CS 516: COMPILERS

Lecture 4

Topics

- Implementing X86lite.

Materials

- lec03.zip (x86lite.ml, runtime.c)

code demo

X86LITE

1. **Implementing X86lite**

```
unzip lec04.zip ; cd lec04/ ; open x86.ml
```

2. **Handcoding X86lite**

   A. Compile main.ml (or something like it) to either native or bytecode
   ```
   cd code; ocamlc x86.ml main.ml -o handcoded.native
   ```
   B. Run it, redirecting the output to some .s file, e.g.:
   ```
   cd .. ; code/handcoded.native > test.s
   ```
   C. Use gcc to compile & link with runtime.c:
   ```
   gcc -arch x86_64 -o test runtime.c test.s
   ```
   D. You should be able to run the resulting exectuable:
   ```
   ./test
   ```

Needed on some architectures

- Some compilers/architectures need "program" rather than "_program"
- If you want to debug in gdb, call gcc with the –g flag too

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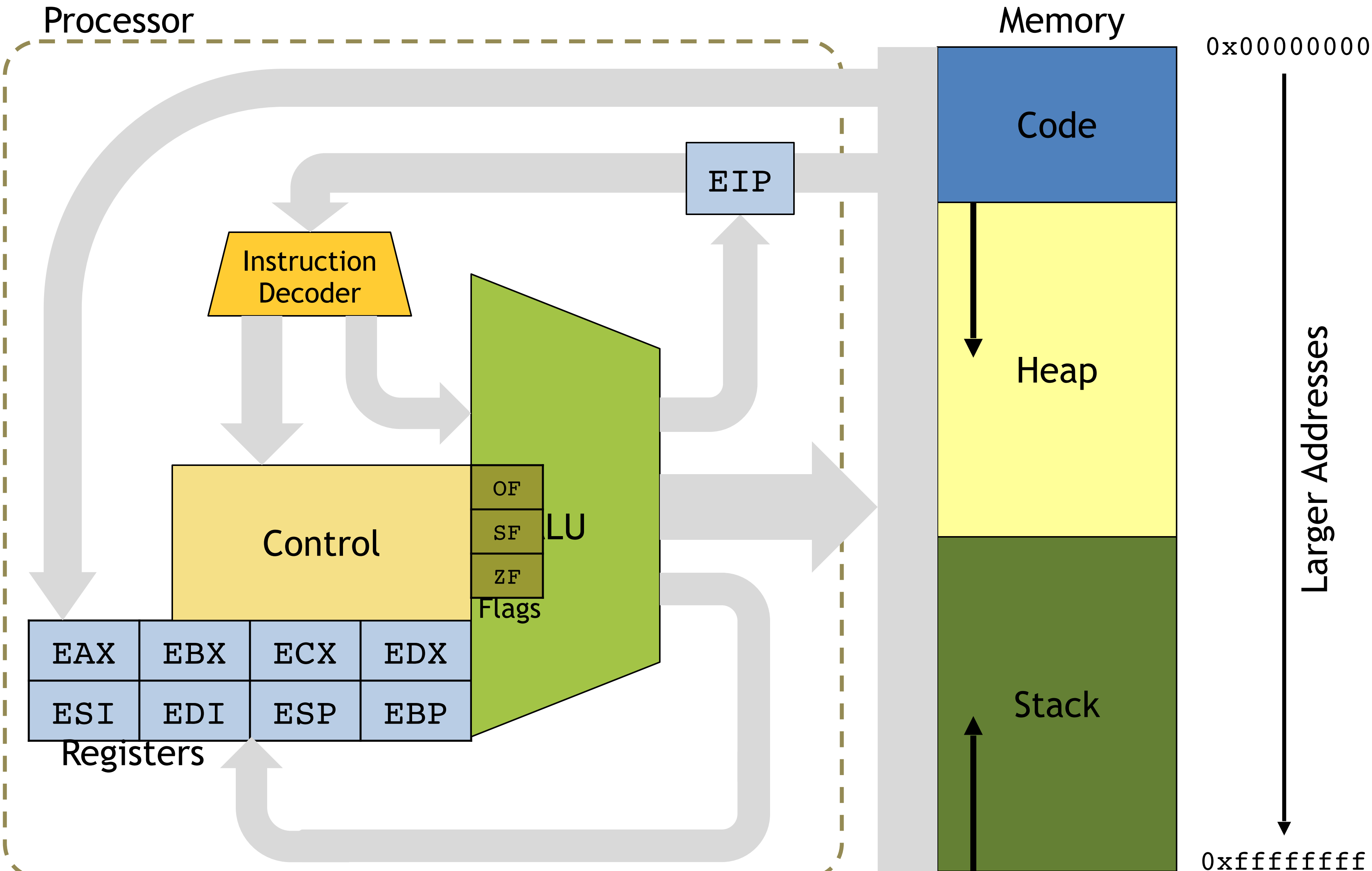
```
make && make test && make run
```

X86 Schematic

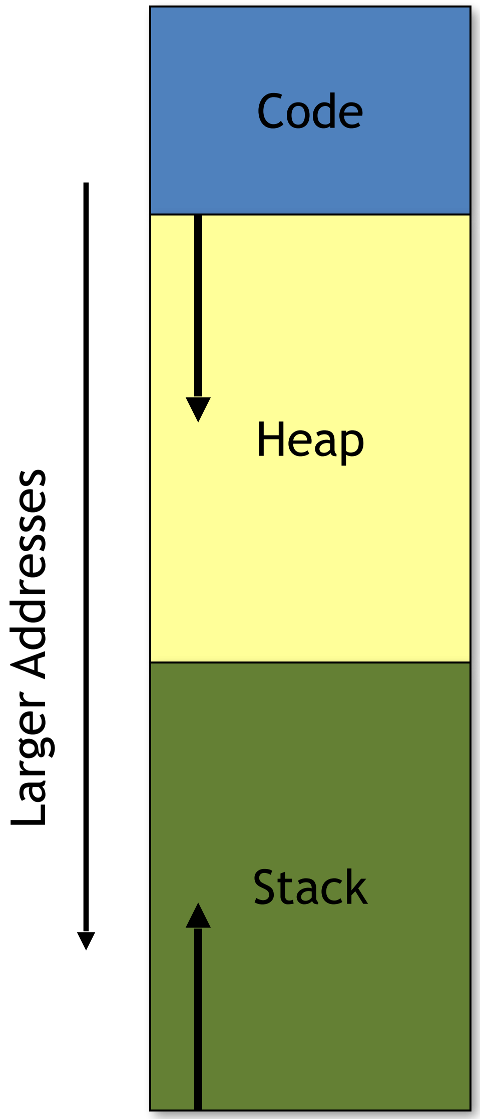


PROGRAMMING IN X86LITE

3 parts of the C memory model

- The code & data (or "text") segment
  - contains compiled code, constant strings, etc.
- The Heap
  - Stores dynamically allocated objects
  - Allocated via "malloc"
  - Deallocated via "free"
  - C runtime system
- The Stack
  - Stores local variables
  - Stores the return address of a function

- In practice, most languages use this model.



Local/Temporary Variable Storage

- Need space to store:
  - Global variables
  - Values passed as arguments to procedures
  - Local variables (either defined in the source program or introduced by the compiler)

- Processors provide two options
  - Registers: fast, small size (32 or 64 bits), very limited number
  - Memory: slow, very large amount of space (2 GB)

- In practice on X86:
  - Registers are limited (and have restrictions)
  - Divide memory into regions including the *stack* and the *heap*

Calling Conventions

- Specify the locations (e.g. register or stack) of arguments passed to a function and returned by the function
- Designate registers either:
  - Caller Save
    - Caller responsible for saving – e.g. freely usable by the called code
  - Callee Save
    - Callee responsible for saving – e.g. must be restored by the called code
- Define the protocol for deallocating stack-allocated arguments
  - Caller cleans up
  - Callee cleans up (makes variable arguments harder)

32-bit cdecl calling conventions

- "Standard" on X86 for many C-based operating systems (i.e. almost all)
  - Still some wrinkles about return values (e.g. some compilers use `EAX` and `EDX` to return small values)
  - 64 bit allows for packing multiple values in one register
- Arguments are passed on the stack in right-to-left order
- Return value is passed in `EAX`
- Registers `EAX`, `ECX`, `EDX` are caller save
- Other registers are callee save
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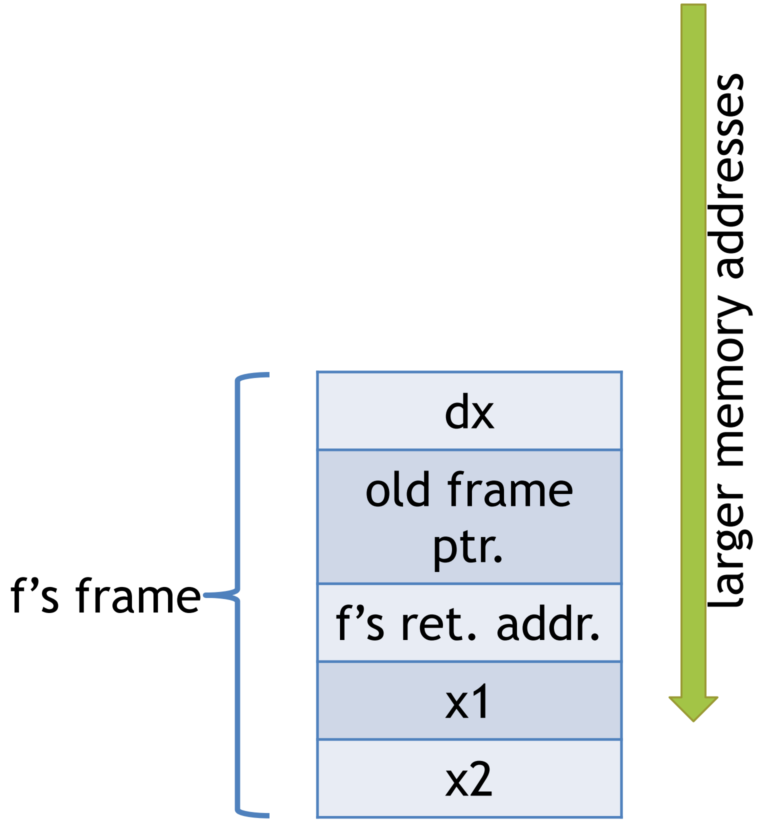
Rationale:
- Most functions may only need to use a few registers.
- Caller doesn't need to save lots of things for no reason.
- If callee needs more space, can do so by saving other registers and

Call Stacks: Example

- Use a stack to keep track of the return addresses:
  - `f` calls `g`, `g` calls `h`
  - `h` returns to `g`, `g` returns to `f`

- Stack frame:
  - Functions arguments
  - Local variable storage
  - Return address
  - Link (or “frame”) pointer



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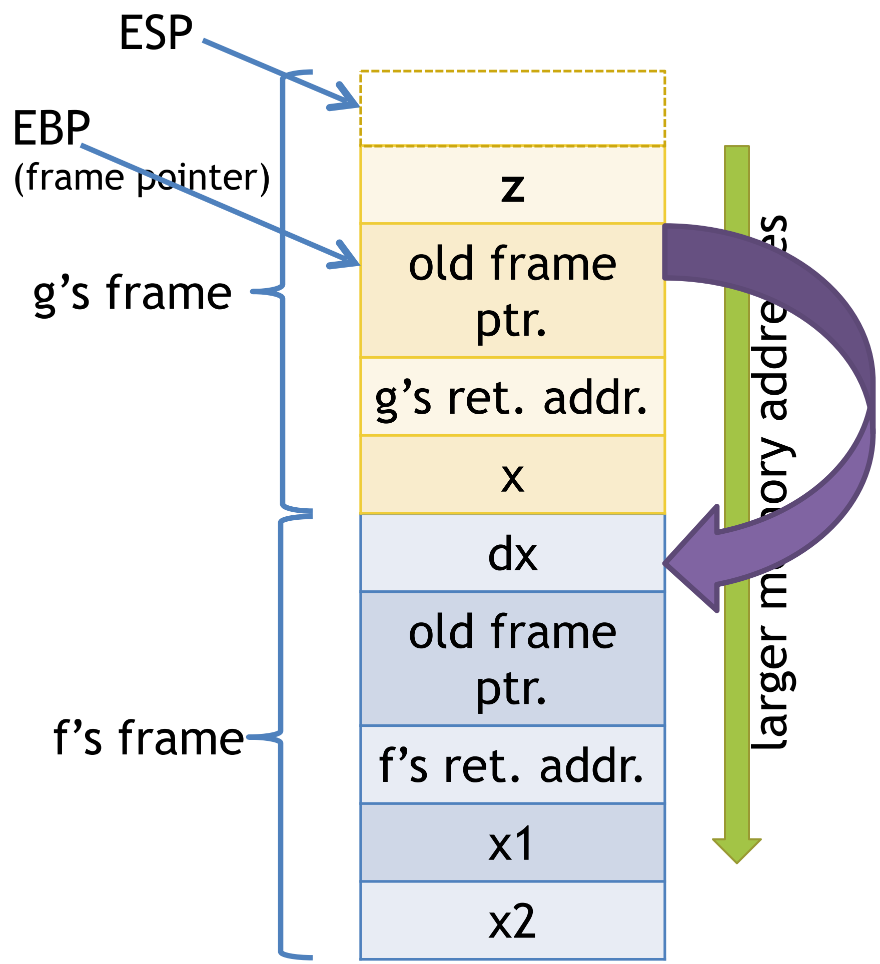
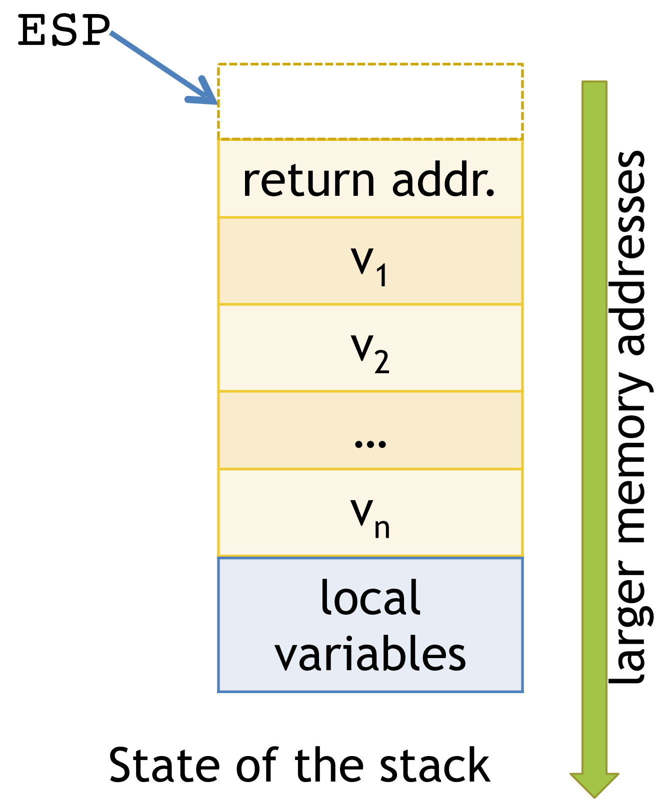


Call Stacks: Caller's protocol

- **Function call**:

  `f(e1, e2, …, en);` — i.e. $f(e_1, e_2, \ldots, e_n)$;

1. Save caller-save registers
2. Evaluate e_1 to v_1, e_2 to v_2, … , e_n to v_n
3. Push v_n to v_1 onto the top of the stack.
4. Use `Call` to jump to the code for `f`
   - pushing the return address onto the stack.



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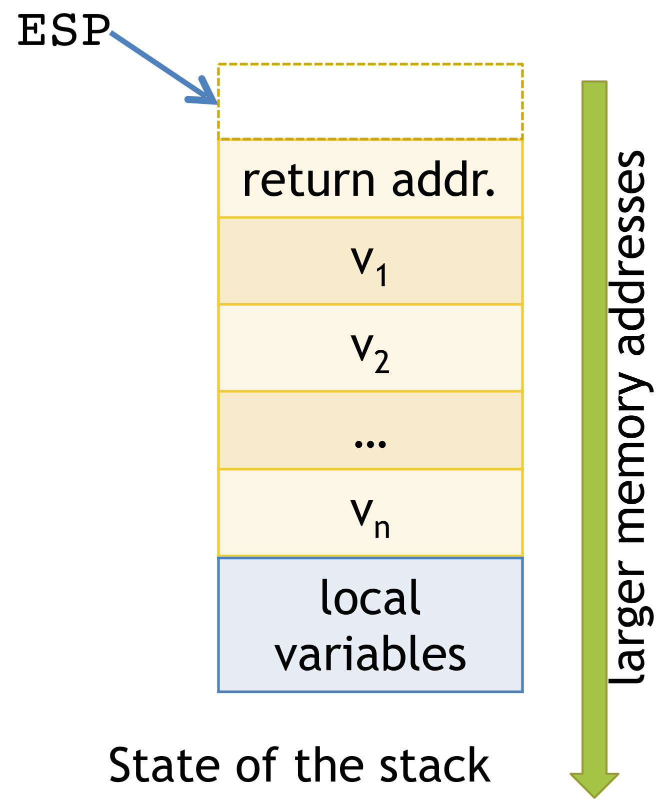
4. Use `Call` to jump to the code for `f`
   – pushing the return address onto the stack.

- **Invariant**: returned value passed in `EAX`

- **After call**:

1. clean up the pushed arguments by popping the stack.
2. Restore caller-saved registers



State of the stack just after the Call instruction:

Call Stacks: Callee's protocol

- On entry:

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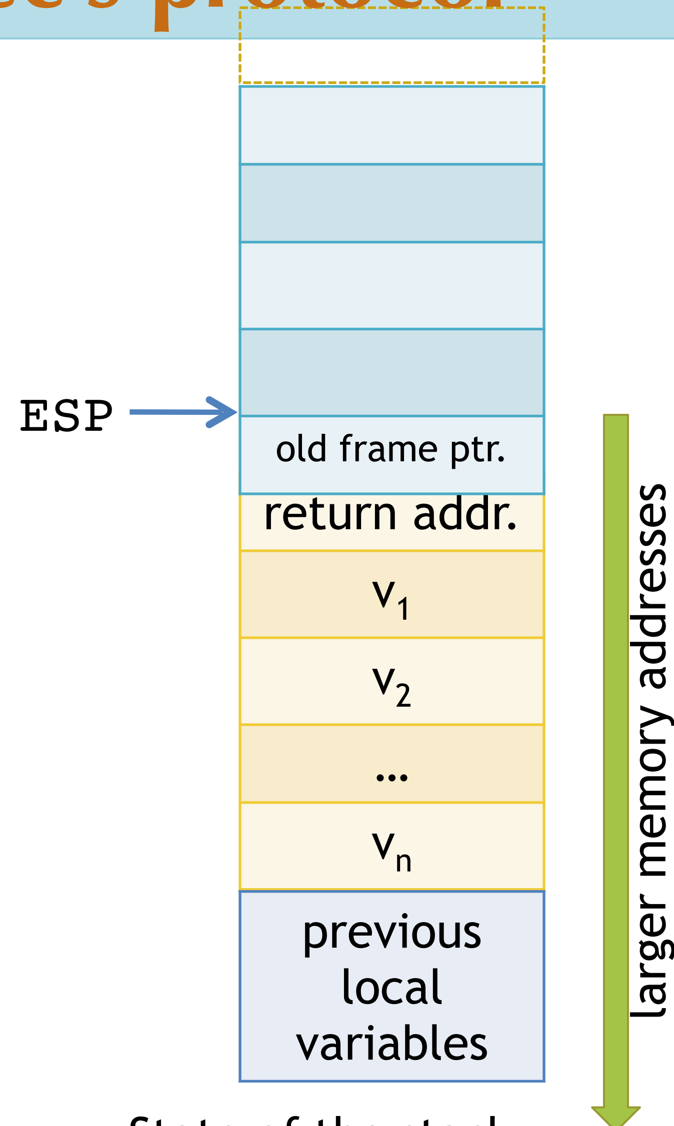
   - EBP is callee save



State of the stack after Step 3 of entry.

Call Stacks: Callee's protocol

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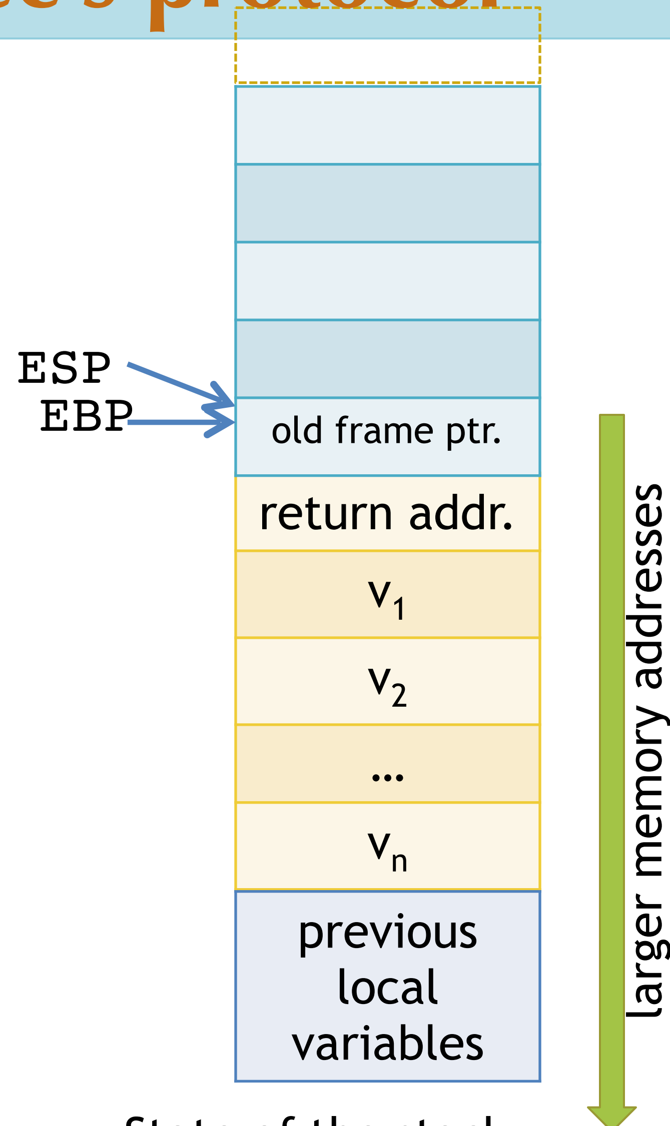
   - Mov(Esp, Ebp)



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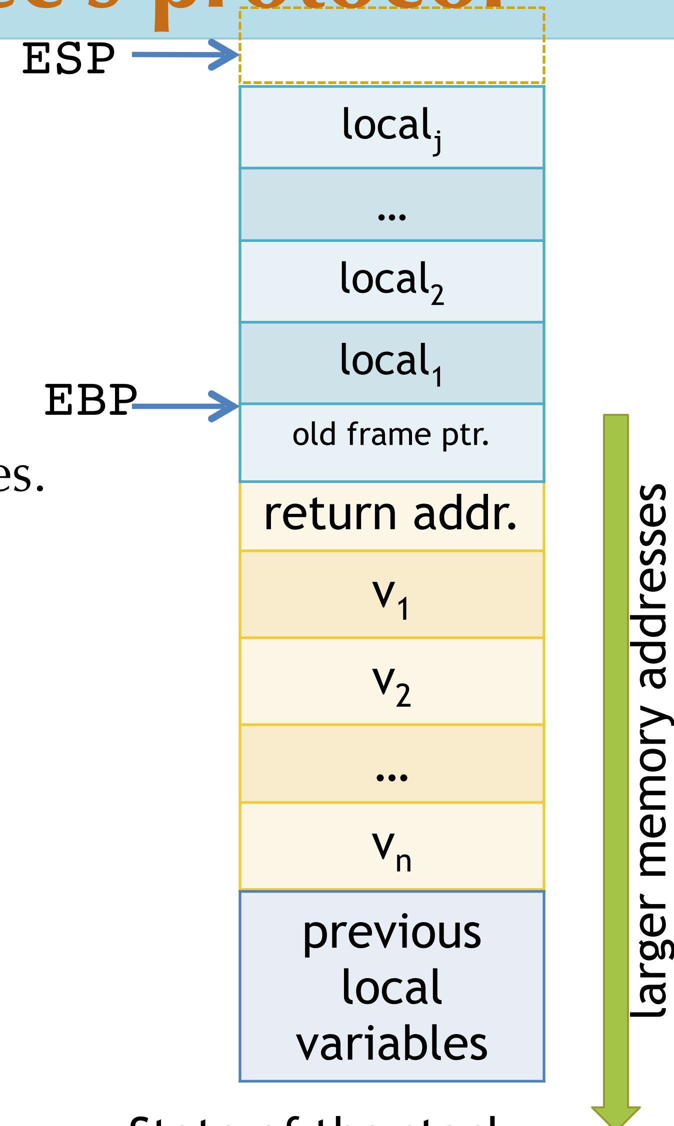

State of the stack after Step 3 of entry.

- On exit:
1. Pop local storage
2. Restore EBP

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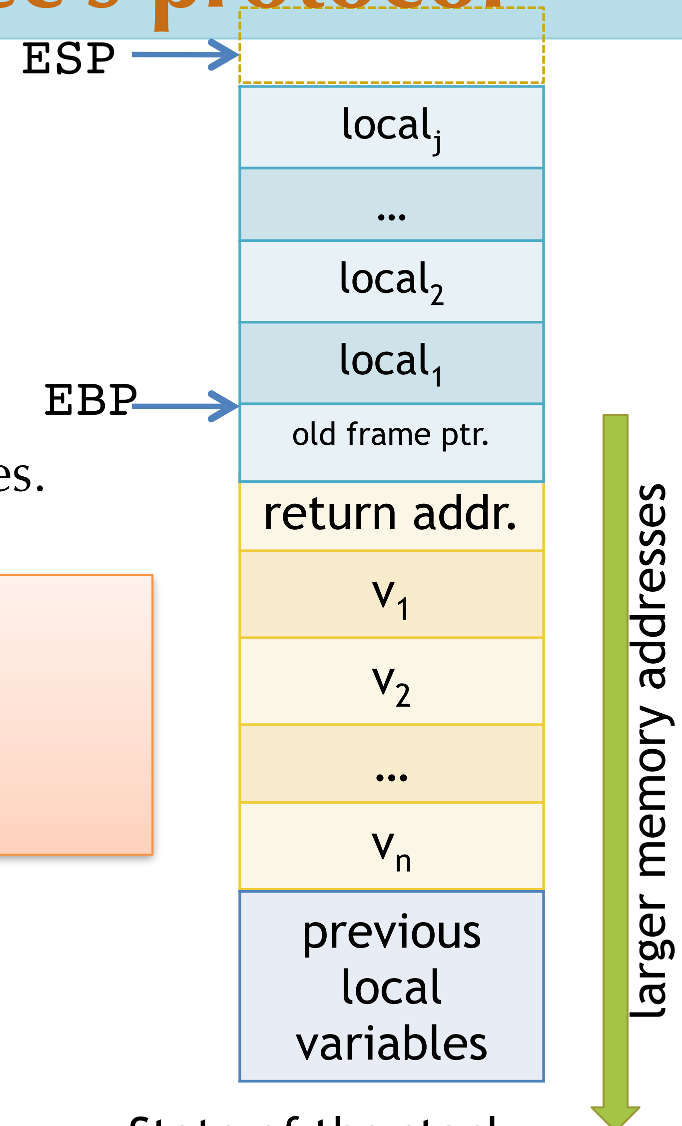
> Invariants: (assuming word-size values)
> Function argument n is located at:
> EBP + (1 + n) * 4
> Local variable j is located at:
> EBP - j * 4

- On exit:

1. Pop local storage
2. Restore EBP



State of the stack after Step 3 of entry.

X86-64 SYSTEM V AMD 64 ABI

- More modern variant of C calling conventions
  - used on Linux, Solaris, BSD, OS X
- Callee save: `rbp, rbx, r12-r15`
- Caller save: all others
- Parameters 1 .. 6 go in: `rdi, rsi, rdx, rcx, r8, r9`
- Parameters 7+ go on the stack (in right-to-left order)
  - so: for n > 6, the nth argument is located at ((n-7)+2)*8 + rbp
- Return value: in `rax`
- 128 byte "red zone" – scratch pad for the callee's data

X86-64 SYSTEM V AMD 64 ABI

```
int64_t ret = program(x1, x2, x3, x4, x5, x6, x7, x8);
```

```
movq %rax, -80(%rbp)
movq -24(%rbp), %rdi
movq -32(%rbp), %rsi
movq -40(%rbp), %rdx
movq -48(%rbp), %rcx
movq -56(%rbp), %r8
movq -64(%rbp), %r9
movq -72(%rbp), %rax
movq -80(%rbp), %r10
movq %rax, (%rsp)
movq %r10, 8(%rsp)
callq _program
movq %rax, -88(%rbp)
```

Caller saves rax

Set up parameters 1 .. 6

Copy parameters 7 and 8 from memory to register to stack

Fetch the return value

Callee save: `rbp, rbx, r12-r15`

Caller save: all others