Run-time Environments

Lecture 12

Status

- We have covered the front-end phases
  - Lexical analysis
  - Parsing
  - Semantic analysis
- Next are the back-end phases
  - Optimization
  - Code generation

- We'll do code generation first . . .

Run-time environments

- Before discussing code generation, we need to understand what we are trying to generate

- There are a number of standard techniques that are widely used for structuring executable code

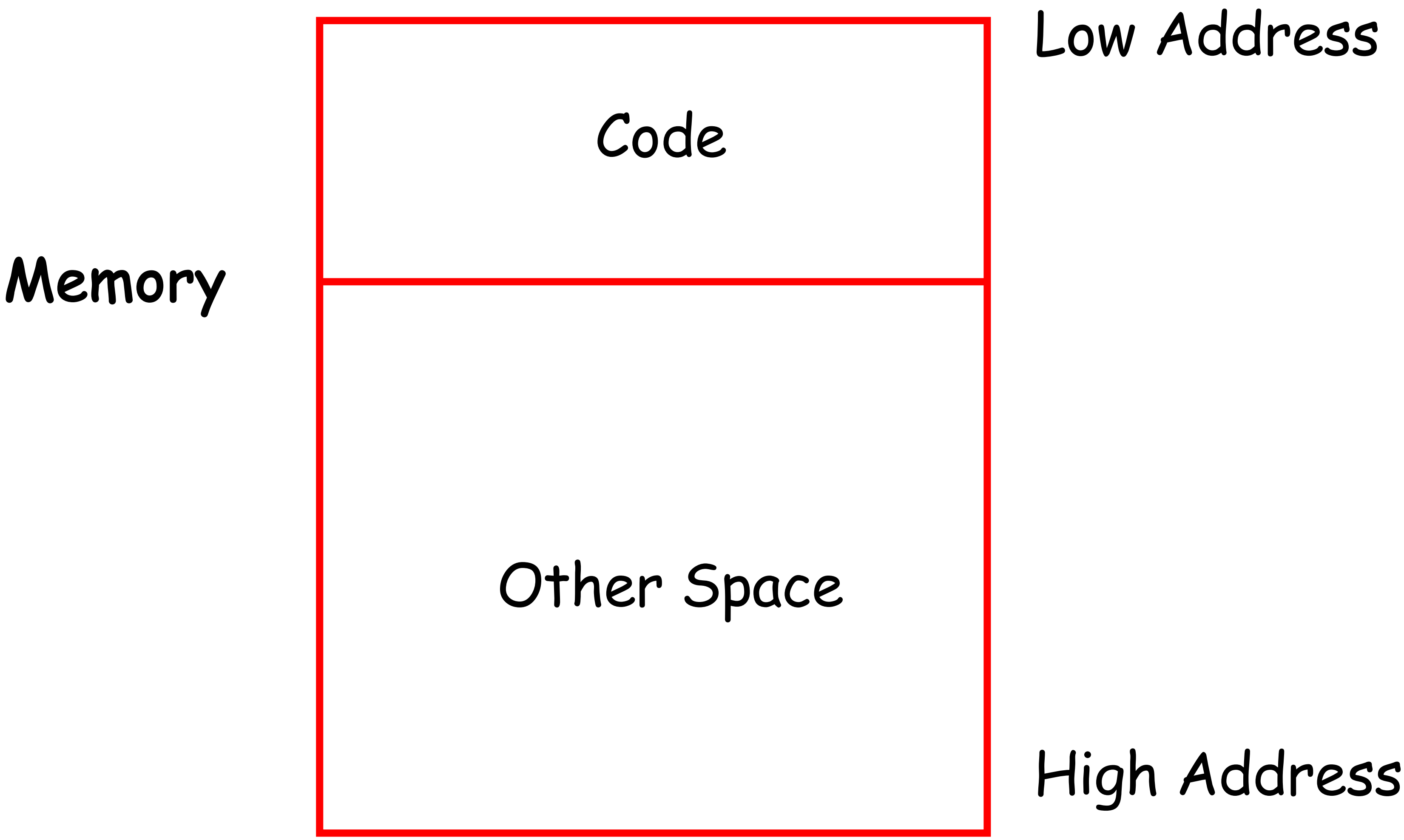
Outline

- Management of run-time resources
- Correspondence between static (compile-time) and dynamic (run-time) structures
- Storage organization

Run-time Resources

- Execution of a program is initially under the control of the operating system
- When a program is invoked:
  - The OS allocates space for the program
  - The code is loaded into part of the space
  - The OS jumps to the entry point (i.e., “main”)

Memory Layout



Notes

- Our pictures of machine organization have:
  - Low address at the top
  - High address at the bottom
  - Lines delimiting areas for different kinds of data
- These pictures are simplifications
  - E.g., not all memory need be contiguous
- In some textbooks lower addresses are at bottom

What is Other Space?

- Holds all data for the program
- Other Space = Data Space

- Compiler is responsible for:
  - Generating code
  - Orchestrating use of the data area

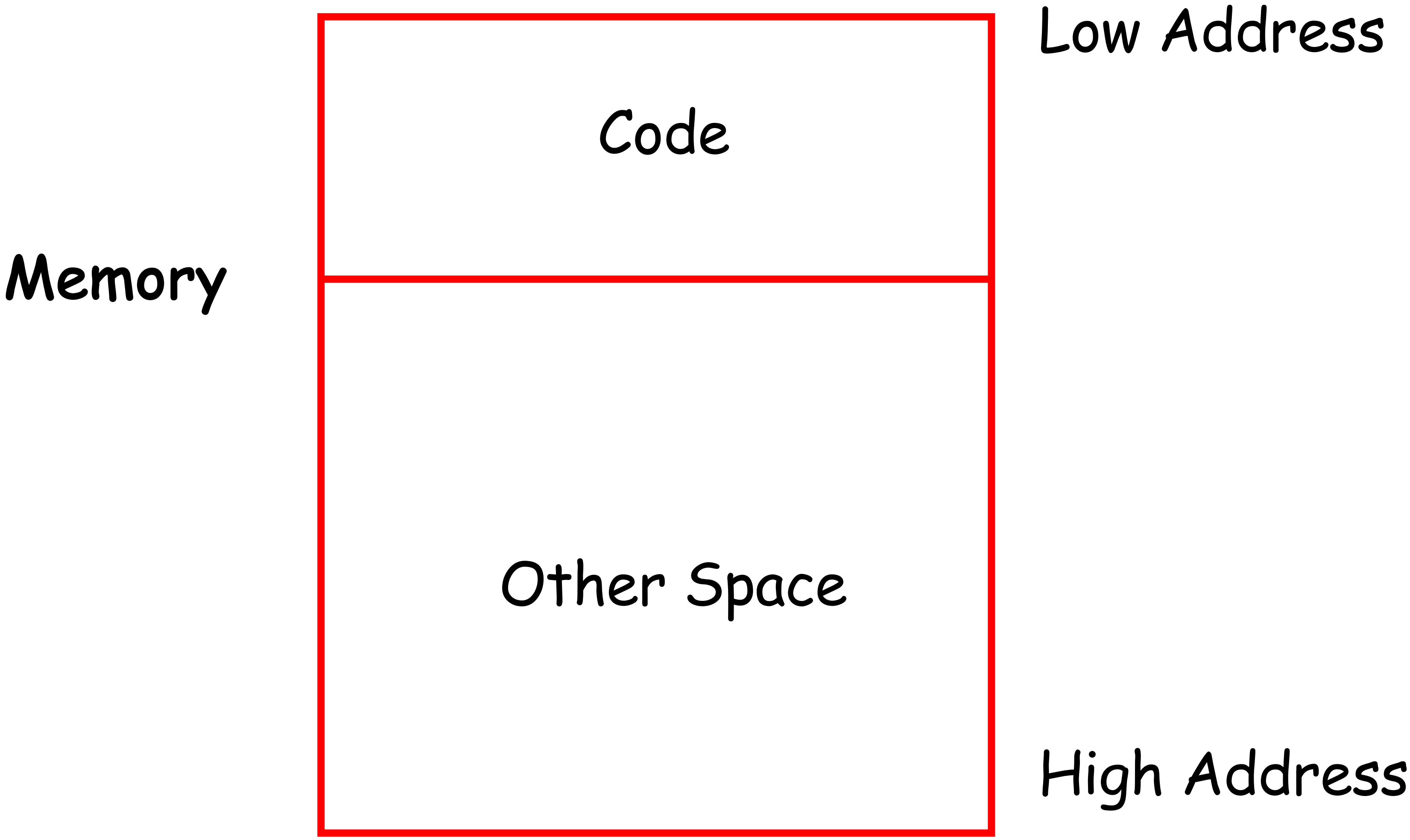
Assumptions about Execution

1. Execution is sequential; control moves from one point in a program to another in a well-defined order

2. When a procedure is called, control eventually returns to the point immediately after the call

Do these assumptions always hold?

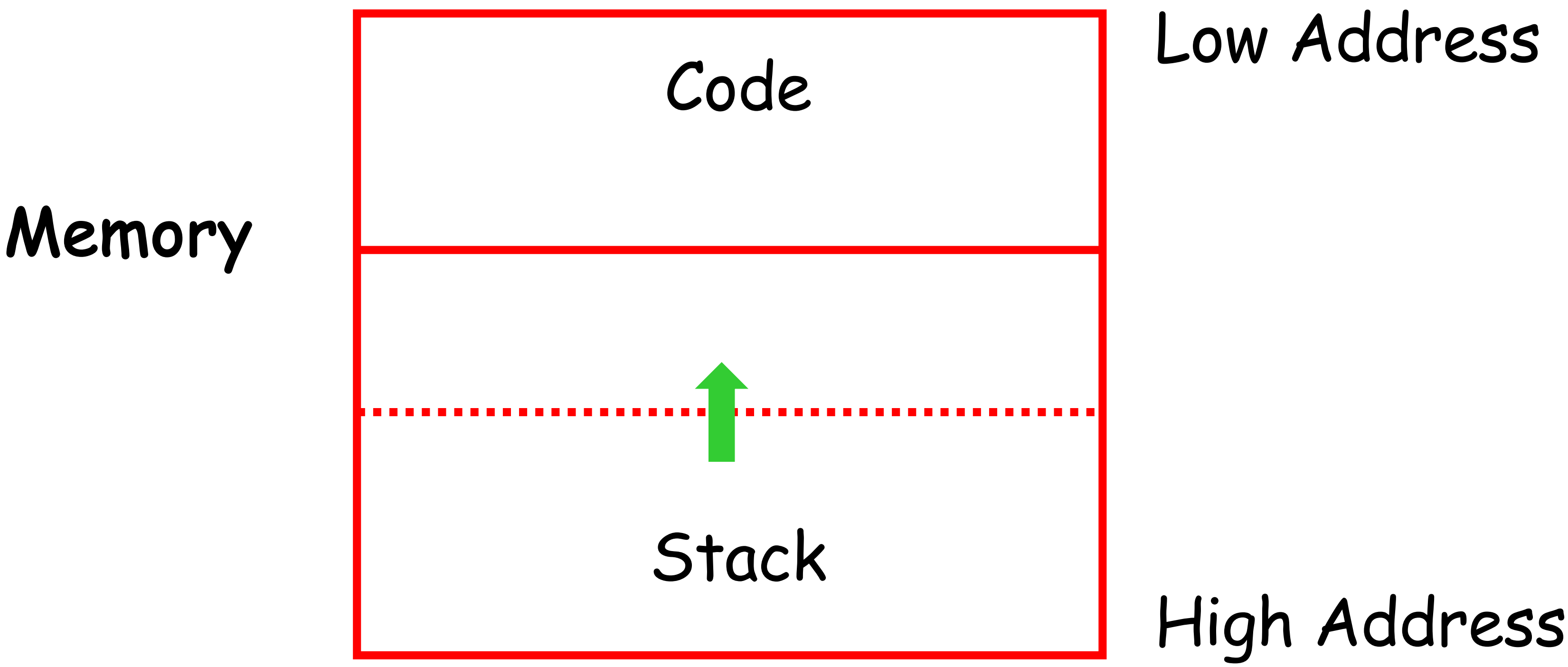
Memory Layout



Activation Frames

- We keep data for each function invocation:
  - Storage for local variables and actual arguments
  - Return address: to resume execution of its caller
  - We store such data in an activation frame
- Activation frames are linked
  - Control link: pointer to caller's activation frame
- A function invocation terminates before the invocation of its caller terminates
  - Activation frames form a stack.
  - Top of the stack is the current activation frame

Revised Memory Layout



- On many machines the stack starts at high-addresses and grows towards lower addresses

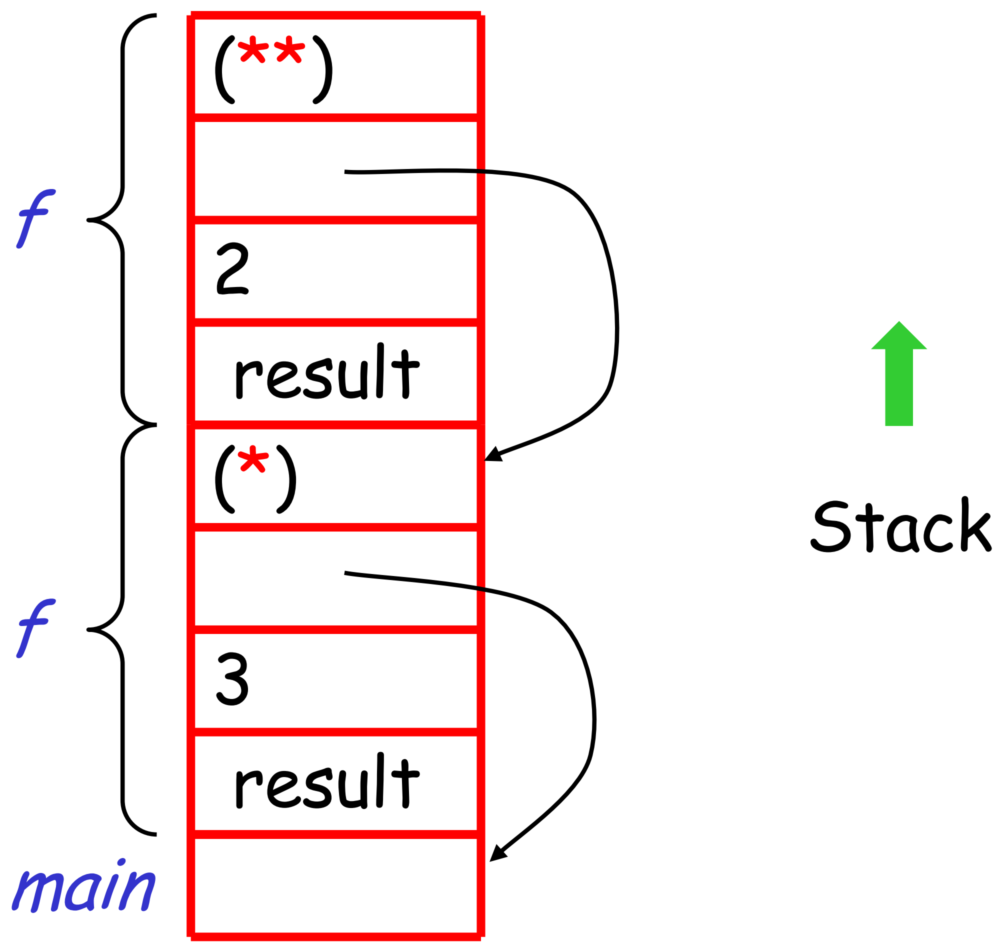
Example

```
def   g() -> int: return 1
def   f(x:int) -> int: if x==0: g() else: f(x - 1)(**)
f(3); (*)
```

AR for f:

return address
control link
argument
space for result

Stack After Two Calls to *f*



Notes

- Top-level has no argument or local variables and its result is never used; its AR is uninteresting
- (*) and (**) are return addresses of the invocations of f
  - The return address is where execution resumes after a procedure call finishes
- This is only one of many possible AR designs
  - Would also work for C, Pascal, FORTRAN, etc.

The Main Point

The compiler must determine, at compile-time, the layout of activation records and generate code that correctly accesses locations in the activation record

Thus, the AR layout and the code generator must be designed together!

Discussion

- The advantage of placing the return value 1st in a frame is that the caller can find it at a fixed offset from its own frame

- There is nothing magic about this organization
  - Can rearrange order of frame elements
  - Can divide caller/callee responsibilities differently
  - An organization is better if it improves execution speed or simplifies code generation

Discussion (Cont.)

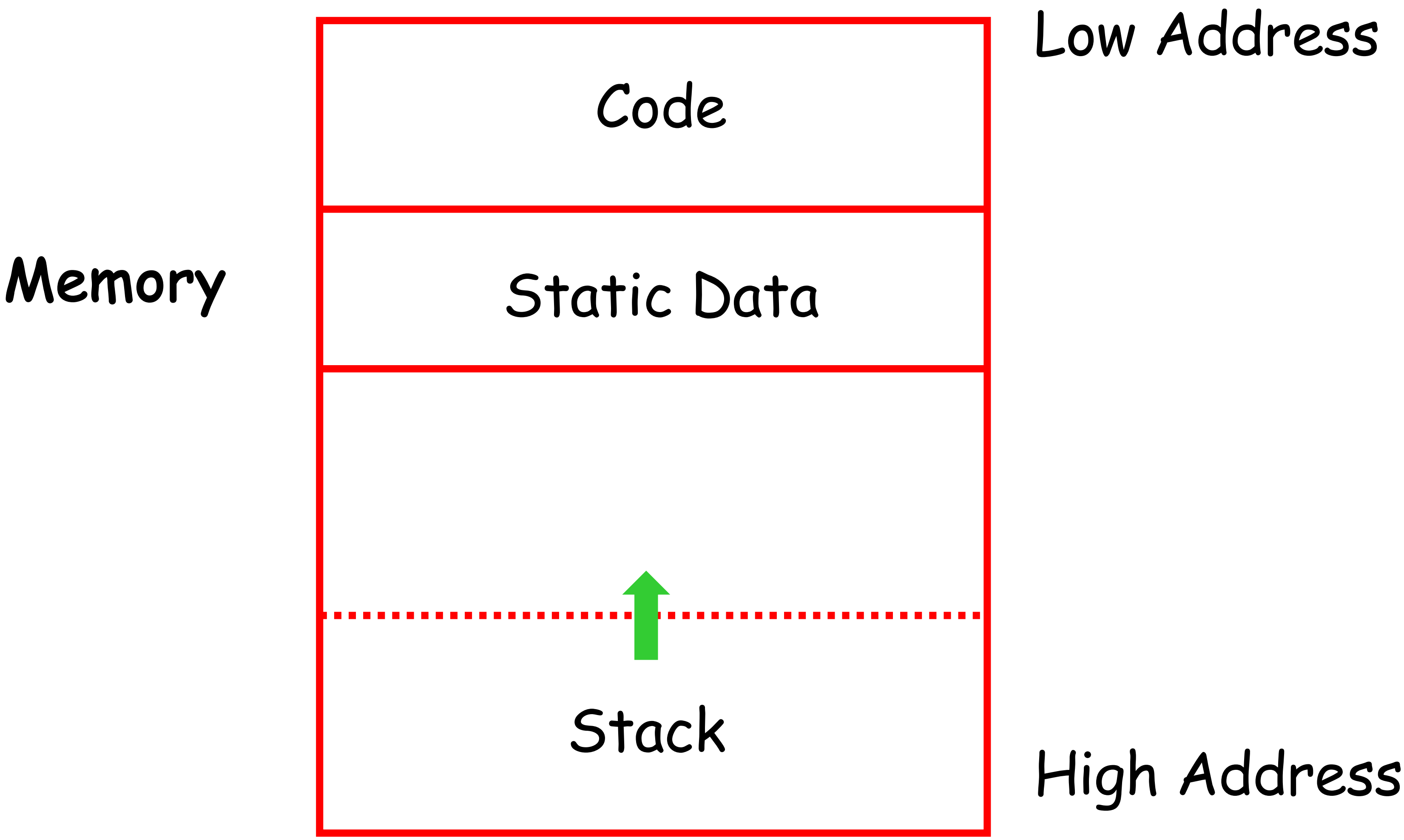
- Real compilers hold as much of the frame as possible in registers
  - Especially the method result and arguments

Globals

- All references to a global variable point to the same object
  - Can't store a global in an activation record

- Globals are assigned a fixed address once
  - Variables with fixed address are "statically allocated"
- Depending on the language, there may be other statically allocated values

Memory Layout with Static Data



Heap Storage

- A value that outlives the procedure that creates it cannot be kept in the AR

```
def foo() -> Bar: return Bar()
```

The Bar value must survive deallocation of foo's AR

- Languages with dynamically allocated data use a <u>heap</u> to store dynamic data

Notes

- The code area contains object code
  - For most languages, fixed size and read only
- The static area contains data (not code) with fixed addresses (e.g., global data)
  - Fixed size, may be readable or writable
- The stack contains an AR for each currently active procedure
  - Each AR usually fixed size, contains locals
- Heap contains all other data
  - In C, heap is managed by *malloc* and *free*

Notes (Cont.)

- Both the heap and the stack grow
- Must take care that they don't grow into each other
- Solution: start heap and stack at opposite ends of memory and let the grow towards each other

Memory Layout with Heap