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# Function calls and the run-time stack

# Beyond jump and return

- We’ve looked at how jumps to saved addresses create the control flow of procedure calls
- Functions also require data in a local environment to be arranged somehow
- Abandoning our hypothetical mini-CPU, we can examine how x86-s do it

# The basic x86 approach

- Arguments need to go on the stack
  - The calling function handles putting them there, and taking them away again
- Return address must go on the stack
  - The calling function handles it, because it knows where to resume execution
- Local variables need to go on the stack
  - The called function knows how much space they will need, and allocates it
- Stack is both local namespace and temporary results
  - Stack pointer deals with intermediate results
  - Frame pointer locates the start of the local namespace
- Return value must go somewhere
  - A designated register plays this part

# Activation record of our factorial function

```
int factorial ( int n ) {
  int result = n;
  if ( result > 1 )
      result *= factorial ( result – 1 );
  return result;
}
```

Next call's local var. "result"

My frame ptr.

Callee places these, when called

Return address

Argument: value of "result-1"

(Intermediate data)

Local var: "result"

Caller's frame ptr.

Generated function body places these

Return address

Argument: "n"

Caller places these, prior to call

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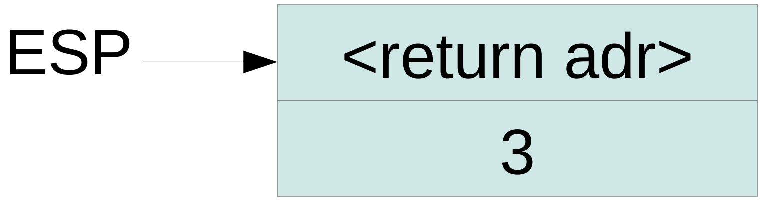
# Calling factorial(3)

push 3

call factorial




(EBP is somewhere below)

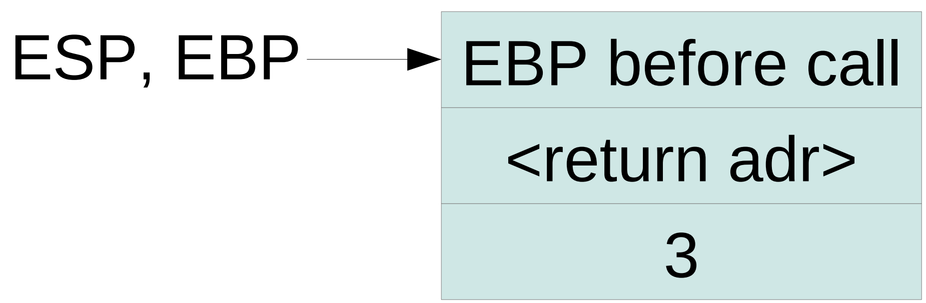
# factorial(3) receives

*push 3*

*call factorial*

push EBP

move ESP into EBP



# factorial() makes local space

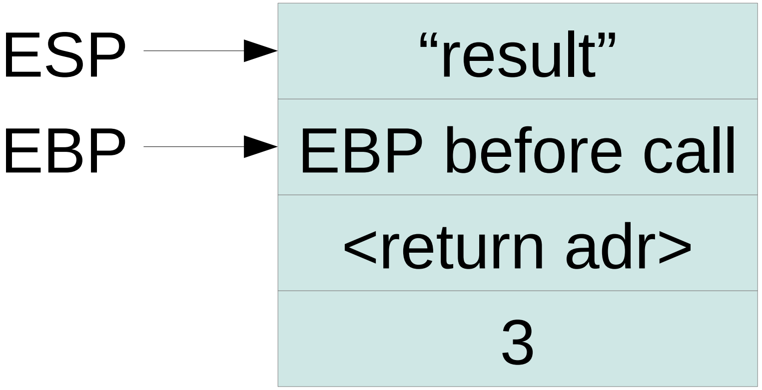
*push 3*

*call factorial*

*push EBP*

*move ESP into EBP*

sub 4, ESP



# Assign argument n to “result”

*push 3*

*call factorial*

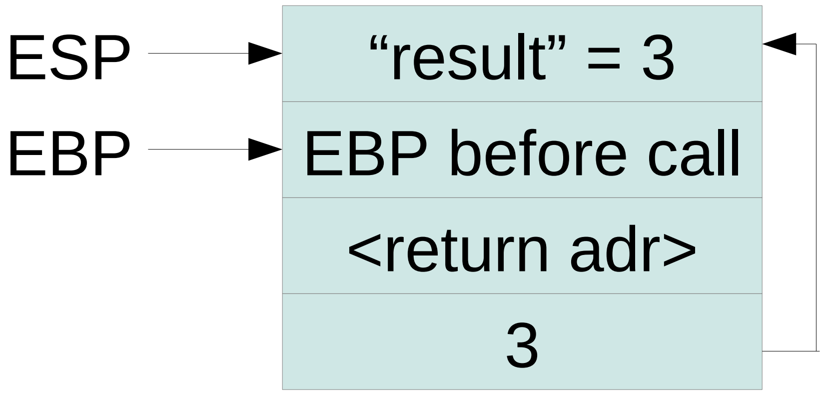
*push EBP*

*move ESP into EBP*

*sub 4, ESP*

move 12(EBP), EAX

move EAX, -4(EBP)



# Calculate result-1 for next call, push it as argument

*push 3*

*call factorial*

*push EBP*

*move ESP into EBP*

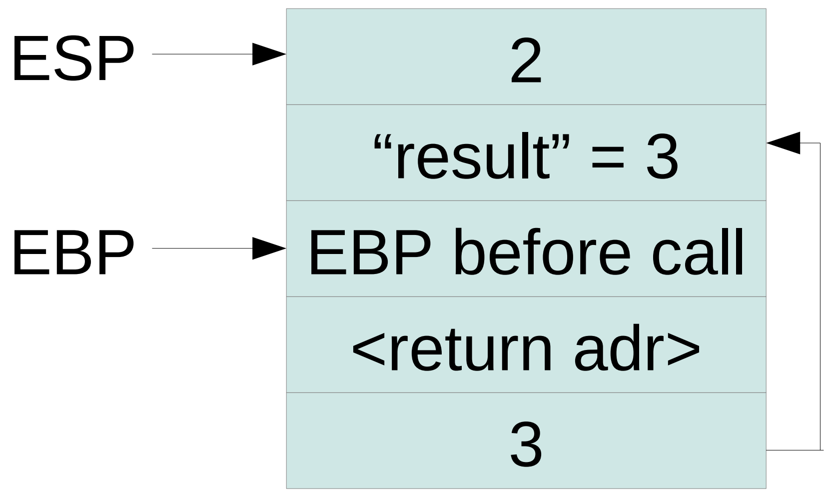
*sub 4, ESP*

*move 8(EBP), EAX*

*move EAX, -4(EBP)*

(...find out that 3-1 = 2…)

push 2



# Make the next call, thus pushing return adr.

*push 3*

*call factorial*

*push EBP*

*move ESP into EBP*

*sub 4, ESP*

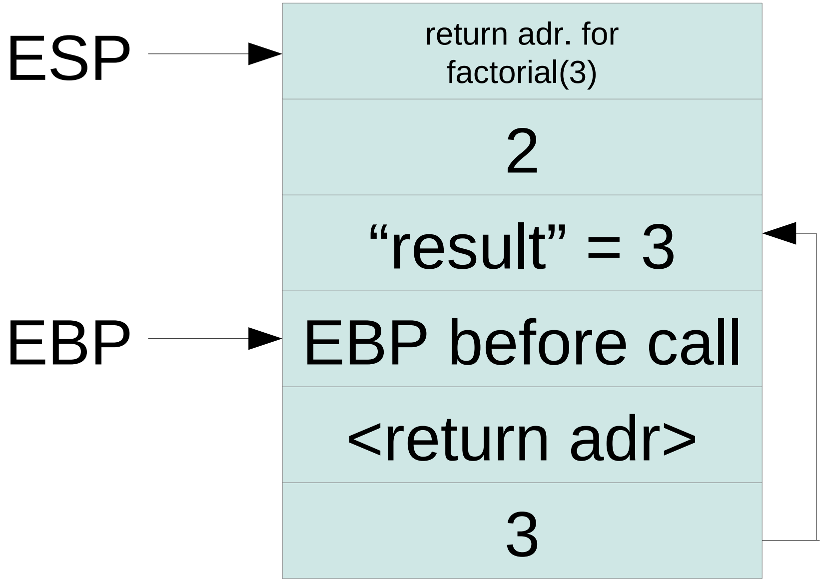
*move 8(EBP), EAX*

*move EAX, -4(EBP)*

*(...find out that 3-1 = 2…)*

*push 2*

call factorial



# ...and the whole circus repeats...

*push 2*

*call factorial*

*push EBP*

*move ESP into EBP*

*sub 4, ESP*

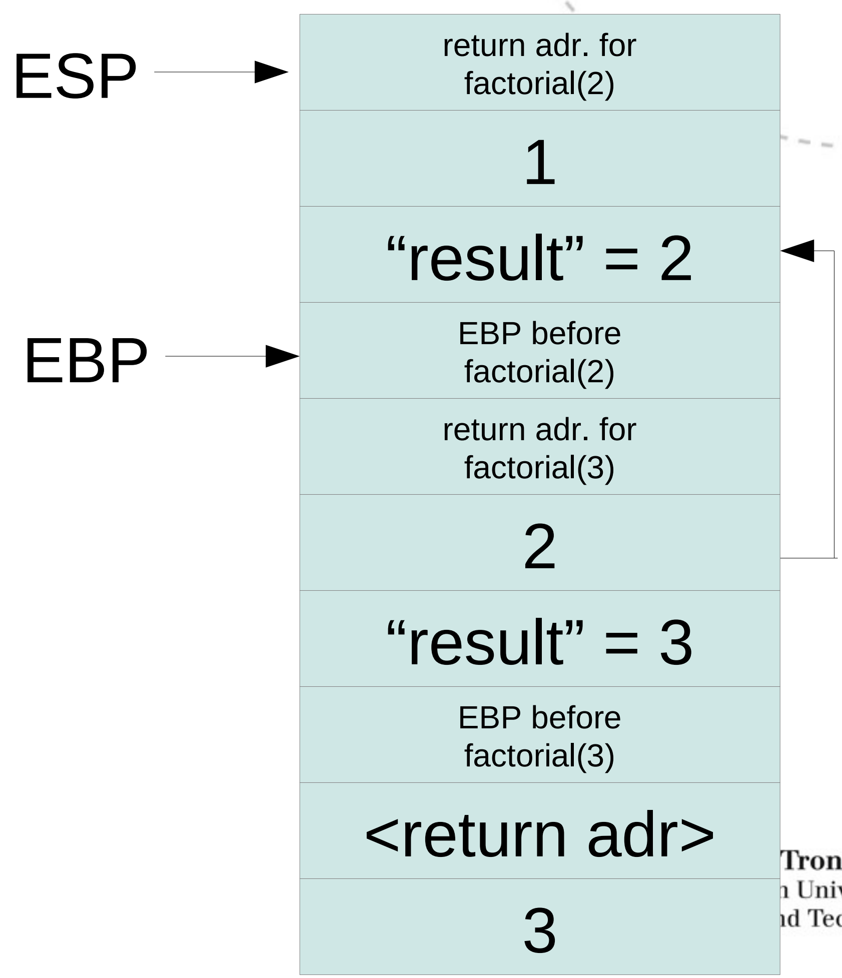
*move 8(EBP), EAX*

*move EAX, -4(EBP)*

*(...find out that 2-1 = 1...)*

*push 1*

*call factorial*



# ...until return.

## Unwind factorial(1):

*push 1*

*call factorial*

*push EBP*

*move ESP into EBP*

*sub 4, ESP*

*move 8(EBP), EAX*

*move EAX, -4(EBP)*

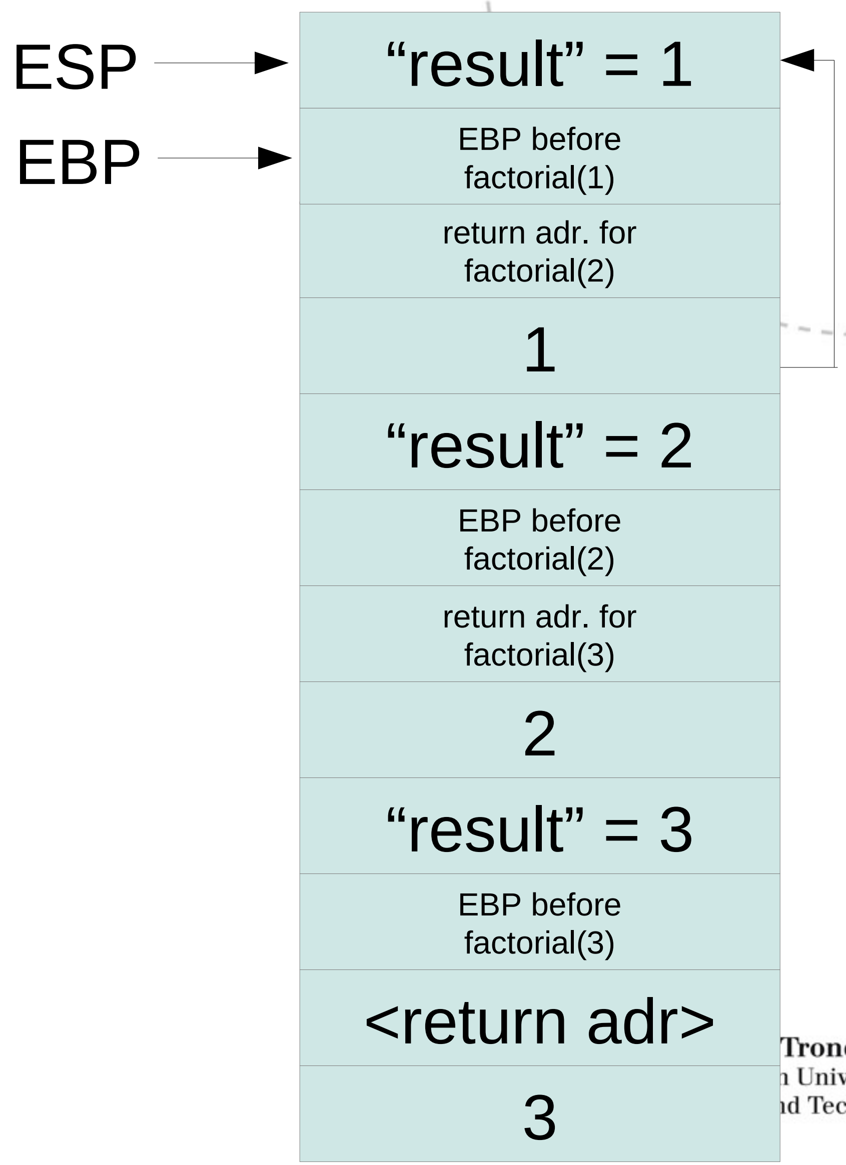
*(...find out that 1 > 1 is false…)*

move -4(EBP), EAX

move EBP, ESP

pop EBP

ret



Result: EAX=2

# Unwinding factorial(2)

add 4, ESP

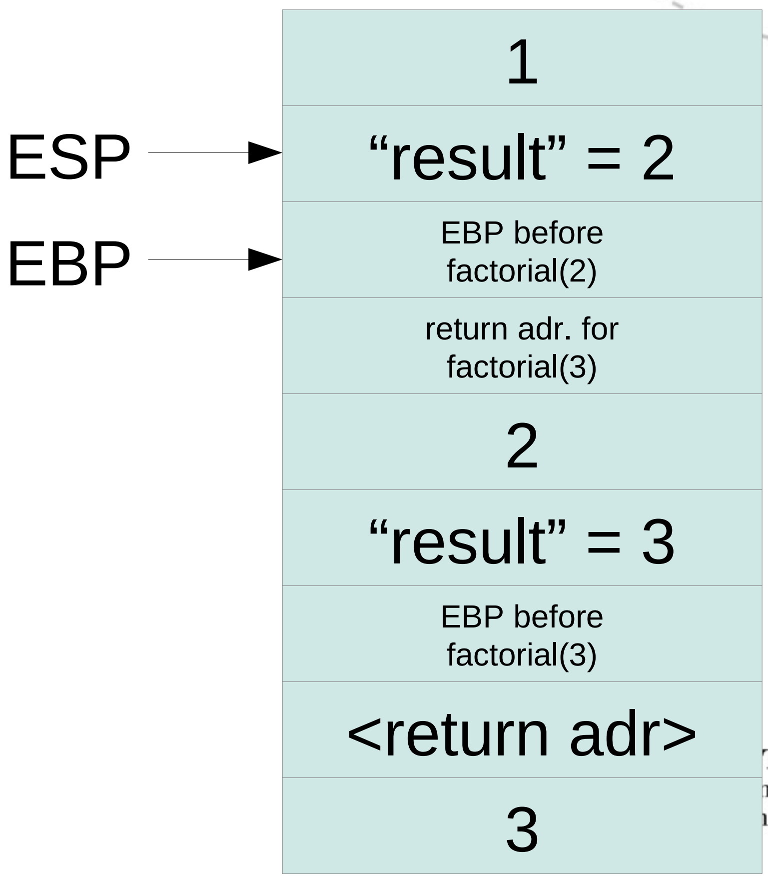
*...multiply EAX into -4(EBP)…*

move -4(EBP), EAX

move EBP, ESP

pop EBP

ret



Result: EAX=6

# Unwinding factorial(3)

add 4, ESP

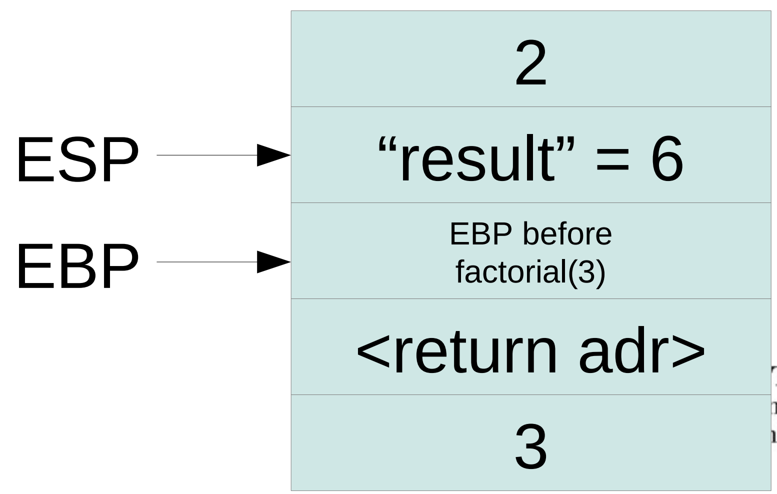
*...multiply EAX into -4(EBP)…*

move -4(EBP), EAX

move EBP, ESP

pop EBP

ret



Result: EAX=6

# Returning to caller

add 4, ESP

*...multiply EAX into -4(EBP)…*

move -4(EBP), EAX

move EBP, ESP

pop EBP

ret

The answer is here

EBP off somewhere below

ESP

3

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# A handful of details

- All my addresses are in multiples of 4, on the assumption that “int” is 32 bits (4 bytes)
- x86 stack space grows from high to low addresses, because it starts from the end of the process image:

| *0* | text | data | heap → | | ← stack | *2^64-1* |
|---|---|---|---|---|---|---|

  – “push” subtracts from the stack pointer
  – “pop” adds to the stack pointer

# A handful of white lies

- This was *almost* the sequence of operations you'll get out if you punch in "factorial.c" and run it through "cc -m32 -S factorial.c" to get the x86 assembly

  ...but not *quite*…
- The dimensioning of local space (movement of ESP at activation) isn't exactly flush with the number of local variables
- I skipped evaluation of conditionals and multiplication
  - We've covered them in TAC, and can do them up in assembly later
- Syntax deviates
  - You can't copy-paste what's written here and expect it to assemble

# The focal point

- Function call in TAC looks like this

```
param t1
param t3
param x
call foo
```

  for a function foo(a,b,c)
- The ‘param’ notation has an immediate interpretation in IA-32 assembly, *i.e.* “push the parameter on stack”
- It has a slightly different one in x86_64 which we’ll look at later
- Together, they may clarify why a low-IR (abstract assembler) has use for the ‘param’ notation

# Secondary points

- We didn’t talk a lot about indirect addressing, except for its use in arrays

  i.e. expressions like t2 = 12(t1)

  to mean “the value 12 addresses away from that in t1”

- The layout of an activation record makes an obvious use of it

  Local variables are translated into stack positions, located by their offset from the frame pointer

# Back to the overview

- Expressions translate into strings of operations, with temporaries for intermediate results
- Loops and conditionals translate into evaluation code for the condition, followed by fixed control flow patterns
- Function call and return translate into buffering up the arguments and jumping to the function
- Function bodies translate into a machine-related convention for where to find the arguments and where to put the local environment

# The Keys to the Kingdom

- What hasn't been mentioned is that these translation patterns are not final definitions taken from the Great Standard of Program Constructions™
  - They are devices we invent to give source languages their meaning
  - If you implement another translation of switch statements, you redefine what every source program with a switch in will do
  - If you invent a new language construct, the translation pattern you assign to it will specify what it can be used for
- This is the biggest takeaway from compiler construction:

  *The evaluation rules you learn for any language only appear because someone decided to implement them that way*

  The processor doesn't care, you can make different rules if you like.

# Inefficiencies that appear

- Duplicate values

  t1 = x

  t2 = y

  t3 = t1 + t2

  might as well be

  t1 = x + y

  if the expression-translation recognizes the special case where its operands are terminals

# Redundant temporaries

- Temporary vars. have limited lifespan:

  t1 = 1
  t2 = 2
  t3 = 1 + 2
  **t4 = 6**
  **t5 = 7**
  **t6 = t4 + t5**

  might as well re-use t1, t2

  t1 = 6
  t2 = 7
  t4 = t1 + t2

  when their work is done.
- Pro: less space
- Con: less *precise* analyses at optimization

↑

We'll return to what this means

# Jumps to unconditional jumps

If a then if b then c=d else e=f else g=h

```
becomes
ifFalse a goto L1
    ifFalse b goto L2
        c=d
    jump Lend2
    L2:
        e=f
    Lend2:
jump Lend1
L1:
    g = h
Lend1:
```

# This may as well shortcut

If a then if b then c=d else e=f else g=h

```
ifFalse a goto L1
    ifFalse b goto L2
        c=d
    jump Lend1
    L2:
        e=f

jump Lend1
L1:
    g = h
Lend1:
```