INF 212
ANALYSIS OF PROG. LANGS
PROCEDURES & FUNCTIONS

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Subroutines aka Procedures

- Historically: blocks of instructions executed several times during program execution

- May have 0 or more input arguments
- May have 0 or more output arguments
- May perform IO, side effects

- Mid-50s

Functions

- Take 0 or more input arguments
- Return one value
- Used as *expressions*

- Additional constraint for **pure** functions:
  - No IO, no side effects

Procedures vs. Functions

- Distinction existed as early as 1958 (FORTRAN)

```
subroutine square_cube(i,isquare,icube)
  integer, intent(in)  :: i              ! input
  integer, intent(out) :: isquare,icube ! output
  isquare = i**2
  icube   = i**3
end subroutine square_cube

program xx
  implicit none
  integer :: i,isq,icub
  i = 4
  call square_cube(i,isq,icub)
  print*,"i,i^2,i^3=",i,isq,icub
end program xx
```

Procedures vs. Functions

- Distinction existed as early as 1958 (FORTRAN)

```
function func(i) result(j)
    integer, intent(in) :: i ! input
    integer             :: j ! output
    j = i**2 + i**3
 end function func

 program xfunc
    implicit none
    integer :: i
    integer :: func
    i = 3
    print*,"sum of the square and cube of",i," is",func(i)
 end program xfunc
```

Additionally, Fortran has a **`pure`** keyword for pure functions

Procedures vs. Functions

- Distinction was lost at some point, mainstream PLs merged the two concepts into one
  - C/C++, Java, Python, Perl, PHP, ... No distinction:
    - Procedures can also return values
  - Lisp, ML, Haskell, ... Only functions, but:
    - Functions can be pure or impure

“Pure” Functional Programming

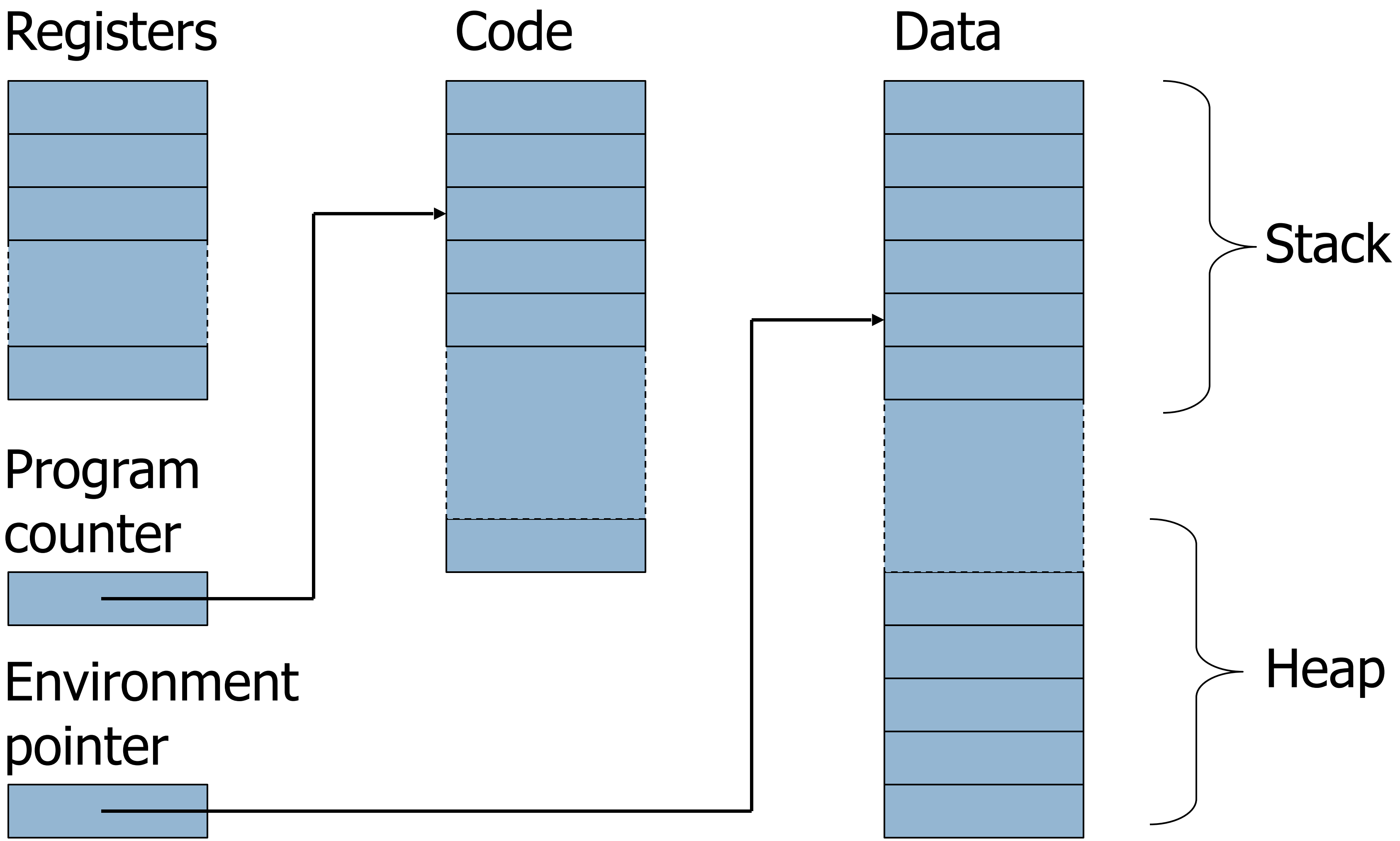
- Mathematical functions
  - No side effects
  - No IO (other than at the beginning and the end)
- “High-order” functions
  - Functions can take functions as arguments
  - Functions can return functions as values

- More on this later…

Function/procedure calls

Implementation details

Simplified Machine Model



Function definition

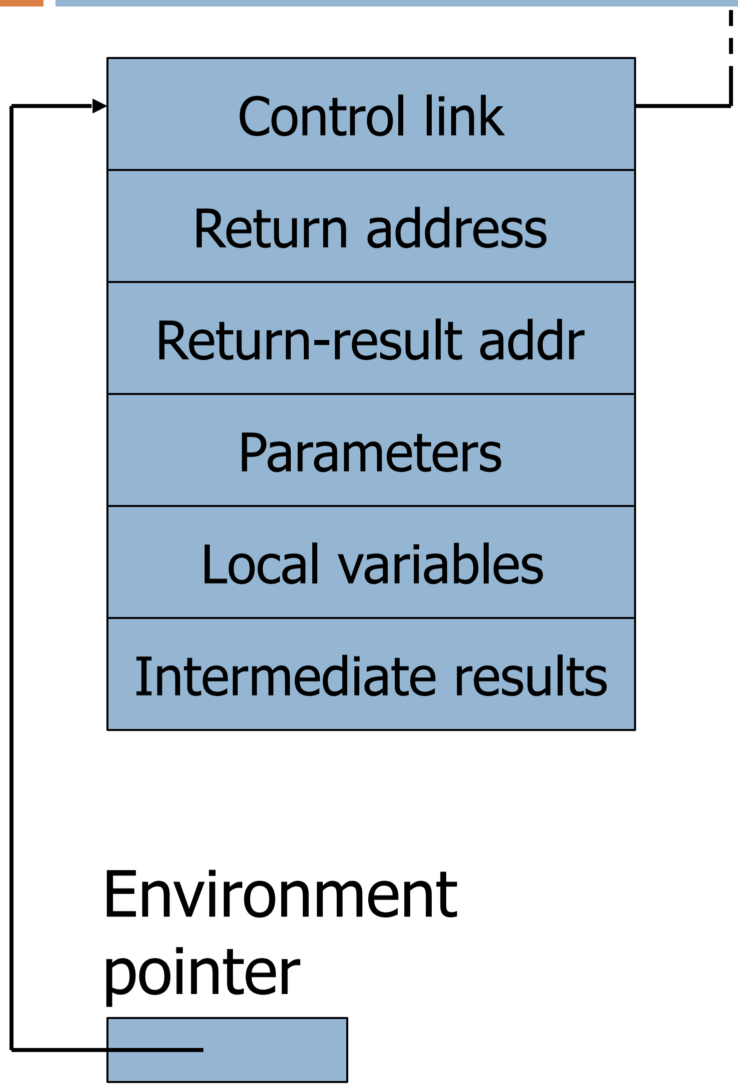
```
def: fact(n) = if n<=1  then 1
               else n * fact(n-1)


      ...
call: fact(3)
      ...
```

?

Activation Records for Functions

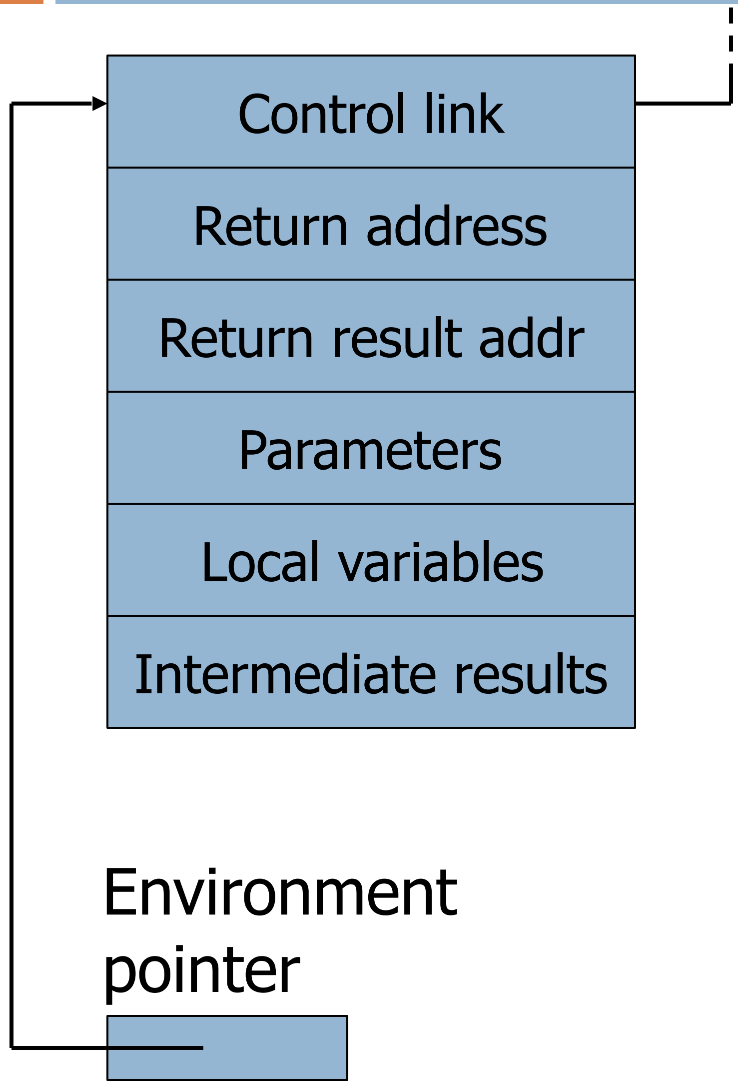
- Block of information ("frame") associated with each function call, including:
  - Parameters
  - Local variables
  - Return address
  - Location to put return value when function exits
  - Control link to the caller's activation record
  - Saved registers
  - Temporary variables and intermediate results
  - (not always) Access link to the function's static parent

Activation Record Layout



- Return address
  - Location of code to execute on function return
- Return-result address
  - Address in activation record of calling block to receive returned value
- Parameters
  - Locations to contain data from calling block

Example

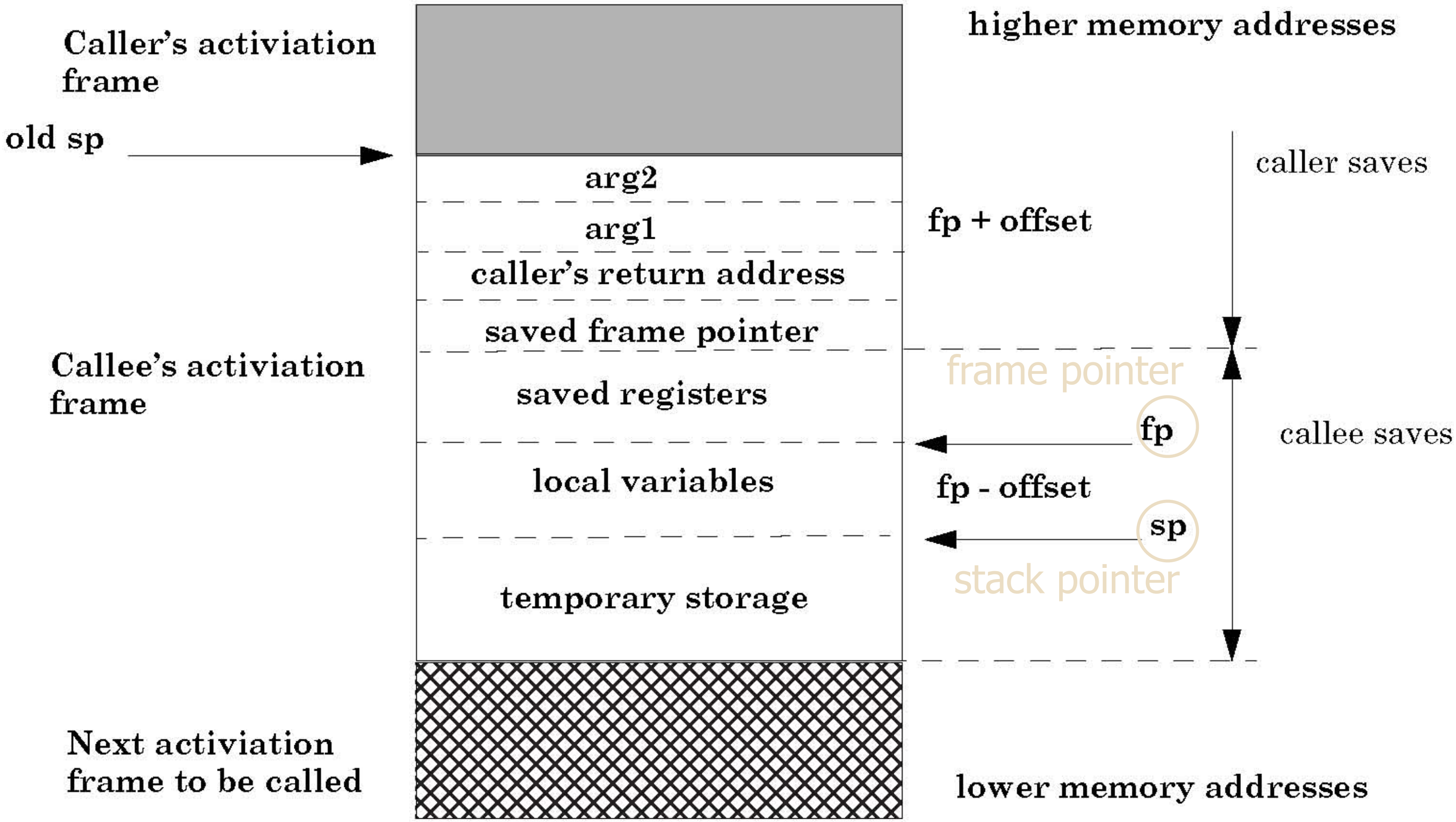


- Function

  fact(n) = if n<=1 then 1
  else n * fact(n-1)

  - Return result address: location to put fact(n)
- Parameter
  - Set to value of n by calling sequence
- Intermediate result
  - Locations to contain value of fact(n-1)

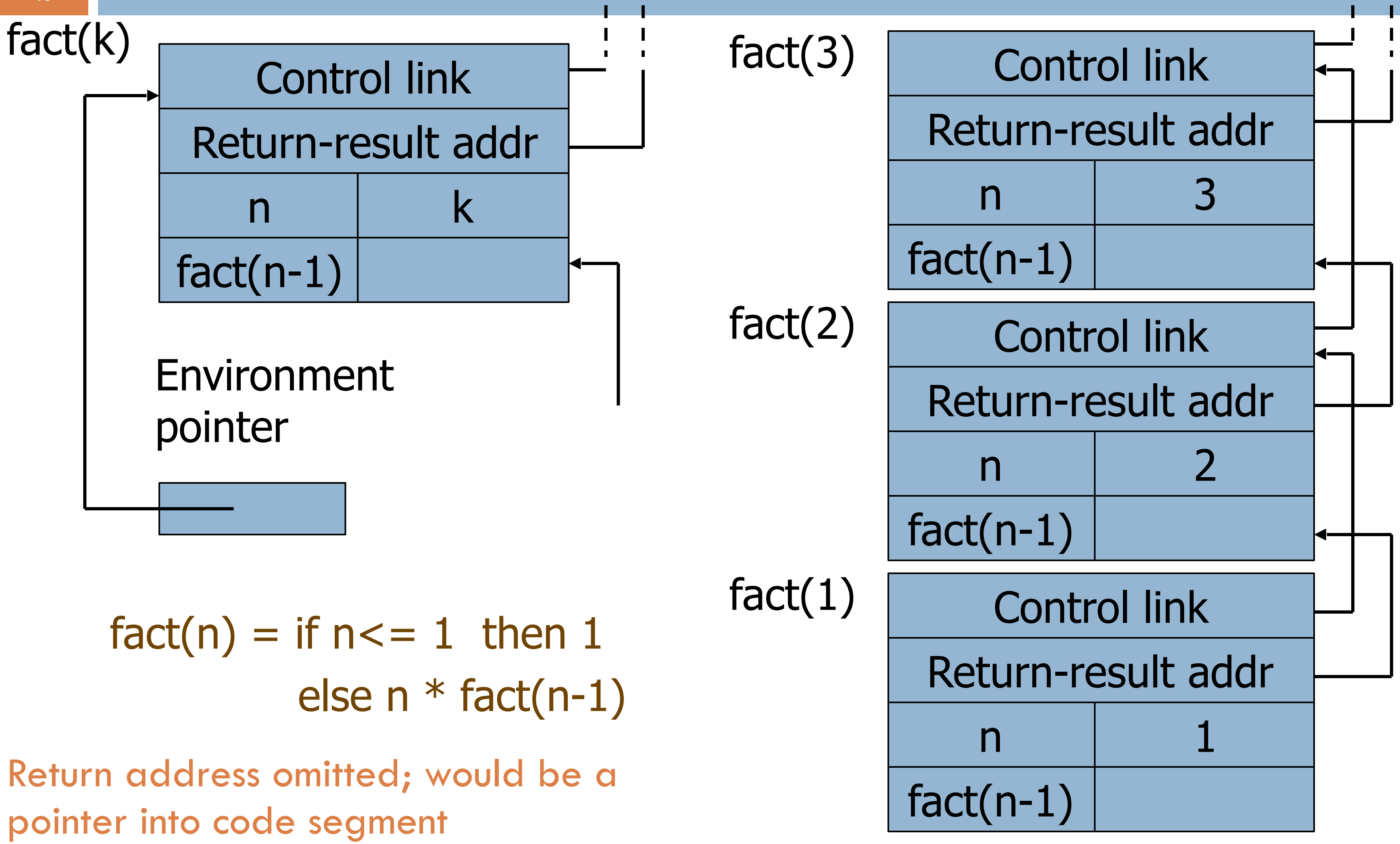
Typical x86 Activation Record



Run-Time Stack

- Activation records are kept on the stack
  - Each new call pushes an activation record
  - Each completing call pops the topmost one
  - Stack has all records of all active calls at any moment during execution (topmost record = most recent call)
- Example: fact(3)
  - Pushes one activation record on the stack, calls fact(2)
  - This call pushes another record, calls fact(1)
  - This call pushes another record, resulting in three activation records on the stack

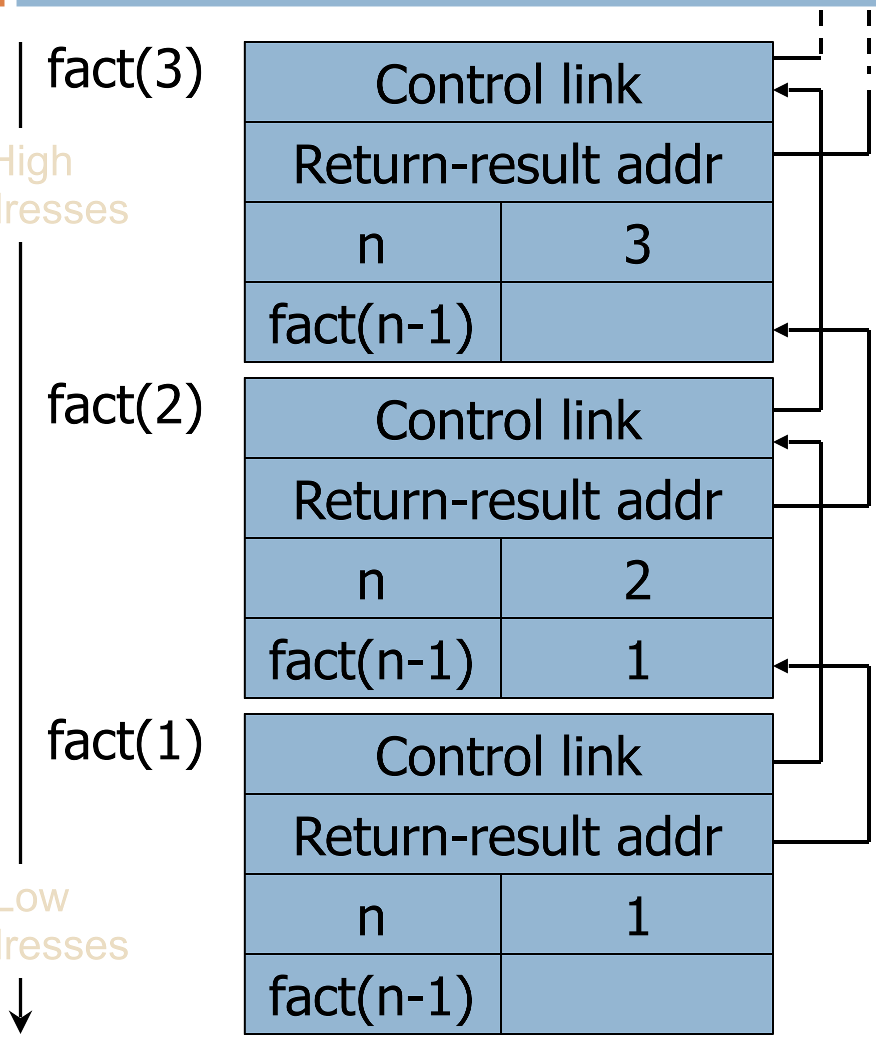
Function Call

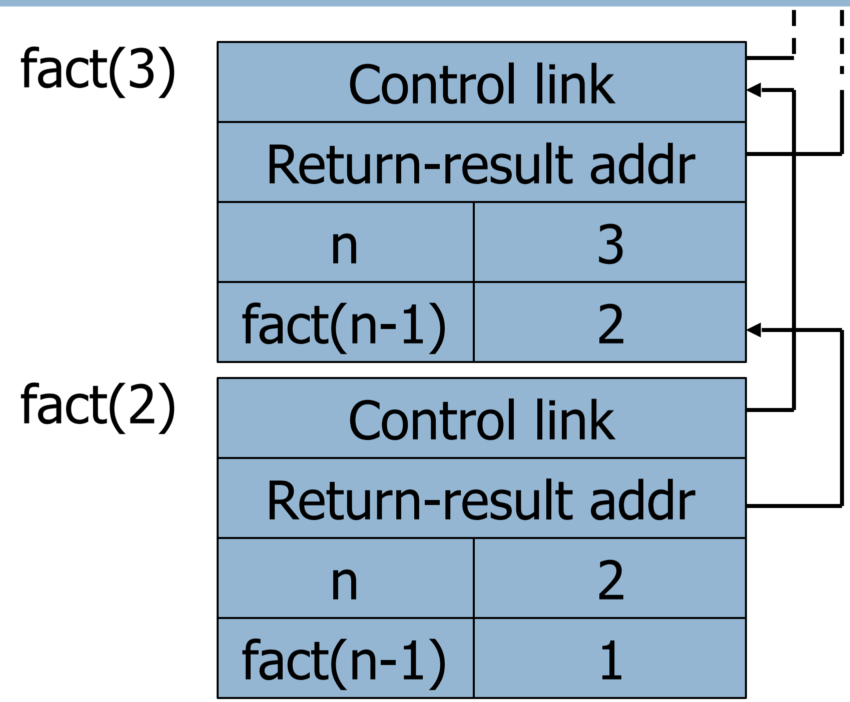


fact(n) = if n<= 1 then 1
else n * fact(n-1)

Return address omitted; would be a pointer into code segment

Function Return





fact(n) = if n<=1 then 1
else n * fact(n-1)