CSE443 Compilers

Dr. Carl Alphonce
alphonce@buffalo.edu
343 Davis Hall

Phases of a compiler

Intermediate Representation (IR): specification and generation

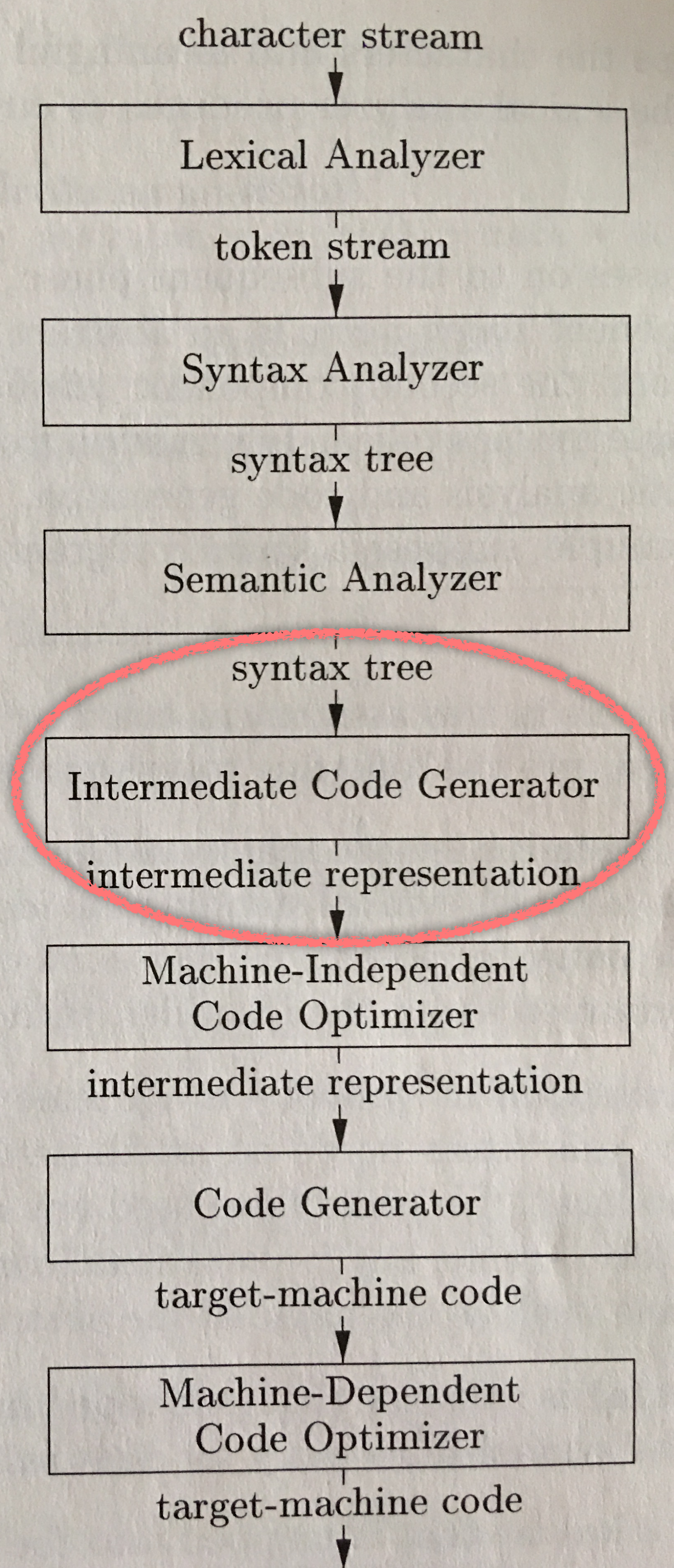


Figure 1.6, page 5 of text

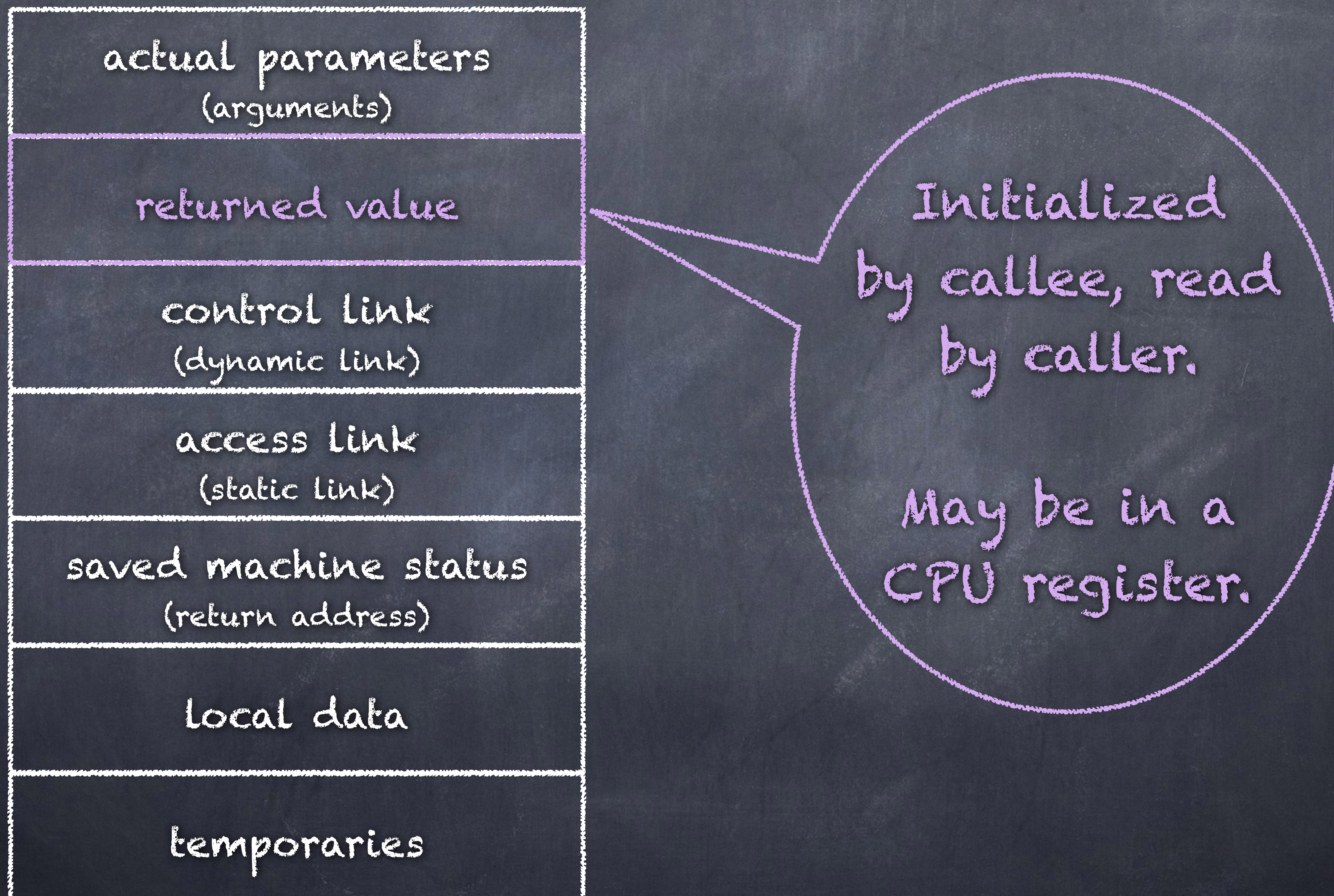
Stack frame organization

- actual parameters (arguments)
- returned value
- control link (dynamic link)
- access link (static link)
- saved machine status (return address)
- local data
- temporaries

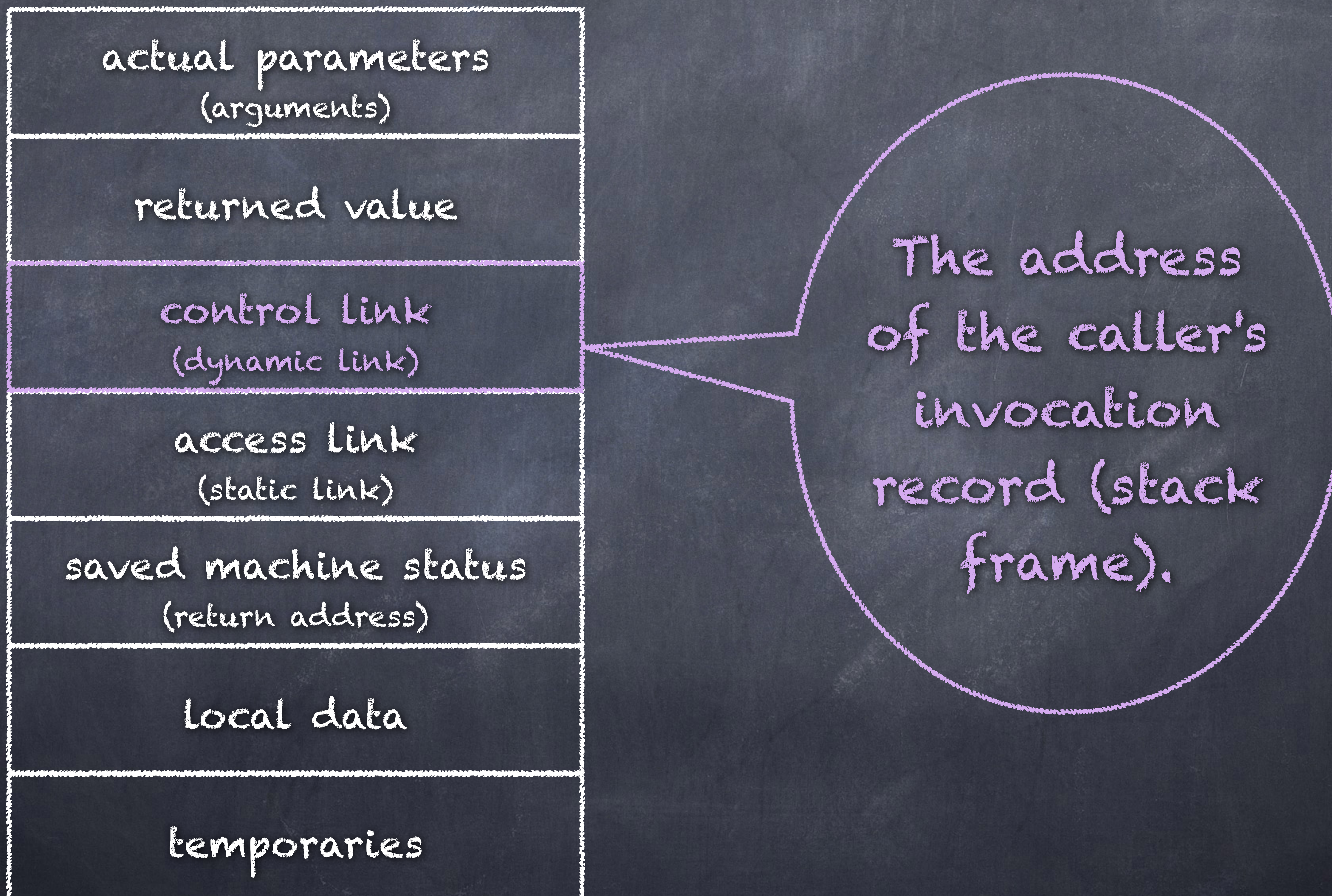
Initialized by caller, used by callee.

May be in CPU registers.

Stack frame organization



Stack frame organization

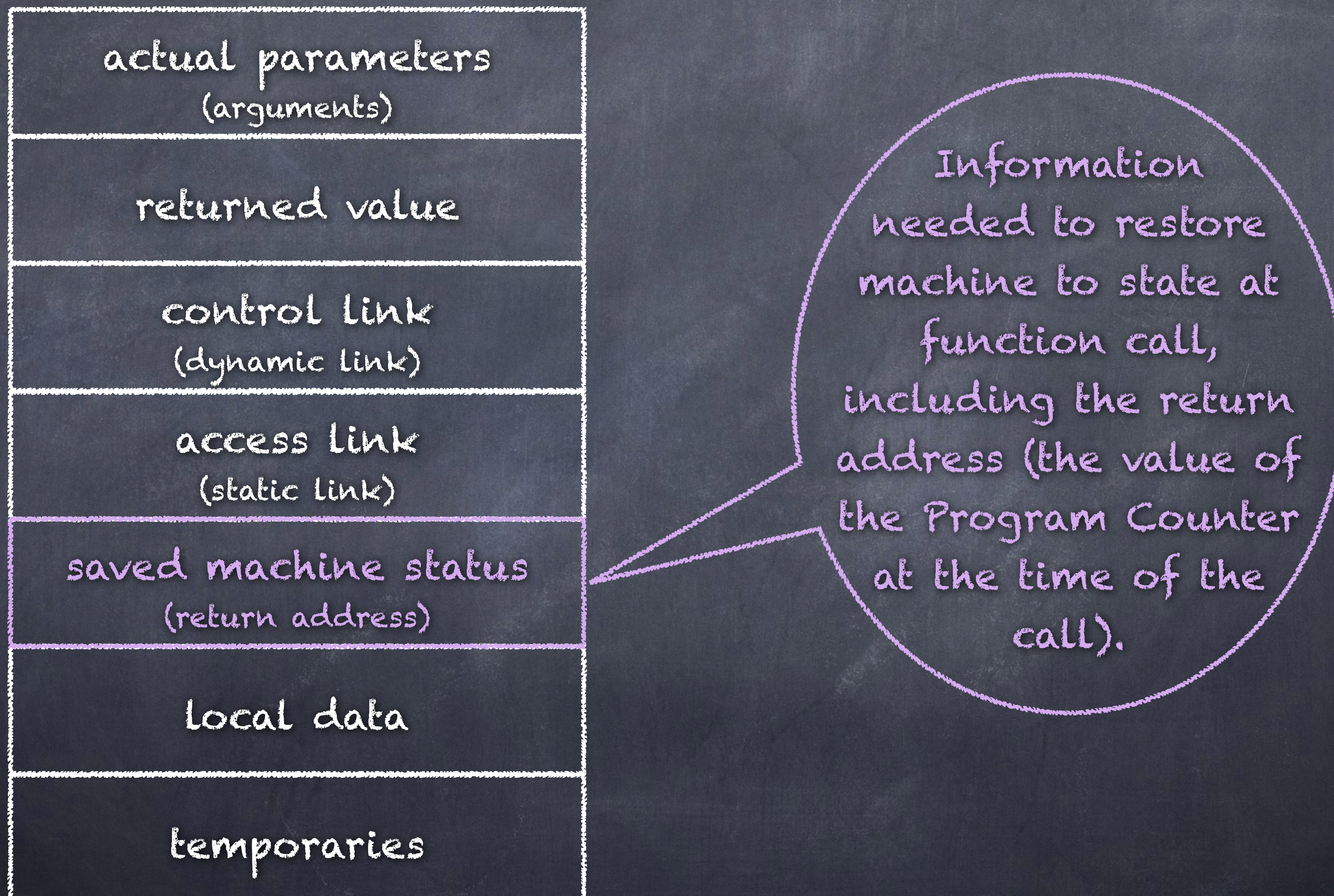


Stack frame organization

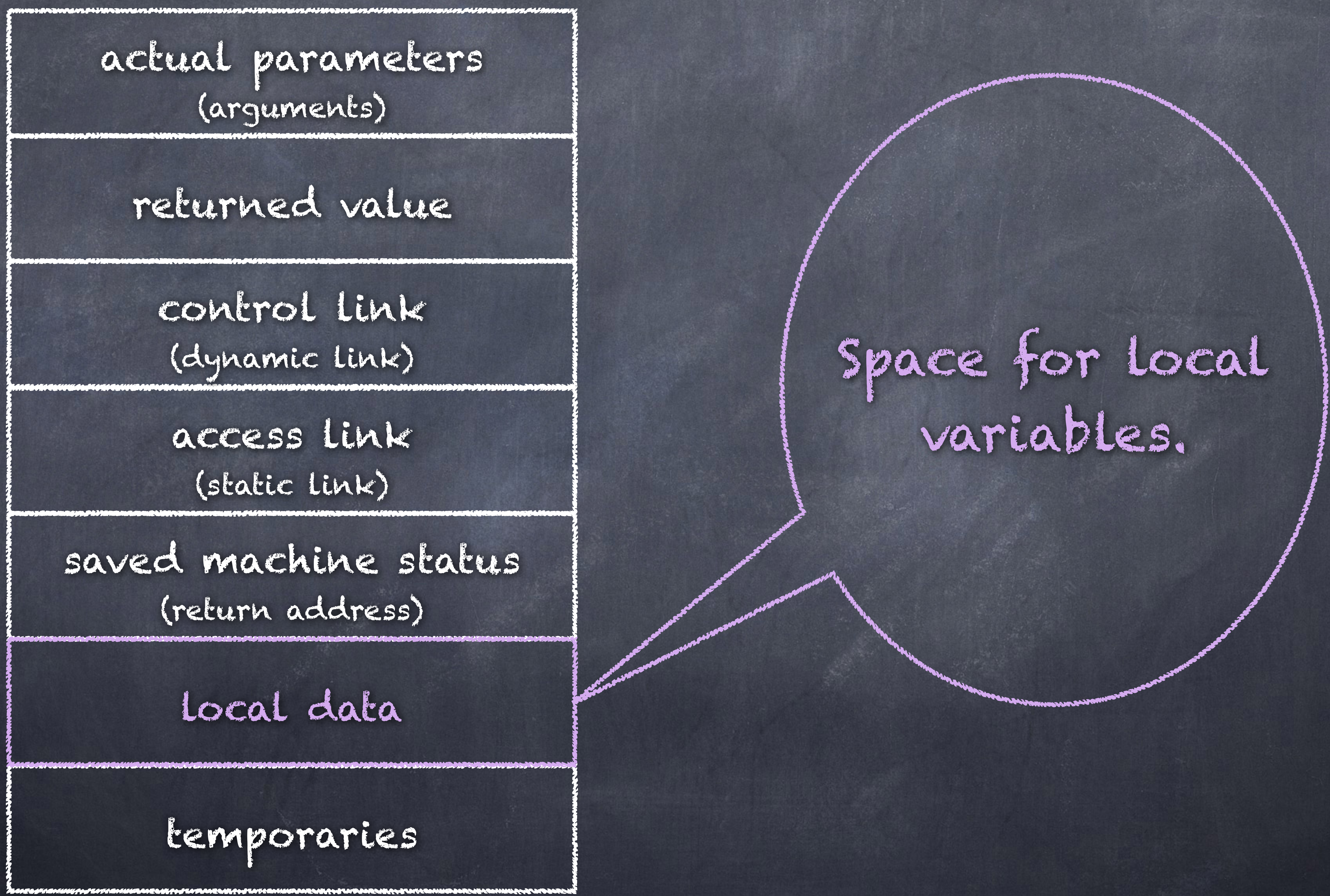
actual parameters (arguments)
returned value
control link (dynamic link)
access link (static link)
saved machine status (return address)
local data
temporaries

> Used to achieve static scope for nested function definitions.
>
> Our language does not use this.
>
> Scheme/ML do.

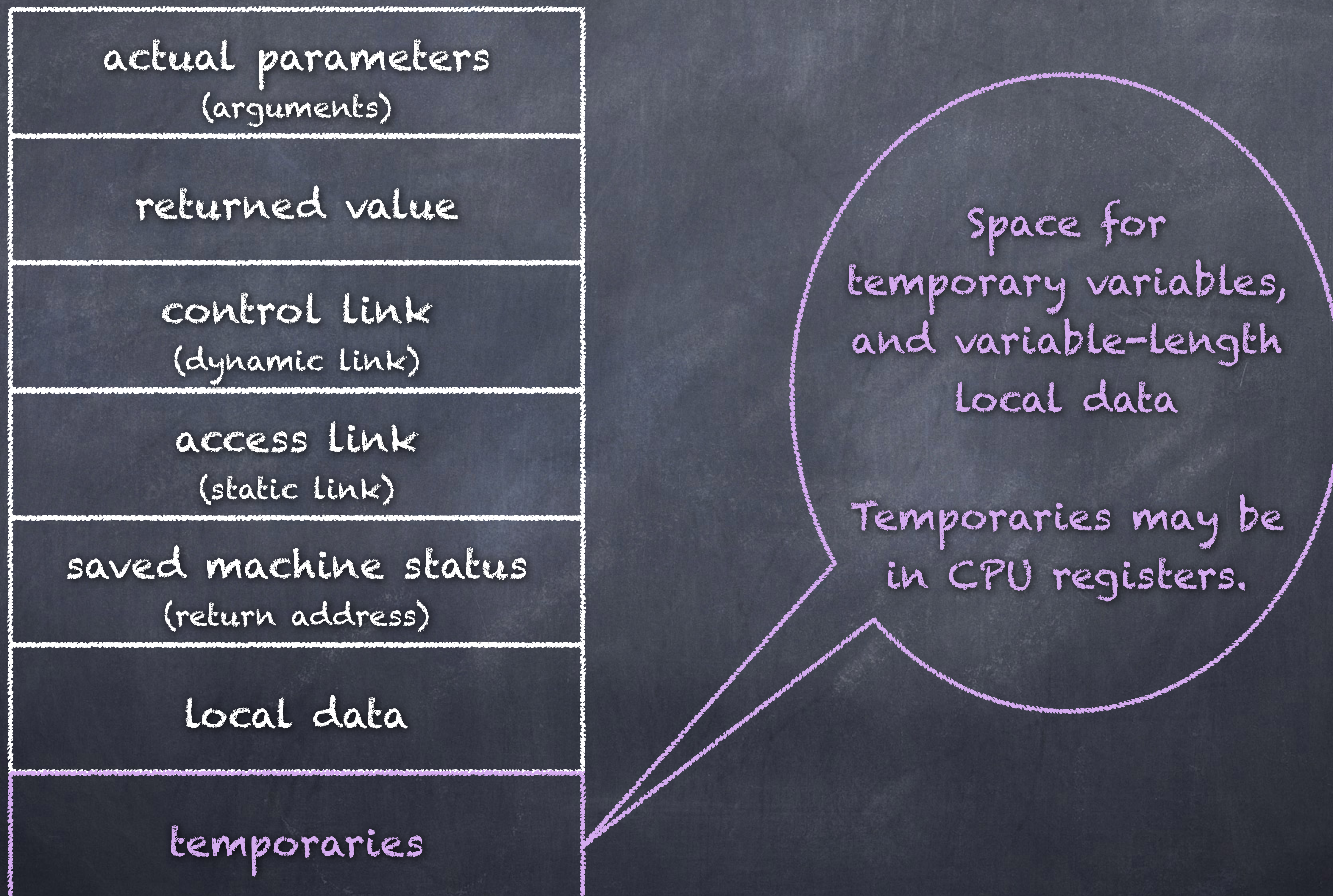
Stack frame organization



Stack frame organization

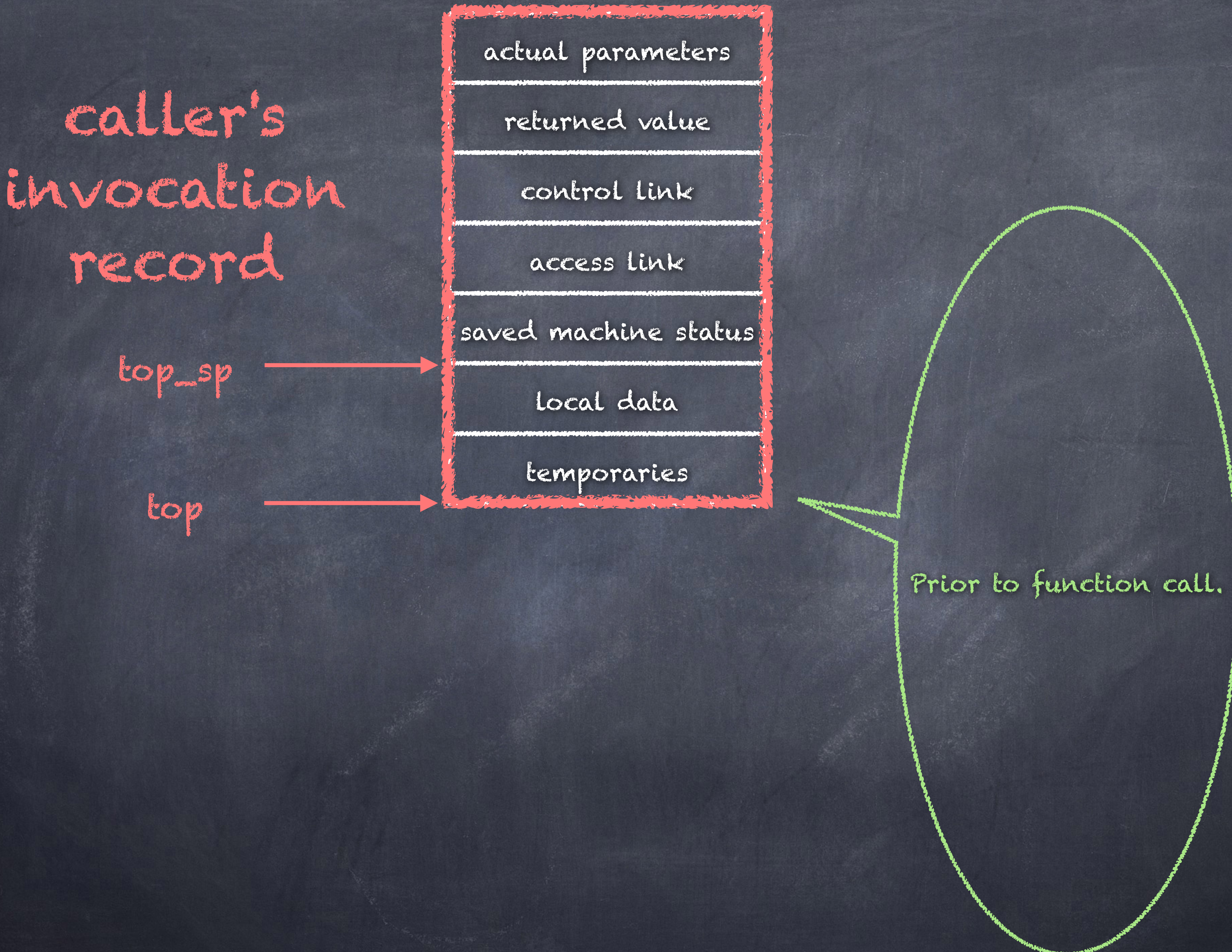


Stack frame organization



7.2.3 Calling Sequence

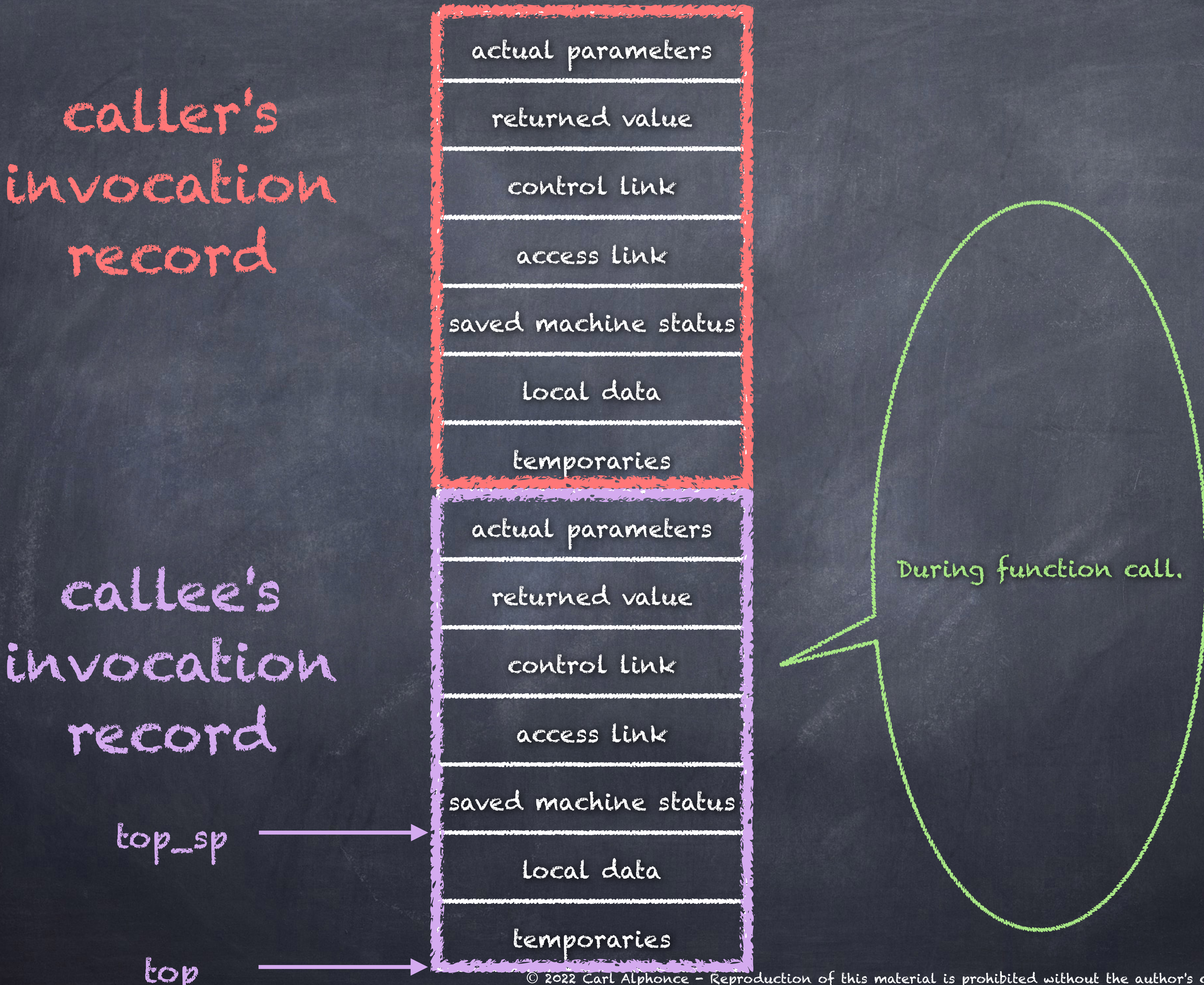
What happens during a function call?


caller's invocation record
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
top_sp
top
Prior to function call.

7.2.3 Calling Sequence

"Procedure calls are implemented by what are known as calling sequences, which consist of code that allocates an activation record on the stack and enters information into its fields."

[p. 436]

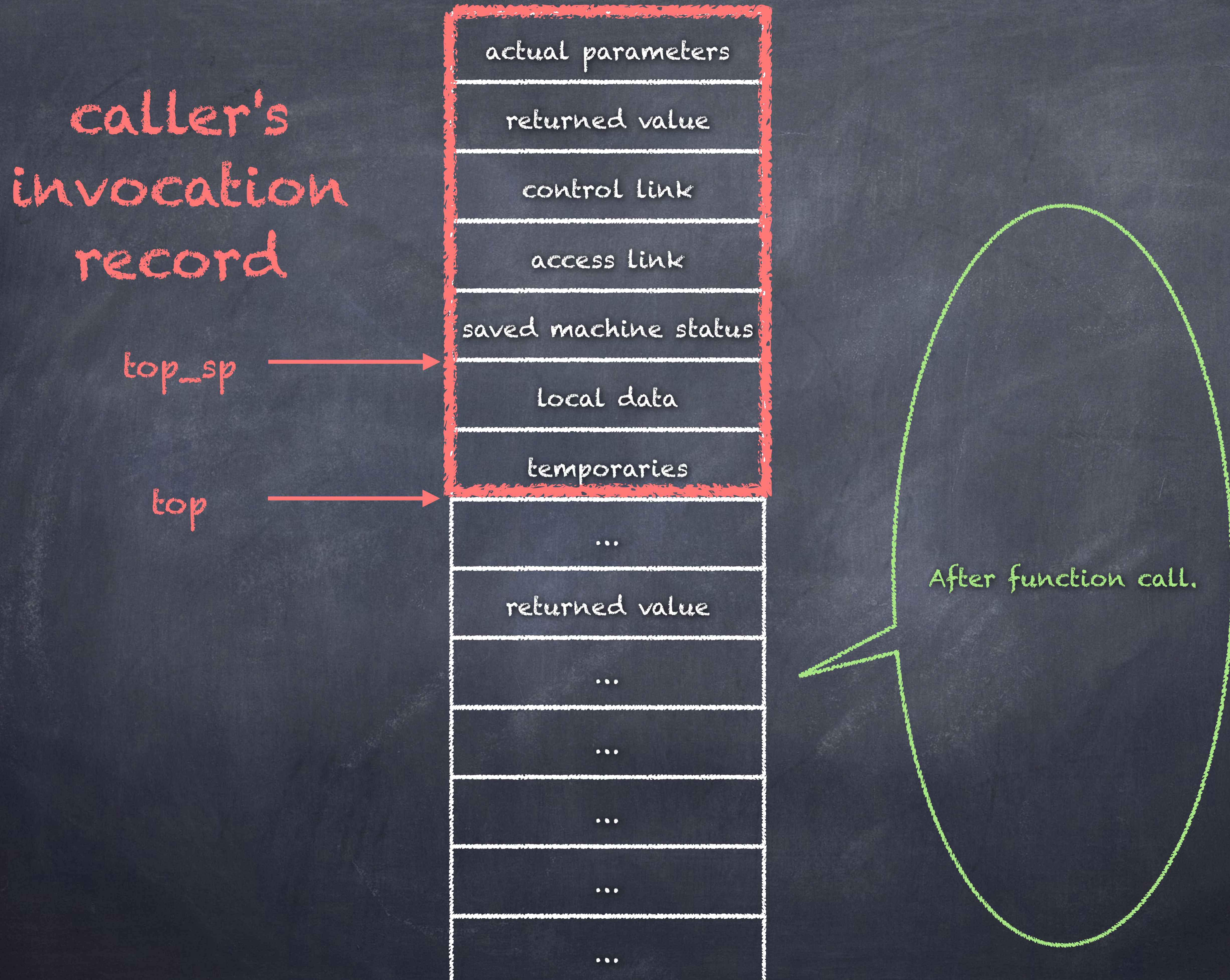


caller's invocation record
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
callee's invocation record
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
top_sp
top
During function call.

7.2.3 Calling Sequence

"A return sequence is similar code to restore the state of the machine so the calling procedure can continue its execution after the call."

[p. 436]


caller's invocation record
actual parameters
returned value
control link
access link
saved machine status
top_sp
local data
temporaries
top
...
returned value
...
...
...
...
...
After function call.

Caller vs Callee responsibilities

"In general, if a procedure is called from n different points, then the portion of the calling sequence assigned to the caller is generated n times. However, the portion assigned to the callee is generated only once."

[p. 436]

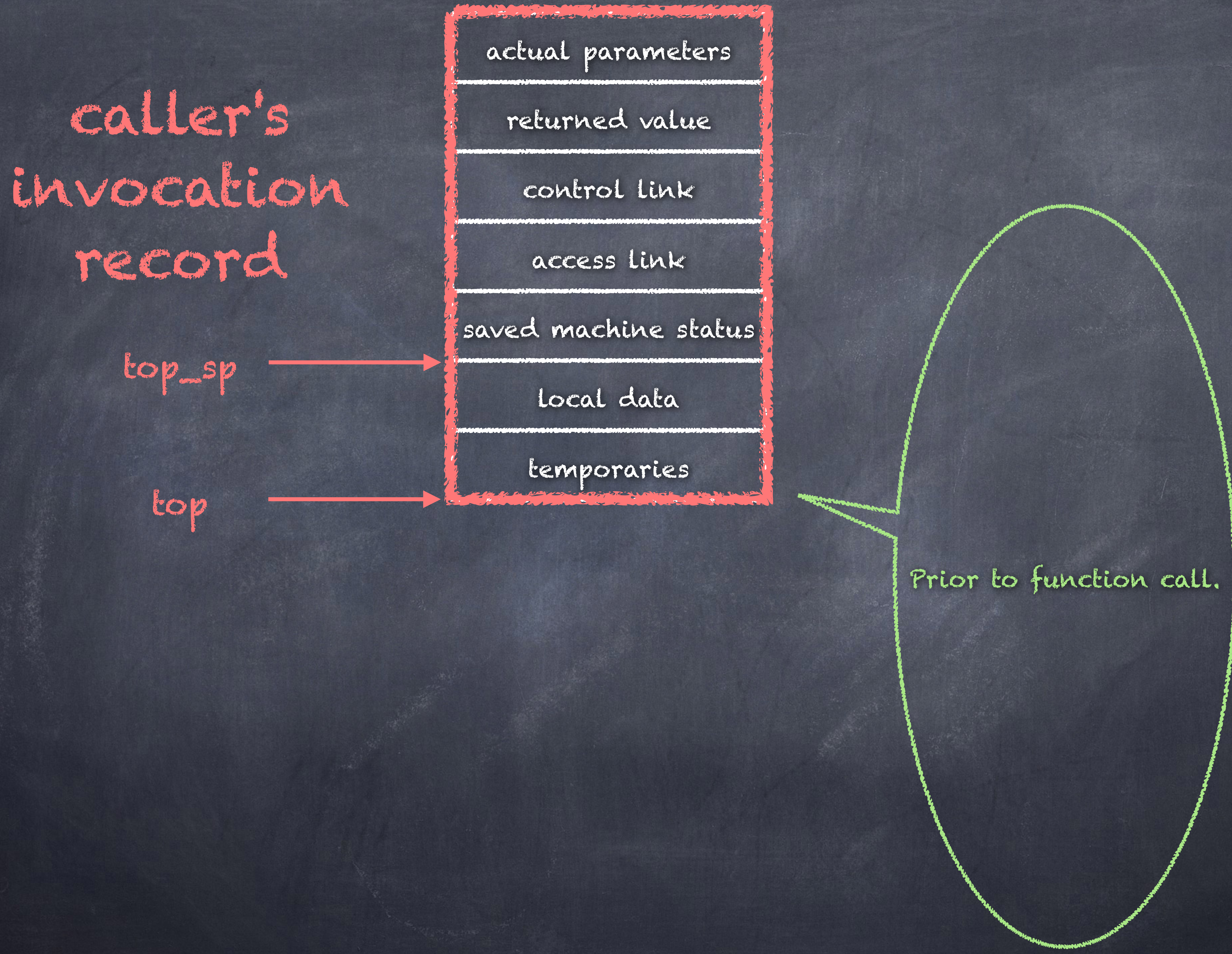
Typical calling sequence [p. 437]

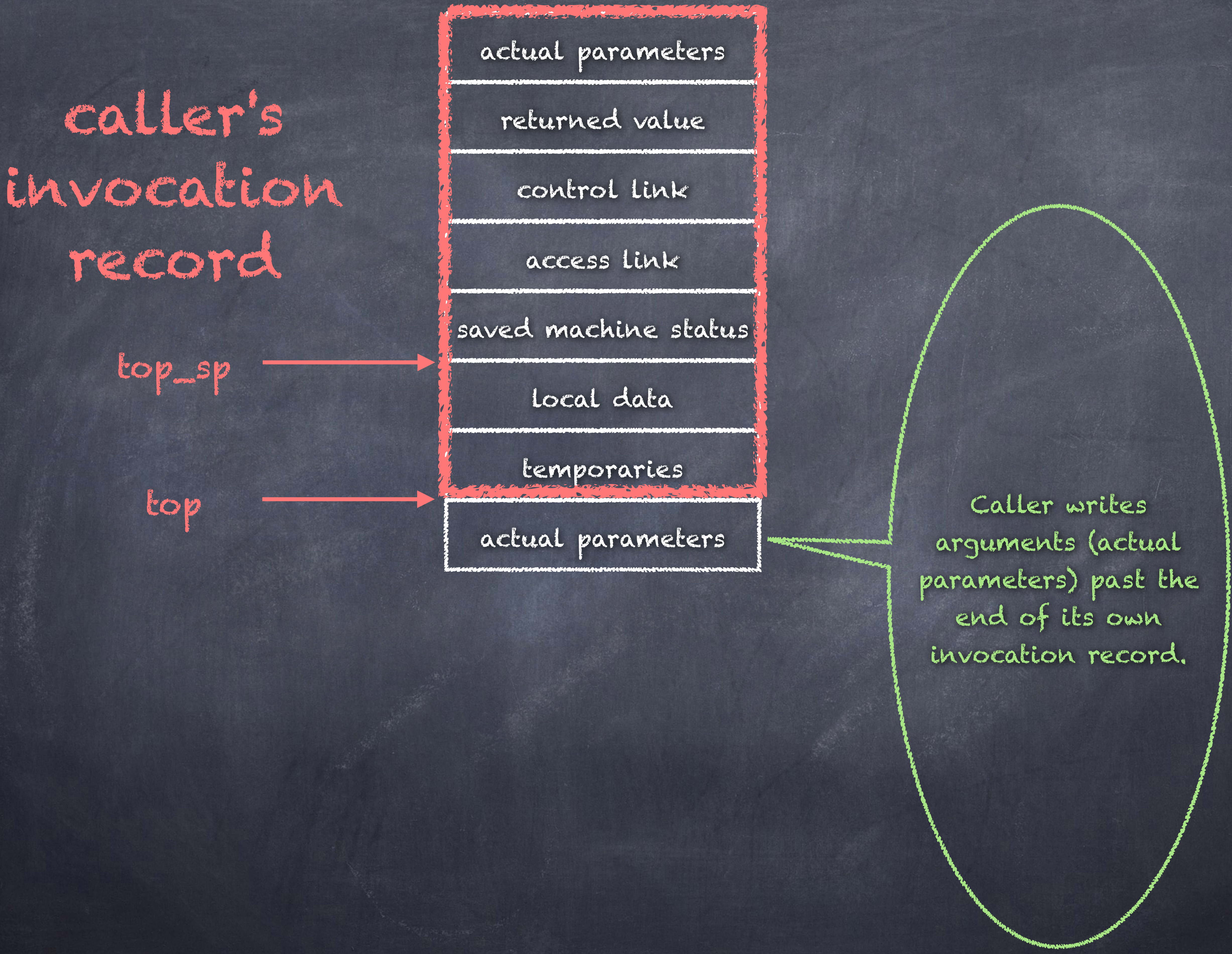
"1. The caller evaluates the actual parameters."

Recall:

formal parameter == parameter

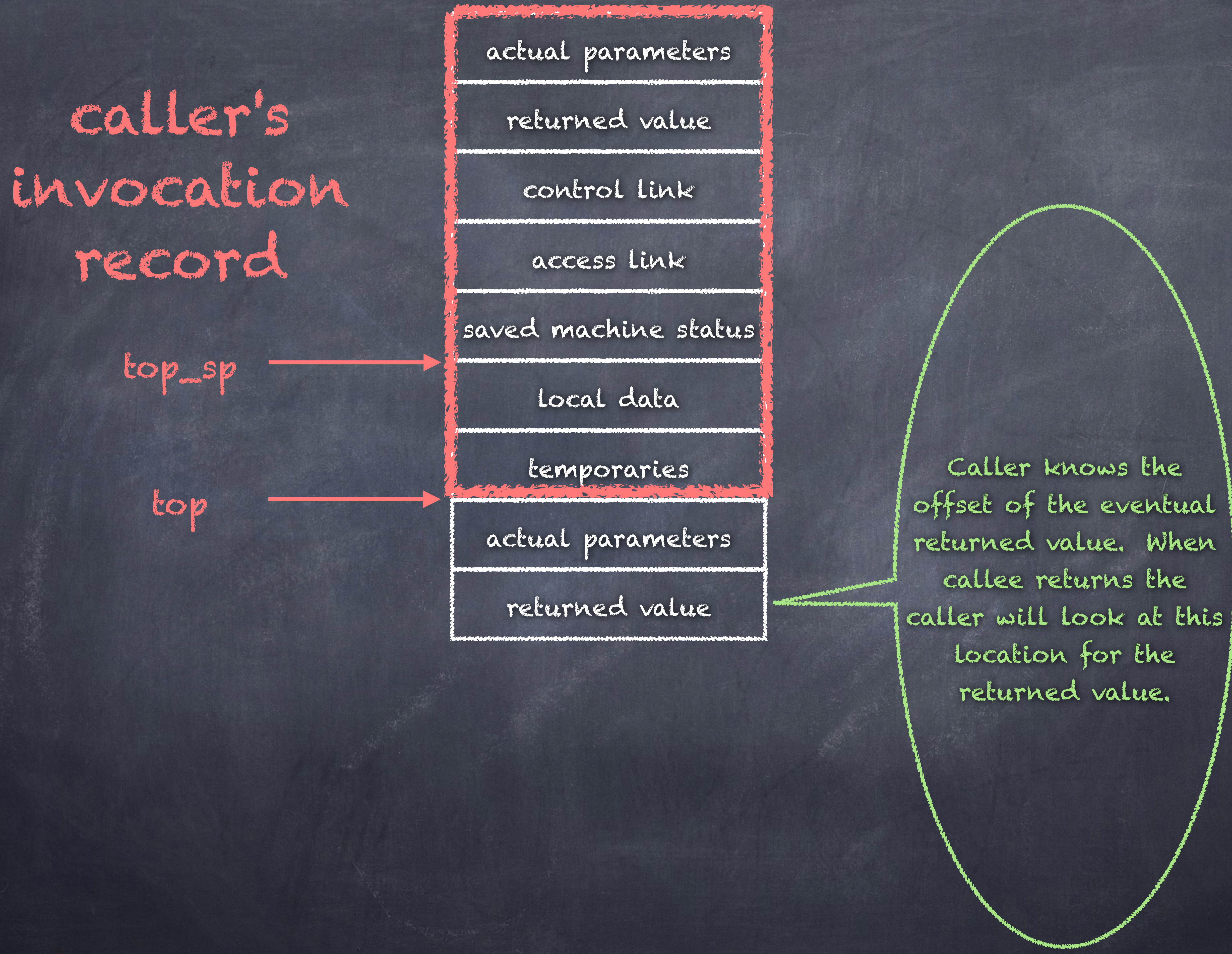
actual parameter == argument


caller's invocation record
top_sp
top
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
Prior to function call.


caller's invocation record
actual parameters
returned value
control link
access link
saved machine status
top_sp
local data
temporaries
top
actual parameters
Caller writes arguments (actual parameters) past the end of its own invocation record.

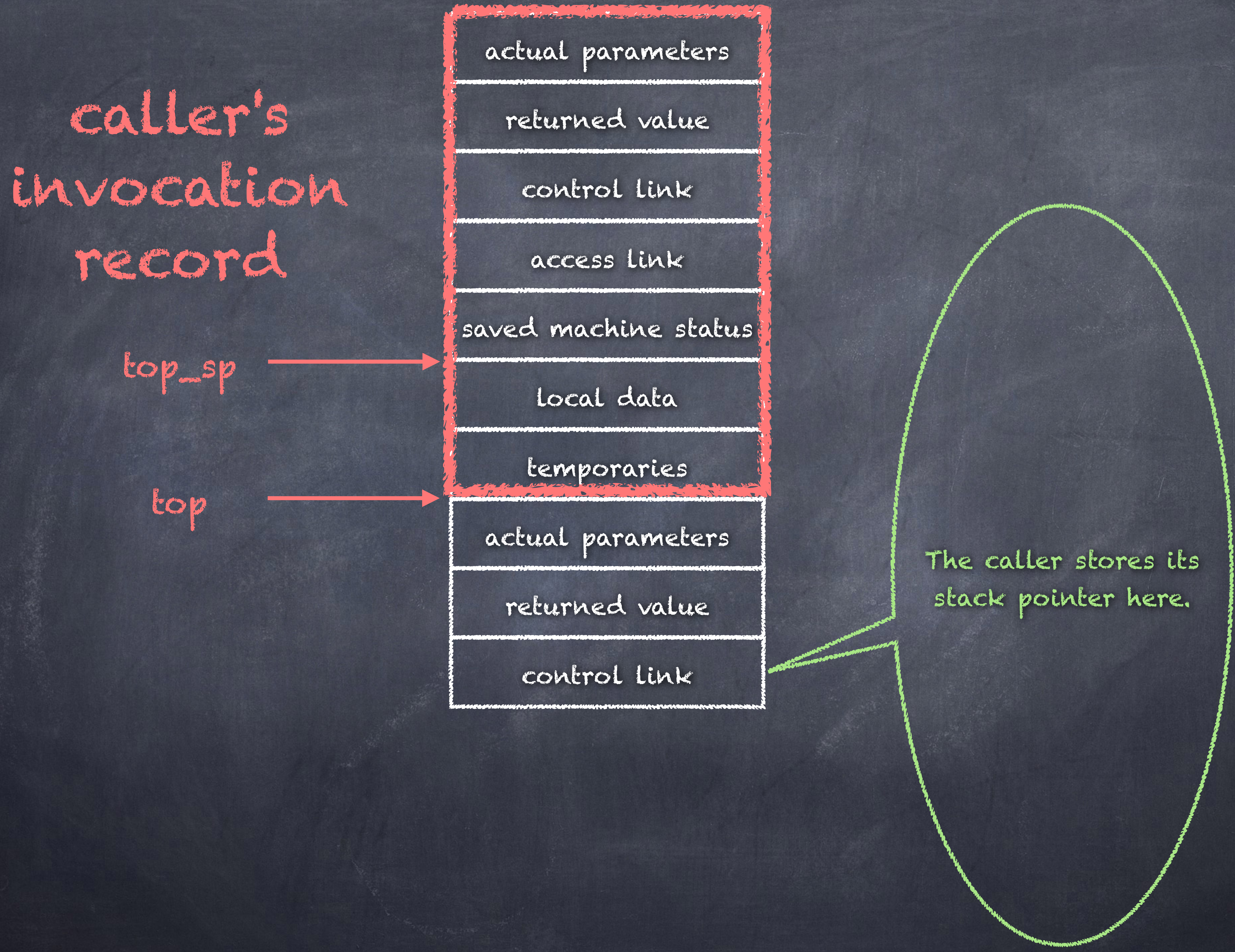
Typical calling sequence [p. 437]

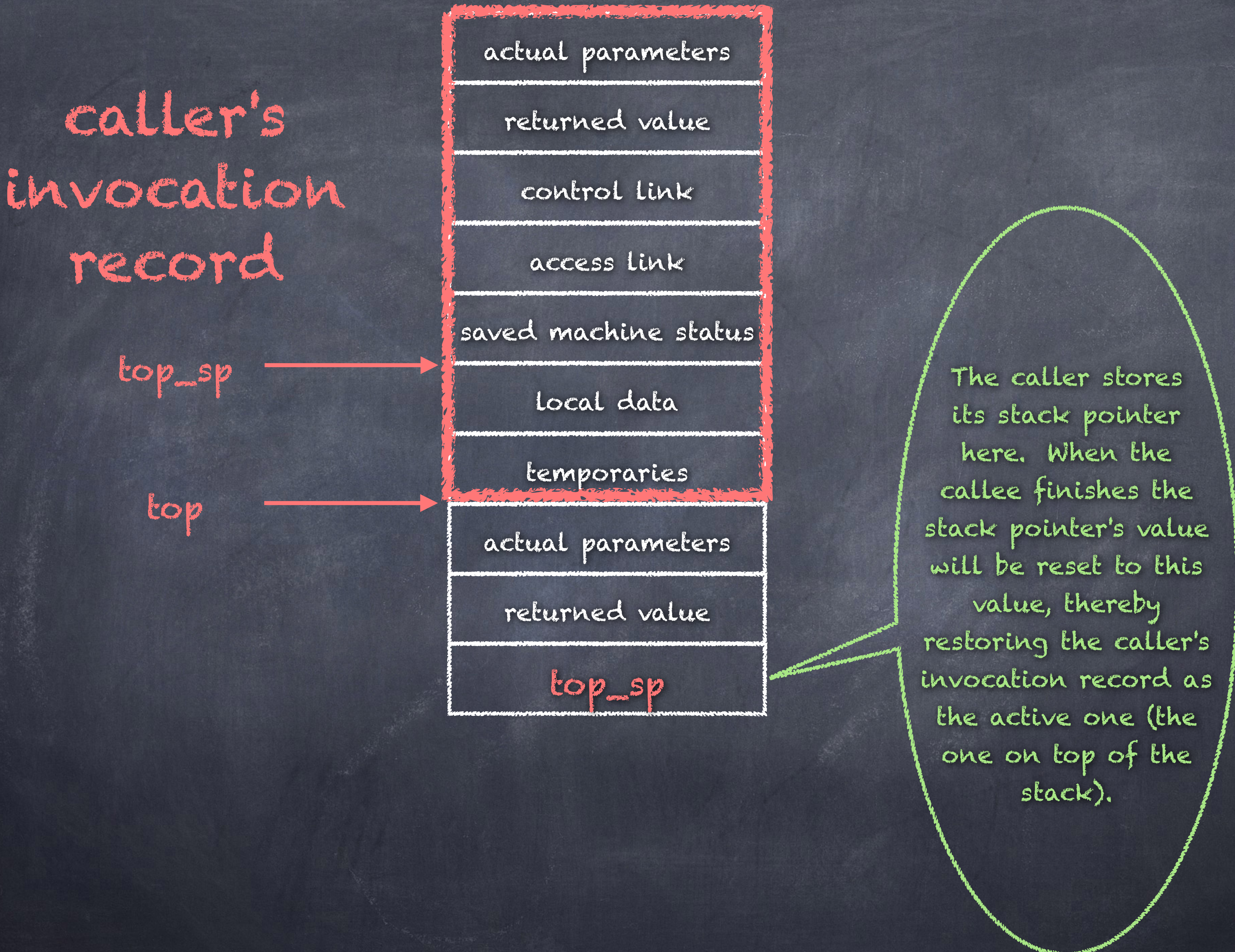
"2. The caller stores a return address and the old value of top_sp into the callee's activation record. The caller then increments top_sp [...] top_sp is moved past the caller's local data and temporaries and the callee's parameters and status fields."


caller's invocation record
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
top_sp
top
actual parameters
returned value
Caller knows the offset of the eventual returned value. When callee returns the caller will look at this location for the returned value.

Typical calling sequence [p. 437]

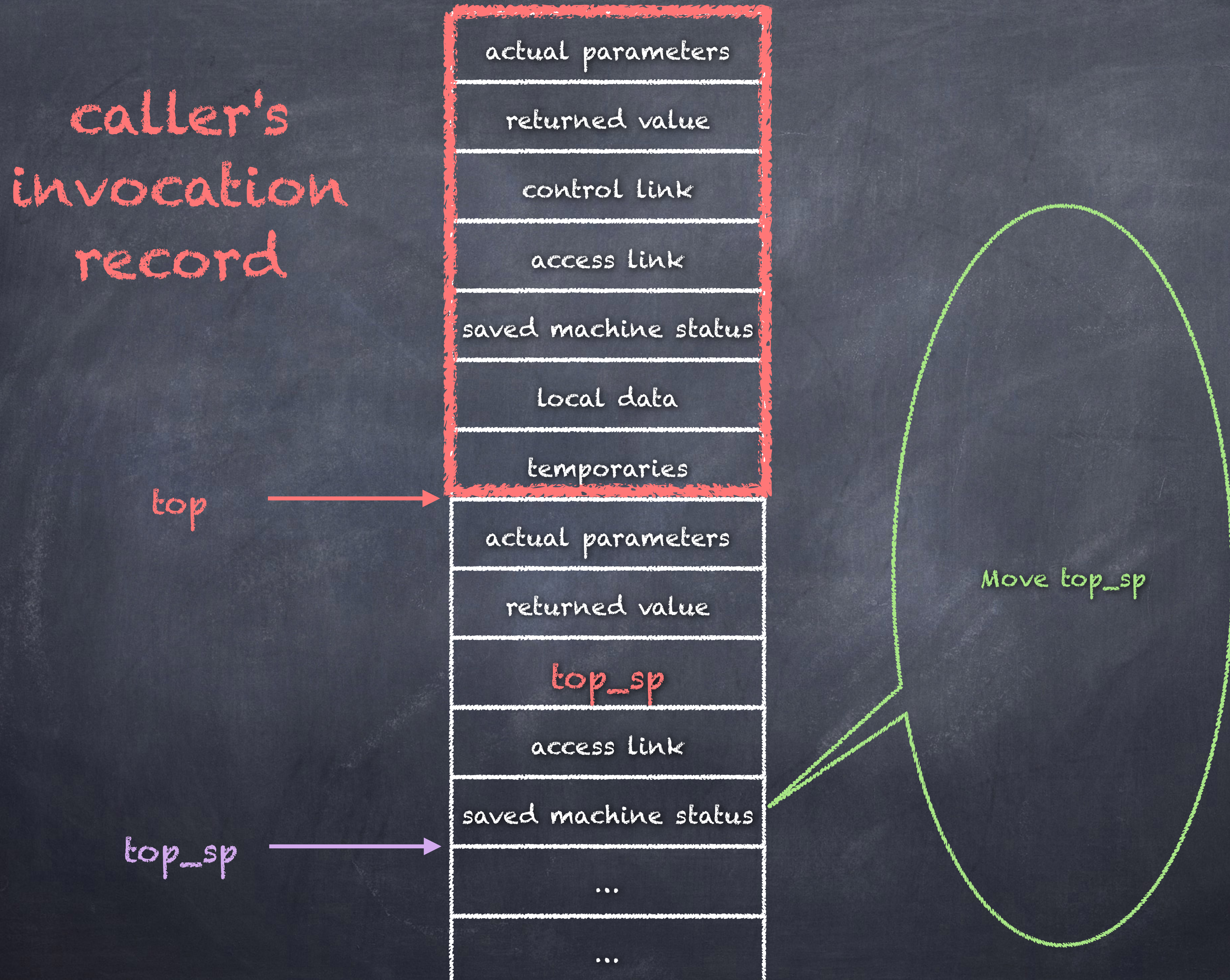
"2. The caller stores a return address and the old value of top_sp into the callee's activation record. … "


caller's invocation record
top_sp
top
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
actual parameters
returned value
control link
The caller stores its stack pointer here.


caller's invocation record
top_sp
top
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
actual parameters
returned value
top_sp
The caller stores its stack pointer here. When the callee finishes the stack pointer's value will be reset to this value, thereby restoring the caller's invocation record as the active one (the one on top of the stack).

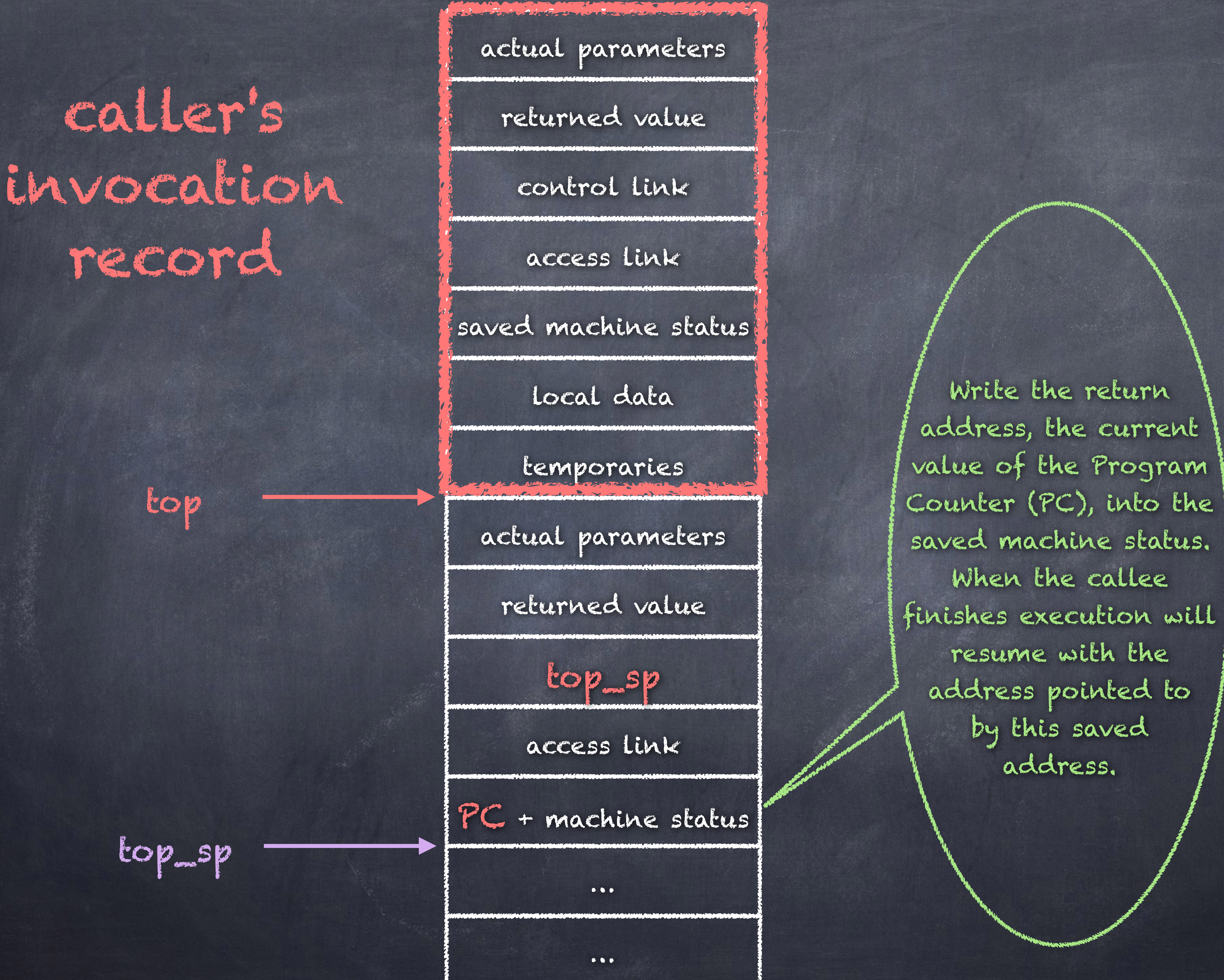
Typical calling sequence [p. 437]

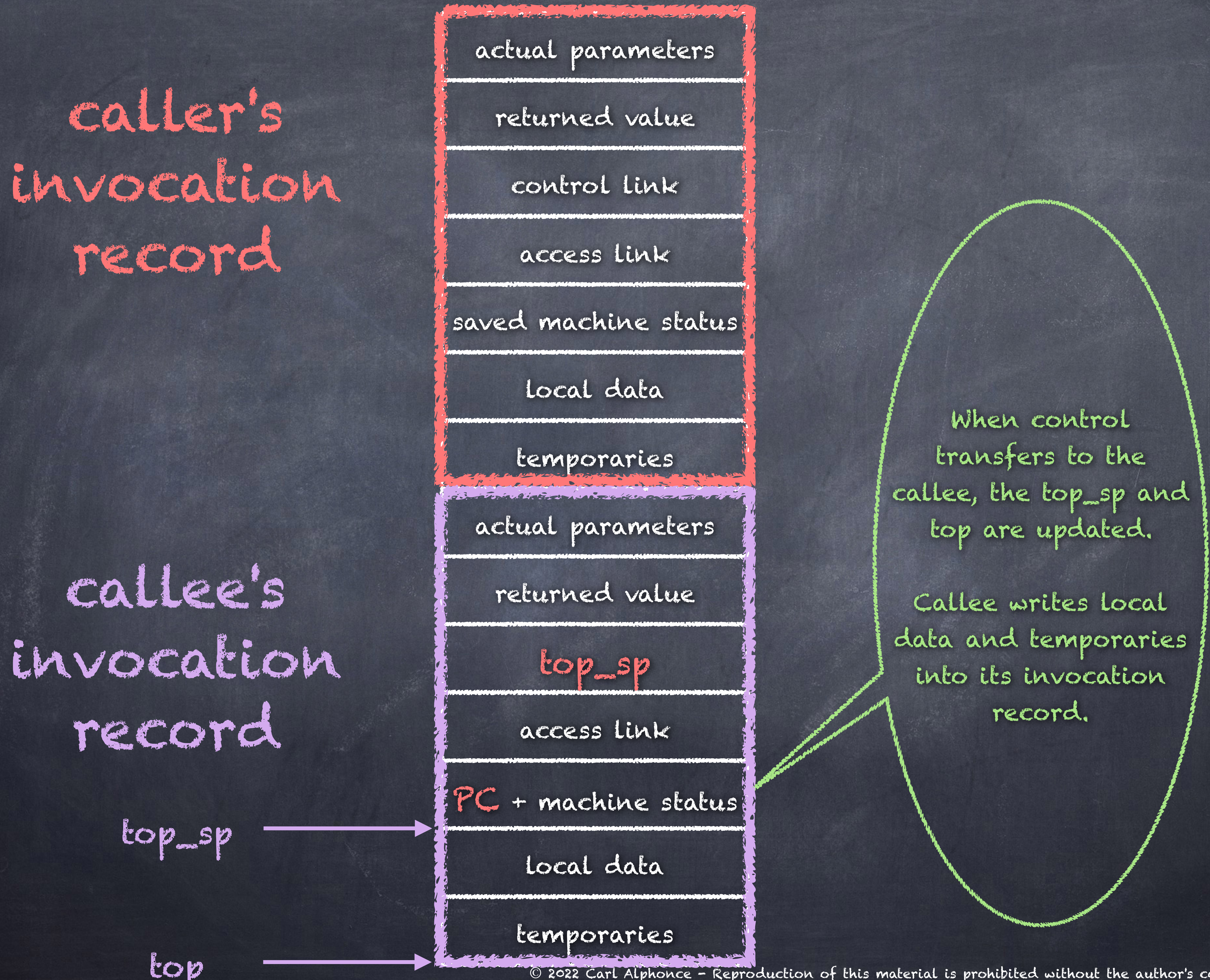
"2. The caller stores a return address and the old value of top_sp into the callee's activation record. The caller then increments top_sp [...] top_sp is moved past the caller's local data and temporaries and the callee's parameters and status fields."


caller's invocation record
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
top
actual parameters
returned value
top_sp
access link
saved machine status
...
...
top_sp
Move top_sp

Typical calling sequence [p. 437]

"3. The callee saves the register values and other status information."


caller's invocation record
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
top
actual parameters
returned value
top_sp
access link
PC + machine status
top_sp
...
...
Write the return address, the current value of the Program Counter (PC), into the saved machine status. When the callee finishes execution will resume with the address pointed to by this saved address.



caller's invocation record
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
callee's invocation record
actual parameters
returned value
top_sp
access link
PC + machine status
local data
temporaries
top_sp
top
When control transfers to the callee, the top_sp and top are updated.
Callee writes local data and temporaries into its invocation record.


caller's invocation record
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
callee's invocation record
actual parameters
returned value
top_sp
access link
PC + machine status
local data
temporaries
top_sp
top
If the number of arguments can vary from call to call (e.g. printf) then the caller writes the arguments to the "actual parameters" area, as well as information about the number of arguments to the status area


caller's invocation record
actual parameters
returned value
control link
access link
saved machine status
local data
temporaries
callee's invocation record
actual parameters
returned value
top_sp
access link
PC + machine status
local data
temporaries
top_sp
top
If the callee has variable length local data (e.g. local arrays whose size is determined by the value of a parameter) then the arrays are allocated space at the end of the invocation record, and pointers to those arrays are stored in the "locals" block.

Relocatable object code

- Compiler produces relocatable object code: addresses are not absolute, but relative to known boundaries (e.g. Stack Pointer, start of record, Program Counter).
- Linker combines object code files into an executable file, in which static relative addresses are made absolute (in virtual address space).
- Loader copies contents of executable file into memory and starts execution.

Relocatable object code

- Compiler produces relocatable object code: addresses are not absolute, but rel ative to known boundaries (e.g. Stack Point , start of record, Program Counter).

- Linker combines object code files i executable file, in which static are made absolute (in virtual

- Loader copies contents of ex memory and starts execution

Leave relative offsets alone during translation.

Target Architecture Code Generation

- We will generate x86-64 assembly
- Examples will not always show x86-64 assembly

Desirable characteristics of generated code:

- correctness (this is non-negotiable)
- small execution time
- small code size
- small power consumption

Desirable charac[...] of generate[...]

- correctness (this is non-[...]
- small execution time
- small code size
- small power consumption

Associate costs with each instruction, then "minimize" (lower) overall cost, with some balance since execution time and code size can be in conflict.

Significant tasks of code generator

- instruction selection
- register allocation and assignment
- instruction ordering

Si… s of code generator

Which variables are kept in registers?

- instruc… on selection
- register allocation and assignment
- instruction ordering

Significant tasks of c… r

Which specific register holds which value?

- instruction selection
- register allocation and assignment
- instruction ordering

Significant tasks of code generator

E.g. to minimize the number of registers needed.

- in
- register a cation and assignment
- instruction ordering

Simple generation strategy vs. code size

If we generate code for each intermediate code instruction in isolation and string the results together the result may include redundant instructions

Small example [p. 509]

Consider:

```
x = y + z
```

This might be translated as:

```
LD R0, y          <- load the value of y into register R0
ADD R0, R0, z     <- put into R0 the result of
                     adding R0 and the value of z
ST x, R0          <- store the value of register R0 to x
```

Larger example [p. 509]

Consider applying the same template to a larger example:

```
a = b + c
d = a + e
```

This might be translated as:

```
LD R0, b
ADD R0, R0, c
ST a, R0
LD R0, a
ADD R0, R0, e
ST d, R0
```

Larger example [p. 509]

Consider applying the same template to a larger example:

```
a = b + c
d = a + e
```

This might be translated as:

```
LD R0, b
ADD R0, R0, c
ST a, R0
LD R0, a
ADD R0, R0, e
ST d, R0
```

This instruction is redundant: it is loading into R0 the value that is already there.