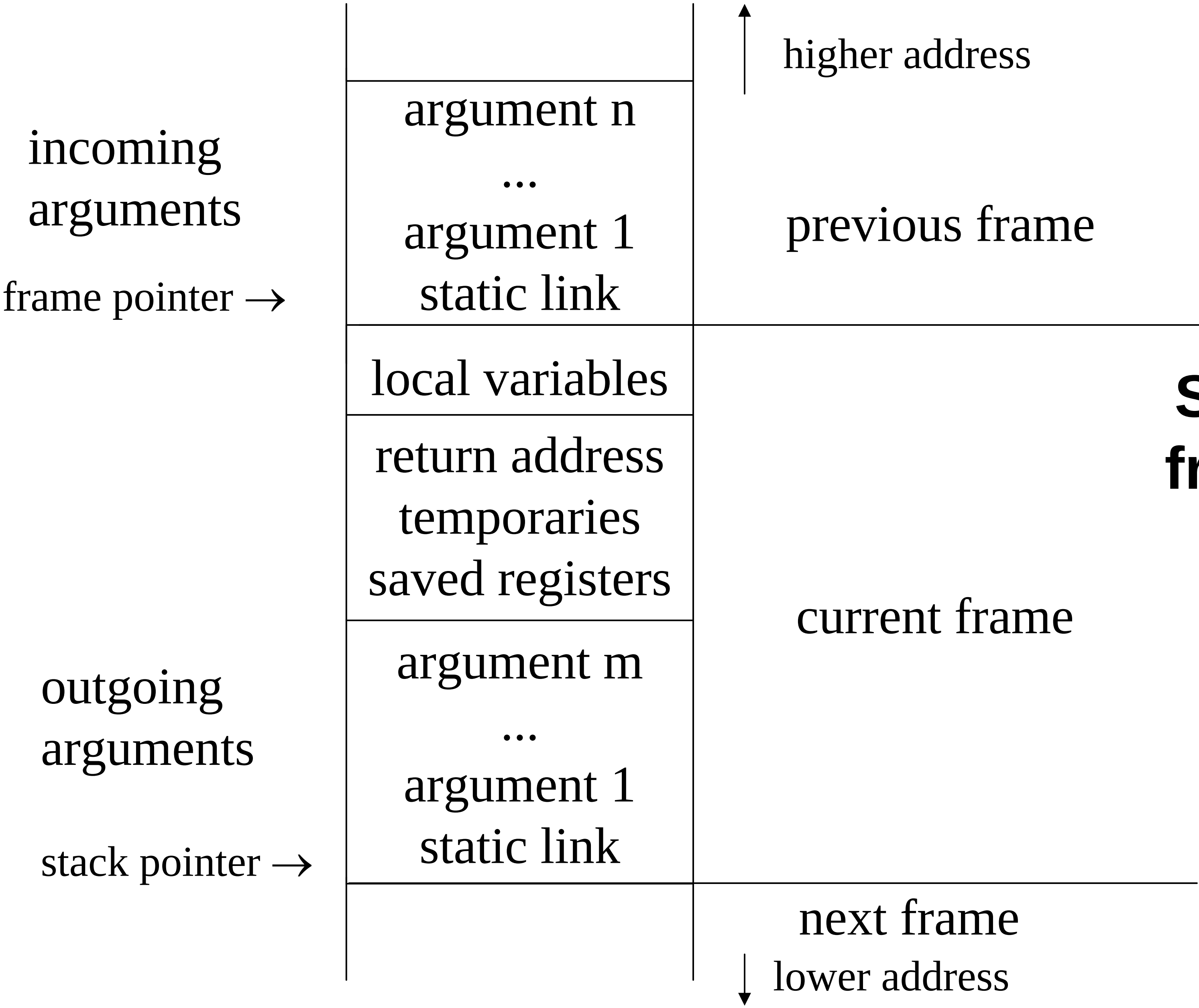
```
int f(int x) {
   int y = x+x;
   if y < 10
     return f(y);
   else
     return y-1;
}
```

- new instantiation of x created & initialised by f's caller each time f called
- recursive calls - many x's exist simultaneously
- new instantiation of y created each time body of f entered

Stack frames

- frame layout design
  - takes into account particular features of instruction set architecture and programming language being compiled
- usually a standard frame layout prescribed by manufacturer
  - not necessarily convenient for compiler writers, but
  - functions/methods written in one language can call functions/methods written in another, so
  - gain programming language interoperability
  - can combine modules/classes compiled from different languages in same running program

Stack frames



Stack frame layout

- set of *incoming arguments* (part of previous frame) passed (stored) by caller code
- *return address* (often stored by CALL instruction)
- *local variables* (those not in registers)
- area for local variables held in registers but that may need to be *saved* into frame
- *outgoing argument* space (to pass (store) parameters when method calls other methods)
- temporaries - locations where code temporarily saves register values when necessary

Frame pointer and stack pointer

- caller *g(...)* calls callee $f(a_1,...,a_n)$
- calling code in *g* puts arguments to *f* at end of *g* frame
  - referenced through SP, incrementing SP
- on entry to *f*,
  - SP points to first argument *g* passes to *f*
  - old SP becomes current *frame pointer* FP
  - *f* then allocates frame by setting SP=(SP - framesize)
- old SP becomes current *frame pointer* FP
- many implementations have FP as separate register
  - so method code:
    - » has incoming arguments referenced by FP-an offset
    - » has local variables referenced by SP+an offset or FP-an offset
    - » has saved registers, return address and outgoing arguments referenced by SP+an offset
- on exit from *f* : SP = FP, removing frame

Registers

- fast execution $\Rightarrow$ keep local variables, intermediate results of expressions etc in registers, not stack frame (memory)
- registers are accessed directly by arithmetic instructions
  - (memory access requires *load* & *store* instructions; even if arithmetic instructions access memory, registers are always faster)
- *caller save* vs *callee save* registers
  - method f uses reg r to hold local variable; then f calls g and g uses r
  - which code saves r contents in stack frame, f or g?
  - often machine conventions defining set of caller- and callee-saves
- sometimes saves & restores unnecessary
  - if variable not required after call, caller code can put in a caller-save register and compiler leaves out the code to save it before call
  - if local variable i in f needed before & after many method calls - put in callee-save register, save once on entry to f, fetch back before returning from f
- register allocator in compiler chooses best register set

Parameter passing

- pre-1960: passed in statically allocated memory blocks - no recursive functions or methods
- 1970s machines: function arguments passed on the stack
- but program analysis shows that very few functions/methods have >4 arguments, and almost none >6.
- so on most modern machines
  - first k arguments (k=4 or 6) are passed in registers $r_p,...,r_{p+k-1}$ and the rest passed in memory on the stack
- but if function or method call $f(a_1,...a_n)$
  - receives its parameters in registers $r_1...r_n$
  - and then calls h(z), argument z is passed in r_1
  - f must save old contents of r_1 (contents of a_1) in stack frame before calling h
  - this is memory traffic, so has use of registers saved any time?
  - *(it of course might be worse:* $h(z_1,z_2,z_3,z_4\ldots)$ *)*

Parameter passing - why use registers?

- *Leaf functions or methods* (don't call other methods)
  - no need to write incoming arguments to memory; often no need even to create new stack frame
- *Interprocedural register allocation*
  - analyse all methods in entire program
  - assign different methods different registers to receive parameters & hold variables
  - eg f(x) receives x in r_1, calls h(z): z in r_7
- *Dead variables* on method call: overwrite registers
- *Register windows*
  - architecture has fresh set of registers (a *window*) for each method invocation
  - but eventually run out; then a window must be saved on stack

Parameter-passing calling convention

- even if arguments are passed in registers, and do not need to be saved into stack (see previous foil), space is reserved in the stack
  - *caller* code reserves space for arguments that are passed in registers next to the space for any other arguments
  - but does not save anything into this space
  - *callee* code saves into this space if necessary
- when is it necessary to save like this?
  - in some languages, the address of a parameter may be taken
    - » this must be a memory (ie stack) address, not a register
  - some languages have call-by-reference parameter passing
  - when a register window (see previous foil) must be saved

Frame-resident variables

- code generator produces code to write values from registers to the stack frame only when
  - variable will be passed-by-reference, or its address is taken
  - variable is accessed by a function/method nested inside current
  - value is too big to fit in a register
  - variable is an array
  - register holding the variable is needed for a specific purpose (eg parameter passing)
  - there are so many local variables and temporary values necessary to perform expression computations that they won't all fit in the available registers (*spilling*)
- a variable *escapes* (code from outside its function/method may access it) if
  - it is passed as a parameter by reference
  - its address is taken
  - it is accessed from a nested function/method

Escapes in MiniJava

- there are none!
  - no nesting of classes and methods
  - not possible to take address of variable
  - integers and booleans passed by value
  - objects, including integer arrays, represented by pointers also passed by value

Block structure - static links

```
type tree =  {key: string, left: tree, right: tree}

function prettyprint(tree: tree) : string =
 let
      var output := ""

      function write(s:string) =
              output := concat(output,s)

      function show(n:int, t:tree) =
              let function indent(s:string) =
                      (for i := 1 to n
                         do write(" ");
                       output := concat(output,s); write("\n"))
              in if t=nil then indent(".")
                 else (indent(t.key);
                      show(n+1,t.left);
                      show(n+1,t.right))
              end

    in show(0,tree); output
  end
```

Static links

- block structure
  - nested method/function definitions use variables or parameters declared in outer definitions
- whenever a function f is called, a pointer to the frame of the function statically enclosing f is passed
  - this is the *static link*
  - it points to the most recent activation of the enclosing function
- when a function f at nesting depth f_d calls (caller) a function g at depth g_d (callee), the static link set up is
  - to caller, if g is declared within f
  - computed by following f_d - g_d static links, if g is declared outside f
- a variable or parameter declared in a function g at depth g_d is accessed from function f at depth f_d
  - by code that follows f_d - g_d static links to get to the appropriate frame

Static links examples

- 21 `prettyprint` calls `show`, passes `prettyprint` 's own frame pointer as `show` 's static link
- 10 `show` stores its static link (address of `prettyprint` 's frame) into its own frame
- 15 `show` calls `indent`, passing its own frame pointer as `indent` 's static link
- 17 `show` calls `show`, passing its own static link (not frame pointer) as static link

12 `indent` uses value n from `show`'s frame - fetches appropriate offset from `indent` 's static link
13 `indent` calls `write`. Passes frame pointer of `prettyprint` as static link. fetches an offset from its own static link (from `show` 's frame) - the static link passed to `show`
14 `indent` uses var `output` from `prettyprint` 's frame; starts with own static link, then fetches `show`'s then fetches `output`

General Frame package

- abstract class Frame.Access
  - describes formals and local variables that may be in frame or registers

  class inFrame extends Frame.Access { int offset; … }

  class inReg extends Frame.Access { Temp temp; … }
- abstract class Frame.Frame
  - a list of formals (an AccessList) denoting locations where formals will be accessed by method/function (callee) code
  - method Frame newFrame(Label *name*, Util.BoolList formals)
    - » for k parameters, list of k booleans, true for each parameter that escapes
  - method Access allocLocal(boolean escape)
    - » allocates space in frame for a local which may be an InFrame or an InReg
  - hides the machine architecture; for particular architecture eg MIPS
    - » will have class MIPS.Frame extends Frame.Frame, and
    - » classes MIPS.InFrame, MIPS.InReg extends Frame.Access
- an abstract syntax tree traversal can calculate escapes
  - none in MiniJava, as we saw earlier

What you should do now…

- read and digest chapter 6
  – you don't need
    » higher order functions
- think about writing a Frame package for MiniJava
  – remember no nested methods in MiniJava
  – so no static links