

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
```

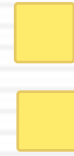
Additionally, Fortran has a **pure** keyword for pure functions

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...



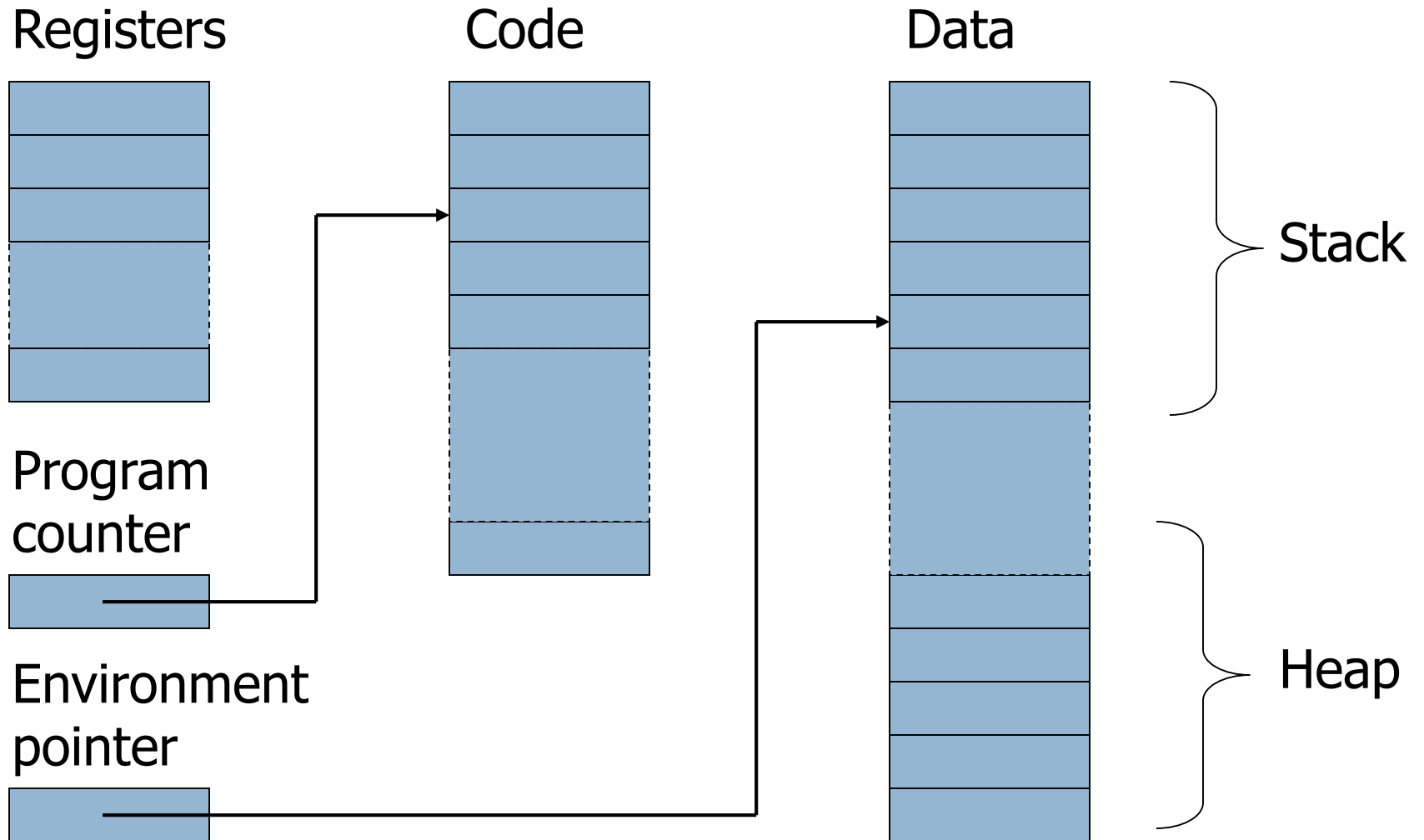
Function/procedure calls

Implementation details

Simplified Machine Model




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Function definition

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

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



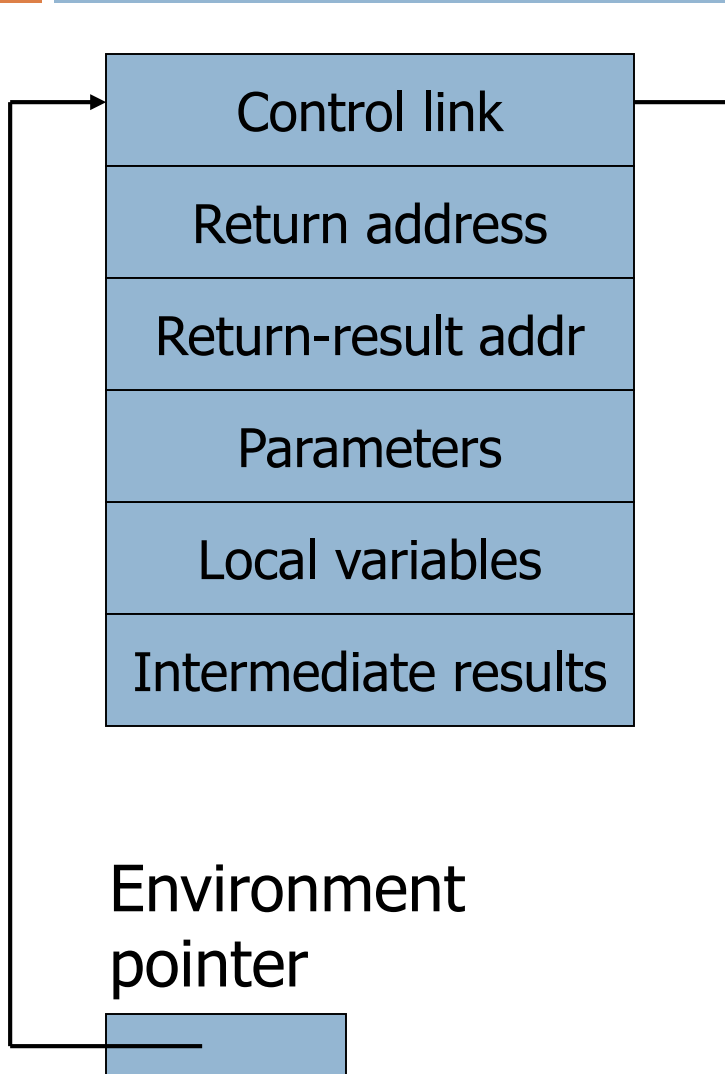
Activation Records for Functions

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- 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

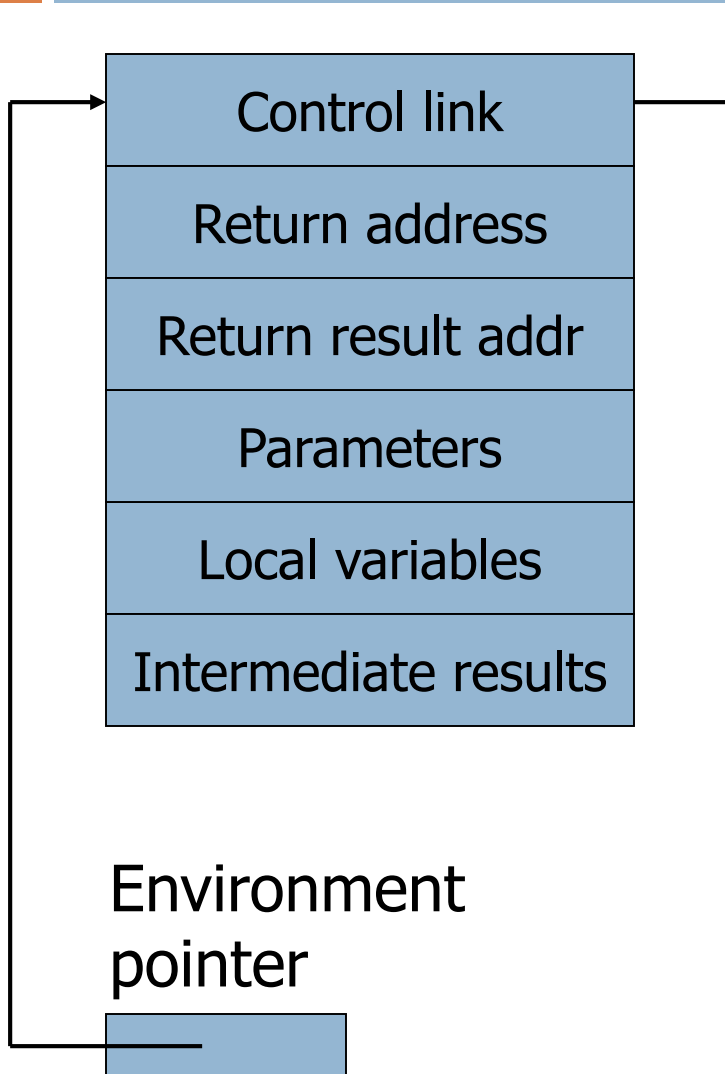
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- Return address
 - ▣ Location of code to execute on function return
- Return-result address
 - ▣ Address in activation record of calling block to receive returned value
- Parameters
 - ▣ Locations to contain data from calling block

Example

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□ Function

$\text{fact}(n) = \text{if } n \leq 1 \text{ then } 1$
 $\text{else } n * \text{fact}(n-1)$

▣ Return result address:
location to put $\text{fact}(n)$

□ Parameter

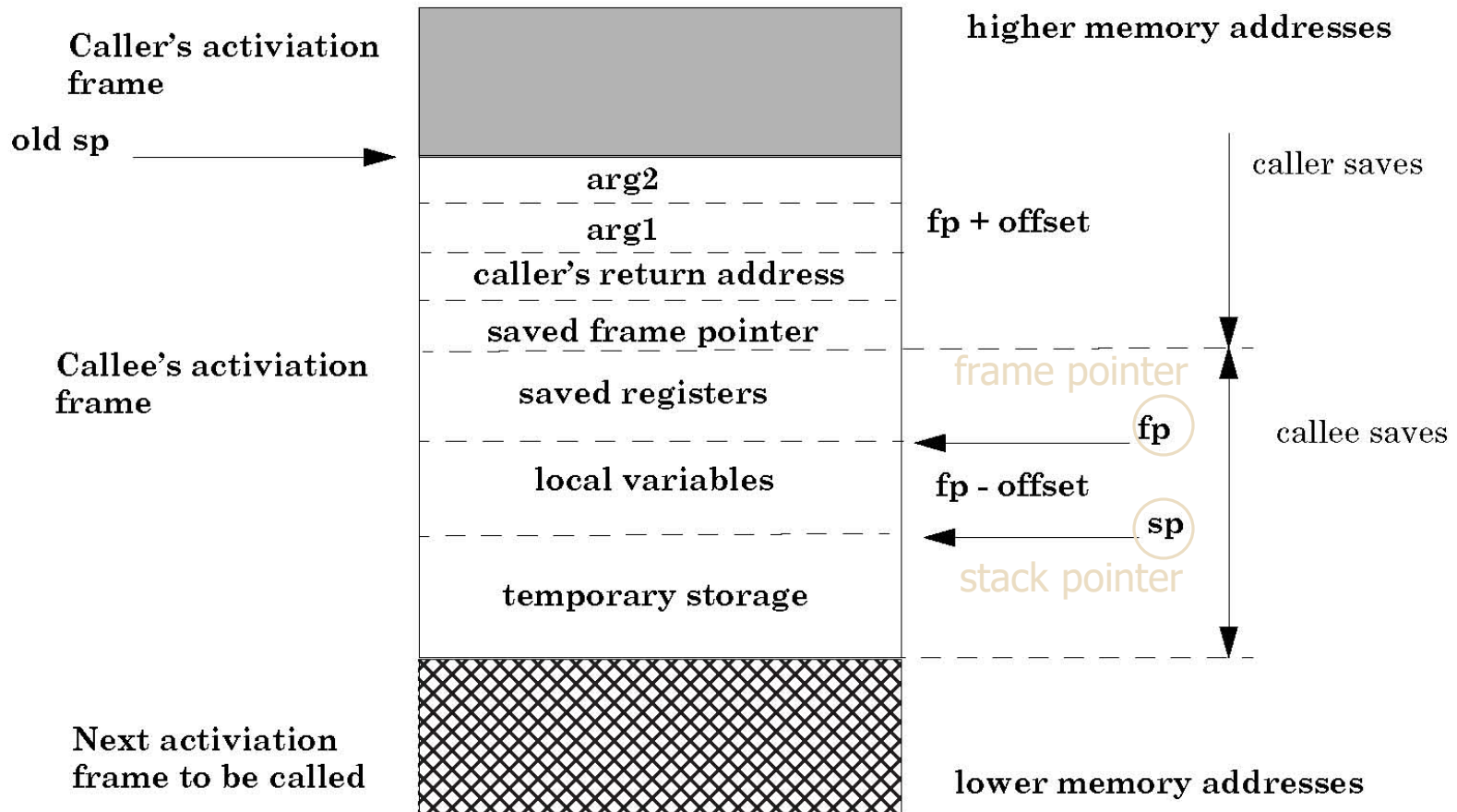
▣ Set to value of n by calling
sequence

□ Intermediate result

▣ Locations to contain value of
 $\text{fact}(n-1)$

Typical x86 Activation Record

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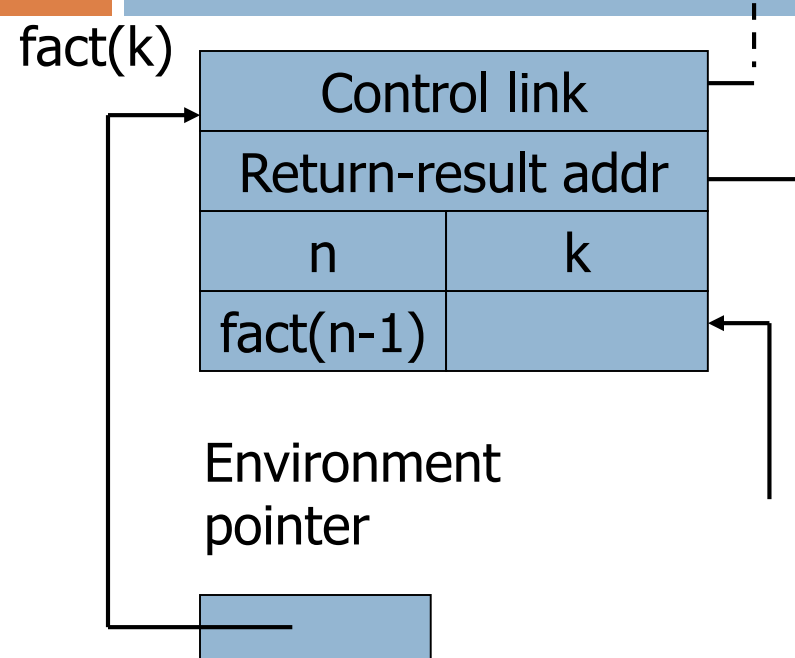
Run-Time Stack

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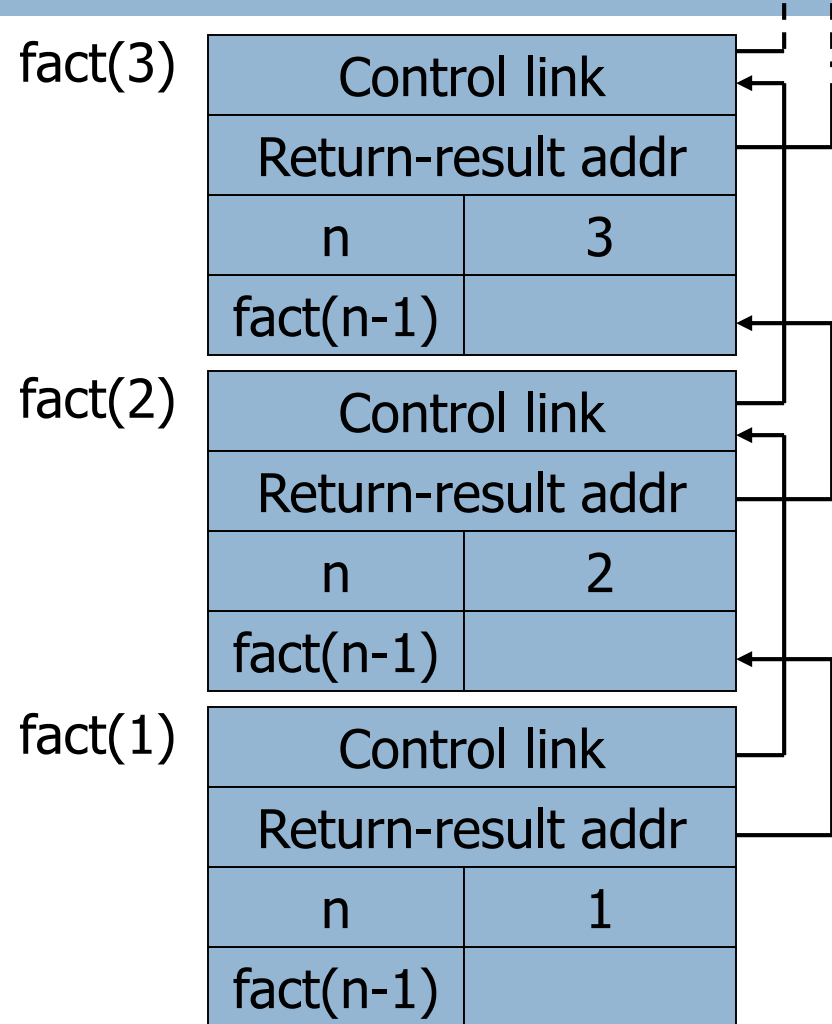
- Activation records are kept on the **stack**
 - ▣ Each new call pushes an activation record
 - ▣ Each completing call pops the topmost one
 - ▣ Stack has all records of all active calls at any moment during execution (topmost record = most recent call)
- Example: `fact(3)`
 - ▣ Pushes one activation 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

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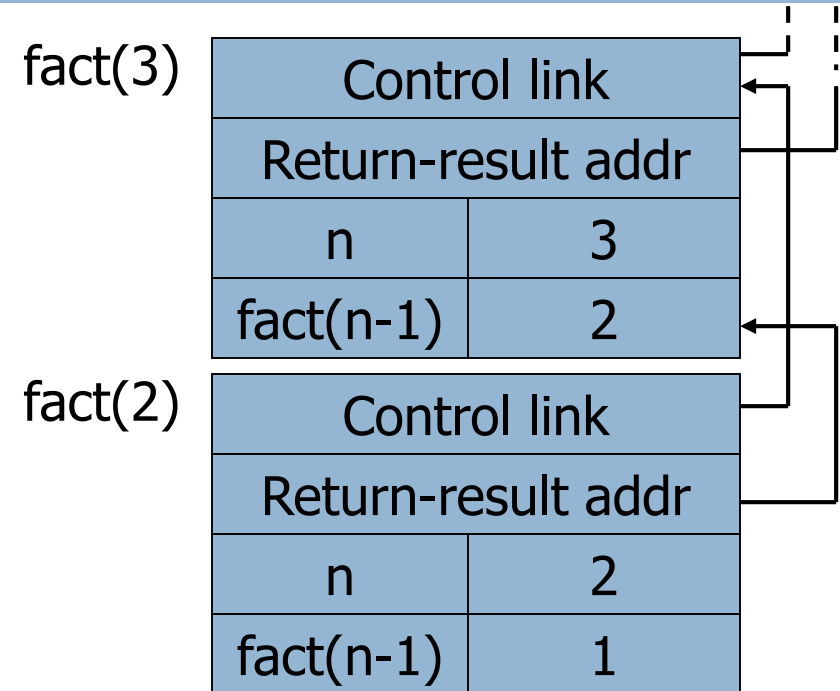
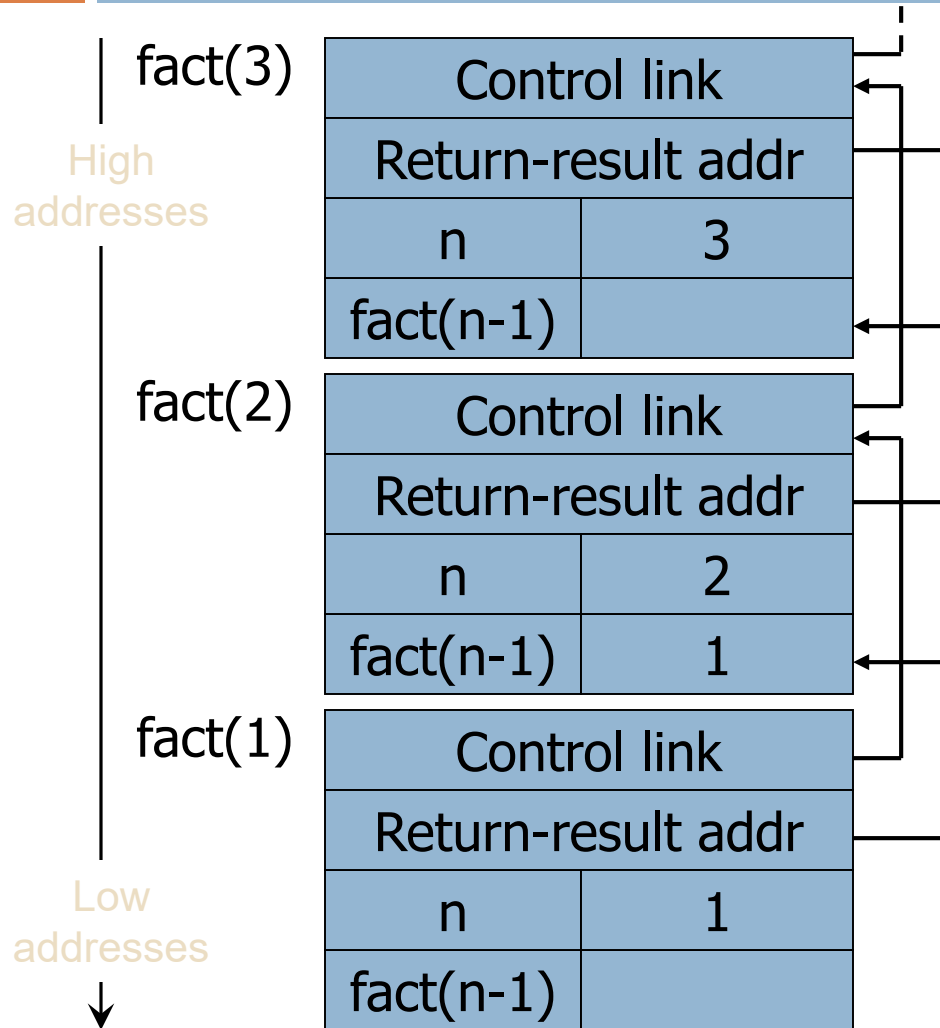
$\text{fact}(n) = \text{if } n \leq 1 \text{ then } 1$
 $\text{else } n * \text{fact}(n-1)$



Return address omitted; would be a
pointer into code segment

Function Return

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$\text{fact}(n) = \text{if } n \leq 1 \text{ then } 1$
 $\text{else } n * \text{fact}(n-1)$

Takeaway about functions

- Functions are ephemeral
 - ▣ They execute and go away
- Pure functions are the most ephemeral of all
 - ▣ They don't leave any traces of their execution
 - ▣ Good for concurrency, testing, etc.