CS 432
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Runtime Environments

Runtime Environment

- Programs run in the context of a system
  - Instructions, registers, memory, I/O ports, etc.
- Compilers must emit code that uses this system
  - Must obey the rules of the hardware and OS
  - Must be interoperable with shared libraries compiled by a different compiler
- Memory conventions:
  - Stack (used for subprogram calls)
  - Heap (used for dynamic memory allocation)

Subprograms

- Subprogram general characteristics
  - Single entry point
  - Caller is suspended while subprogram is executing
  - Control returns to caller when subprogram completes
  - Caller/callee info stored on stack
- Procedure vs. function
  - Functions have return values

Subprograms

- New-ish terms
  - Header: signaling syntax for defining a subprogram
  - Parameter profile: number, types, and order of parameters
  - Signature/protocol: parameter types and return type(s)
  - Prototype: declaration without a full definition
  - Referencing environment: variables visible inside a subprogram
  - Name space / scope: set of visible names
  - Call site: location of a subprogram invocation
  - Return address: destination in caller after call completes

Parameters

- Formal vs. actual parameters
  - Formal: parameter inside subprogram definition
  - Actual: parameter at call site
- Semantic models: *in*, *out*, *in-out*
- Implementations (key differences are *when* values are copied and exactly *what* is being copied)
  - **Pass-by-value (*in, value*)**
  - Pass-by-result (*out, value*)
  - Pass-by-copy (*in-out, value*)
  - **Pass-by-reference (*in-out, reference*)**
  - Pass-by-name (*in-out, name*)

Parameters

- Pass-by-value
  - Pro: simple
  - Con: costs of allocation and copying
  - Often the default
- Pass-by-reference
  - Pro: efficient (only copy 32/64 bits)
  - Con: hard to reason about, extra layer of indirection, aliasing issues
  - Often used in object-oriented languages

Subprogram Activation

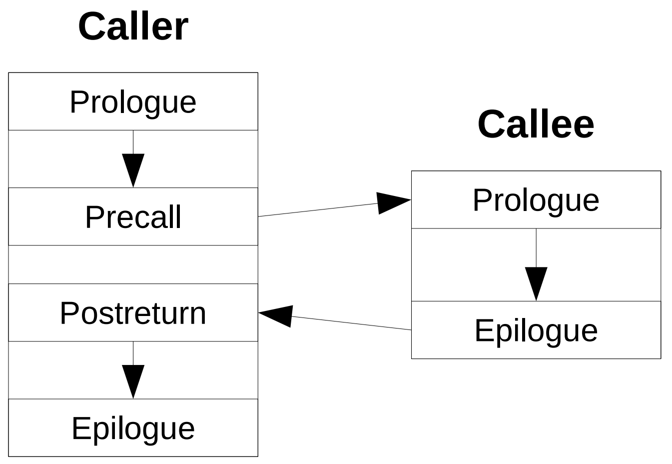
- Call semantics:
  - Save caller status
  - Compute and store parameters
  - Save return address
  - Transfer control to callee
- Return semantics:
  - Save return value(s) and out parameters
  - Restore caller status
  - Transfer control back to the caller

Linkage contract or Calling conventions (caller and callee must agree)

- Activation record*:* data for a single subprogram execution
  - Local variables
  - Parameters
  - Return address
  - Dynamic link

Standard Linkages

- Caller and callee must agree
- Standard contract:
  - Caller: precall sequence
    - Evaluate and push parameters
    - Save return address
    - Transfer control to callee
  - Callee: prologue sequence
    - Save & initialize base pointer
    - Allocate space for local variables
  - Callee: epilogue sequence
    - De-allocate activation record
    - Transfer control back to caller
  - Caller: postreturn sequence
    - Clean up parameters



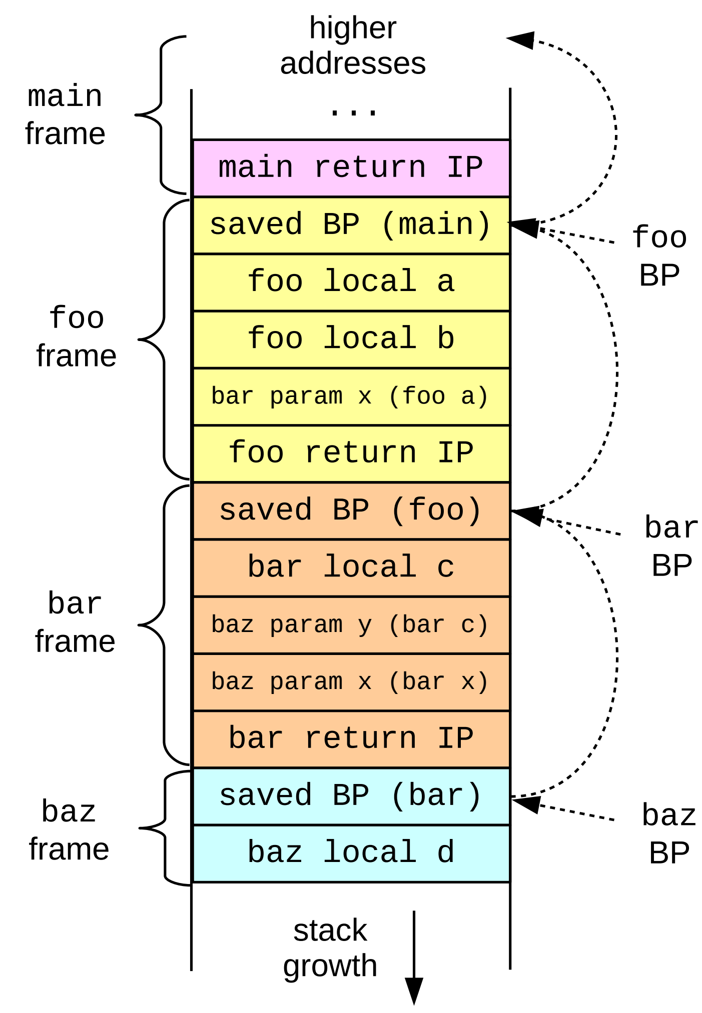
x86 Stack Layout

- Address space
  - Code, static, stack, heap
- Instruction Pointer (IP)
  - Current instruction
- Stack pointer (SP)
  - Top of stack (lowest address)
- Base pointer (BP)
  - Start of current frame (i.e., saved BP)
- "cdecl" calling conventions
  - callee may use AX, CX, DX
  - callee must preserve all other registers
  - parameters pushed in reverse order (RTL)
  - return value saved in AX

```
void foo()
{
      int a,b;
      bar(a)
      return;
}

void bar(x)
{
      int c;
      baz(x,c);
      return;
}

void baz(x,y)
{
      int d;
      return;
}
```



x86 Calling Conventions

Prologue:

```
push %ebp              ; save old base pointer
mov  %esp, %ebp        ; save top of stack as base pointer
sub  X, %esp           ; reserve X bytes for local vars
```

Within function:

```
+OFFSET(%ebp)          ; function parameter
-OFFSET(%ebp)          ; local variable
```

Epilogue:

```
<optional: save return value in %eax>
leave                  ; mov %ebp, %esp
                       ; pop %ebp
ret                    ; pop stack and jump to popped address
```

Function calling:

```
<push parameters>      ; precall
<push return address>
<jump to fname>        ; call
<pop parameters>       ; postreturn
```

Decaf Calling Conventions

- **`param`** instruction to pass parameters; call in reverse order (RTL)
  - Pushed on system stack (accessible in function using [BP+offset])
- **`call`** instruction to transfer control
  - *TODO: before call, save live registers (P6)*
  - Save return address on stack and set up stack frame (BP and SP)
  - Reserve space for local variables (accessible in function using [BP-offset])
  - Set IP to function entry point
  - *TODO: after call, clean/pop parameters from stack*
  - *TODO: after call, restore saved registers (P6)*
- **`return`** instruction to return to caller
  - Tear down stack frame (BP and SP) and pop return address into IP
  - Return value saved in "ret" special register

Calling Conventions

	Integral parameters	Base pointer	Caller-saved registers	Return value
cdecl (x86)	On stack (RTL)	Always saved	EAX, ECX, EDX	EAX
AMD64 (x64)	RDI, RSI, RDX, RCX, R8, R9, then on stack (RTL)	Saved only if necessary	RAX, RCX, RDX, R8-R11	RAX
Decaf	On stack (RTL)	Always saved	All virtual registers	RET

Other Design Issues

- How are name spaces defined?
  - Lexical vs. dynamic scope
- How are formal/actual parameters associated?
  - Positionally, by name, or both?
- Are parameter default values allowed?
  - For all parameters or just the last one(s)?
- Are method parameters type-checked?
  - Statically or dynamically?

Other Design Issues

- Are local variables statically or dynamically allocated?
- Can subprograms be passed as parameters?
  - How is this implemented?
- Can subprograms be *nested*?
- Can subprograms be *polymorphic*?
  - Ad-hoc/manual, subtype, or parametric/generic?
- Are function side effects allowed?
- Can a function return multiple values?

Misc. Topics

- Macros
  - Call-by-name, “executed” at compile time
- Closures
  - A subprogram and its referencing environment
- Coroutines
  - Co-operating procedures
- Just-in-time (JIT) compilation
  - Defer compilation of each function until it is called

Heap Management

- Desired properties
  - Space efficiency
  - Exploitation of locality (time and space)
  - Low overhead
- Allocation (malloc/new)
  - First-fit vs. best-fit vs. next-fit
  - Coalescing free space (defragmentation)
- Manual deallocation (free/delete)
  - Dangling pointers
  - Memory leaks

Automatic De-allocation

- Criteria: overhead, pause time, space usage, locality impact
- Basic problem: finding reachable structures
  - Root set: static and stack pointers
  - Recursively follow pointers through heap structures
- Reference counting (incremental)
  - Track the number of active references to each structure
  - Catch the transition to unreachable (count becomes zero)
  - Has trouble with cyclic data structures
- Mark and sweep (batch-oriented)
  - Occasionally pause and detect unreachable structures
  - High overhead and undesirable "pause the world" semantics
  - Partial collection: collect only a subset of memory on each run
  - Generational collection: collect newer objects more often

Object-Oriented Languages

- Classes vs. objects
- Inheritance relationships (subclass/superclass)
  - Single vs. multiple inheritance
- Closed vs. open class structure
- Visibility: public vs. private vs. protected
- Static vs. dynamic dispatch
- Object-records and virtual method tables