Programming Language & Compiler

Control Abstraction

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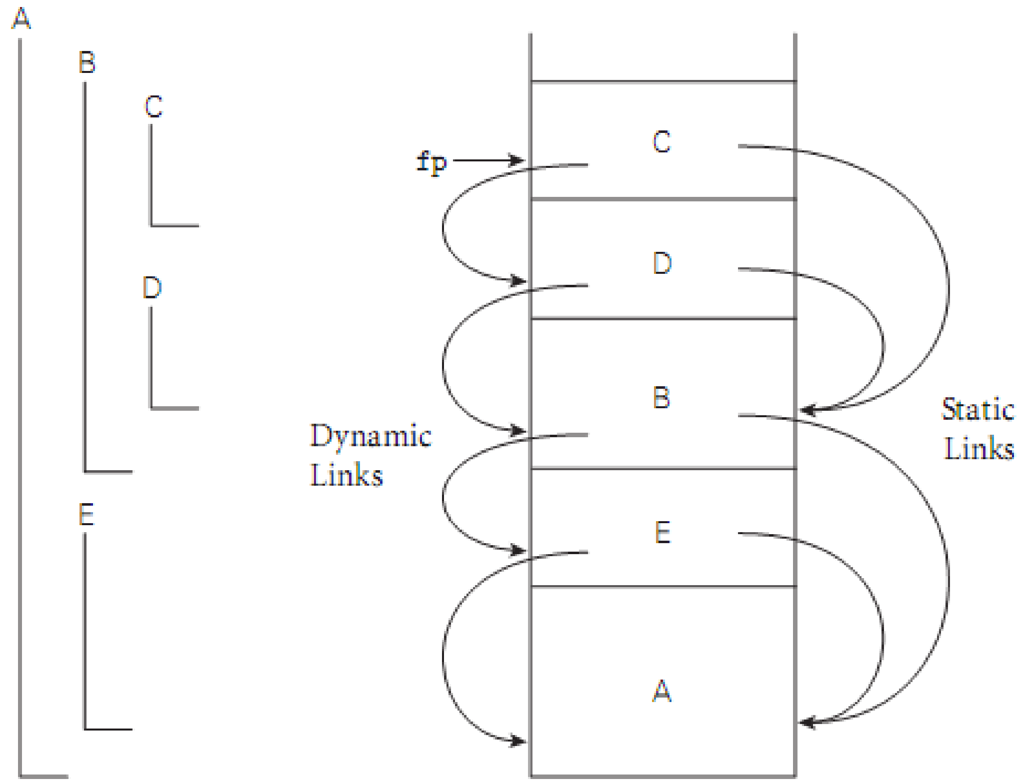
Review of Static Allocation

- Static allocation strategies
  - Code
  - Global variables
  - *Own* variables (live within an encapsulation - *static* in C)
  - Explicit constants (including strings, sets, other aggregates)
    - Small scalars may be stored in the instructions themselves

Review Of Stack Layout



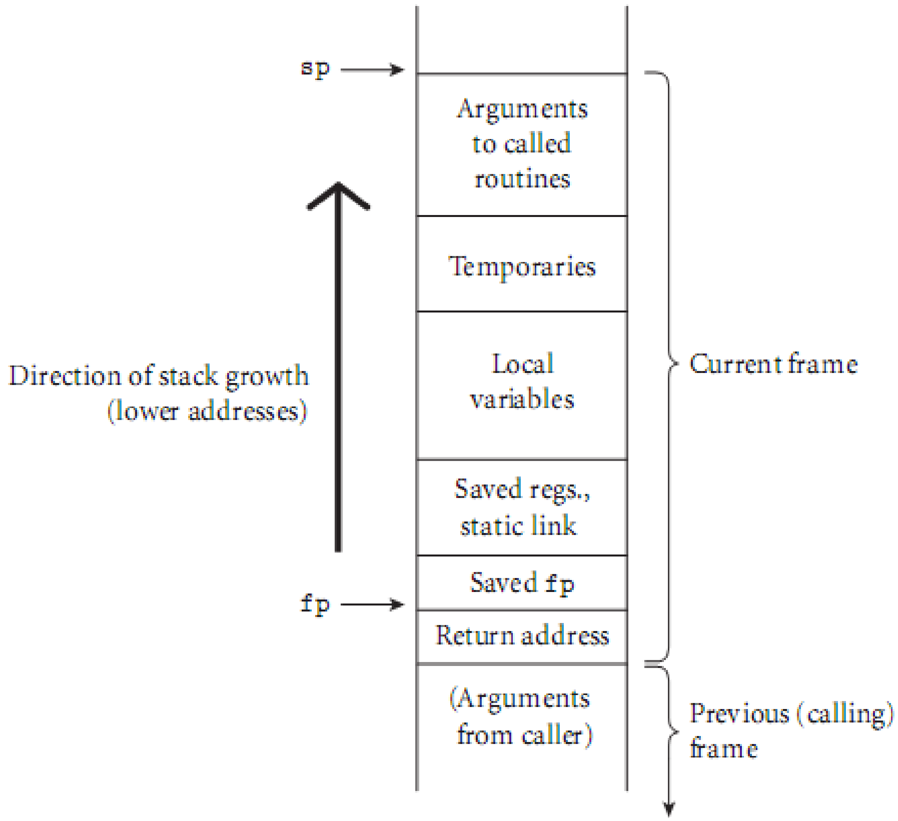
Review of Allocation Strategies

- Stack allocation
  - Parameters
  - Local variables
  - Temporaries
  - Bookkeeping

- Heap allocation
  - Dynamic allocation

Stack Frame

- Contents of a stack frame
  - Bookkeeping
    - Return PC (dynamic link)
    - Saved registers
      - Including dynamic link in fp
    - Static link
  - Arguments and returns
  - Local variables
  - Temporaries



Stack Frame Maintenance

- Maintenance of stack is the responsibility of
  - Calling sequence
  - Subroutine prolog and epilog

- Space is saved in callee
  - By putting as much in the prolog and epilog as possible
- Time *may* be saved in caller
  - By putting stuff in the caller instead, where more information may be known (caller-saved registers)

Register Save & Local Variables

- Common strategy is to divide registers into *caller-saves* and *callee-saves* sets
  - Caller uses the *callee-saves* registers first
    - Callee-saves registers are for local variables which are more likely live across function calls
  - *Caller-saves* registers if necessary
    - Caller-saves registers are mostly for temporary values (less likely live across function calls)

- Local variables and arguments
  - Assigned at *fixed offsets* from the frame (or stack) pointer at compile time

Calling Sequences

- Before the call, Caller
  - Saves into the temporaries any caller-saves registers whose values will be needed after the call (*i.e.* live registers)
  - Puts small arguments into registers (or in the stack)
    - It depends on the types of the parameters and the order in which they appear in the argument list
  - Puts the rest of the arguments into the argument build area at the top of the stack frame
  - Use a special call instruction to jump to the subroutine and store return address on the stack or in a register

Calling Sequences

- In the prolog, Callee
  - Subtracts the frame size from sp (frame grows towards lower address)
  - Saves callee-saves registers if used anywhere inside callee
- In the epilog, Callee
  - Puts return value into registers (memory if large)
  - Restores callee-saves registers
  - Adds to sp to deallocate the frame (restore sp)
  - Restore fp to old fp
  - Return to caller

Calling Sequences

- After call, Caller
  - Moves return value from register to wherever it's needed (if appropriate)
  - Restores caller-saves registers if needed (lazily over time, as their values are needed)

Arguments in Registers

- All arguments have space in the stack, whether passed in registers or not
  - The subroutine may begin with some of the arguments already cached in registers, and *stale* values in memory
- This is a normal state of affairs
  - Optimizing compilers keep things in registers whenever possible,
  - Flushing to memory only when they run out of registers, or when code may attempt to access the data through a pointer or from an inner scope

Optimization for Calling Sequence

- Many parts of the calling sequence, prologue, and/or epilogue can be omitted in common cases

- Particularly, *leaf* routines don't call other routines
  - If another routine is called, `ra` (which contains return address) should be saved, but leaf routines don't save it
  - Simple leaf routines can be exceptionally fast
    - No local variables and nothing to save and restore in the stack
    - Don't even use memory, just compute with (*caller-saves*) registers

Parameter Passing

- Three basic implementations for parameter passing
  - Call-by-value
  - Call-by-reference
  - Call-by-closure (subroutine address + environment)

- Variations
  - Call-by-result – copying back when return
  - Call-by-value/result – copying and copying back
  - Call-by-sharing – copying in reference model
  - Call-by-name – substitute as macros
  - Read-only – prevent modification
  - Named parameter – specify corresponding formal parameters

Parameter Passing in C/C++

- C/C++: functions
  - Parameters passed by value (C)
  - Parameters passed by reference can be simulated with pointers (C)

```
void proc(int* x, int y) { *x = *x+y; }
proc(&a,b);
```

Or directly passed by reference (C++)

```
void proc(int& x, int y) { x = x + y; }
proc(a,b);
```

Parameter Passing in Ada

- Ada goes for semantics: who can do what
  - in: callee reads only
  - out: callee writes and can then read
    (formal not initialized; actual modified)
  - in out: callee reads and writes; actual modified

- Ada in/out is always implemented as
  - Value/result for scalars, and either
  - Value/result or reference for structured objects

Parameter Passing in Others

- Language with a reference model of variables (Lisp, Clu)
  - Pass by reference (*sharing*) is the obvious approach
- Fortran always uses call-by-reference (only option)
  - If you pass a constant or expression, the compiler creates a temporary location to hold the value and pass its reference
  - If you modify the temporary, who cares?
- Call-by-name is an old Algol technique
  - Think of it as call by textual substitution
    (procedure with all name parameters works like macro)
  - A way to mimic macros for assembly language programmers

Parameter Passing Modes

parameter mode	representative languages	implementation mechanism	permissible operations	change to actual?	alias?
value	C/C++, Pascal, Java/C# (value types)	value	read, write	no	no
`in`, `const`	Ada, C/C++, Modula-3	value or reference	read only	no	maybe
`out`	Ada	value or reference	write only	yes	maybe
value/result	Algol W	value	read, write	yes	no
`var`, `ref`	Fortran, Pascal, C++	reference	read, write	yes	yes
sharing	Lisp/Scheme, ML, Java/C# (reference types)	value or reference	read, write	yes	yes
`in out`	Ada	value or reference	read, write	yes	maybe
name	Algol 60, Simula	closure (thunk)	read, write	yes	yes
need	Haskell, R	closure (thunk) with memoization	read, write*	yes*	yes*

Exceptions

- What is an exception?
  - A hardware-detected run-time error *or*
  - Unusual condition detected by software
- Examples
  - Arithmetic overflow
  - End-of-file on input
  - Wrong type for input data
  - User-defined conditions, not necessarily errors

Exception Handling

- What is an exception handler?
  - Code executed when exception occurs
  - May need a different handler for each type of exception

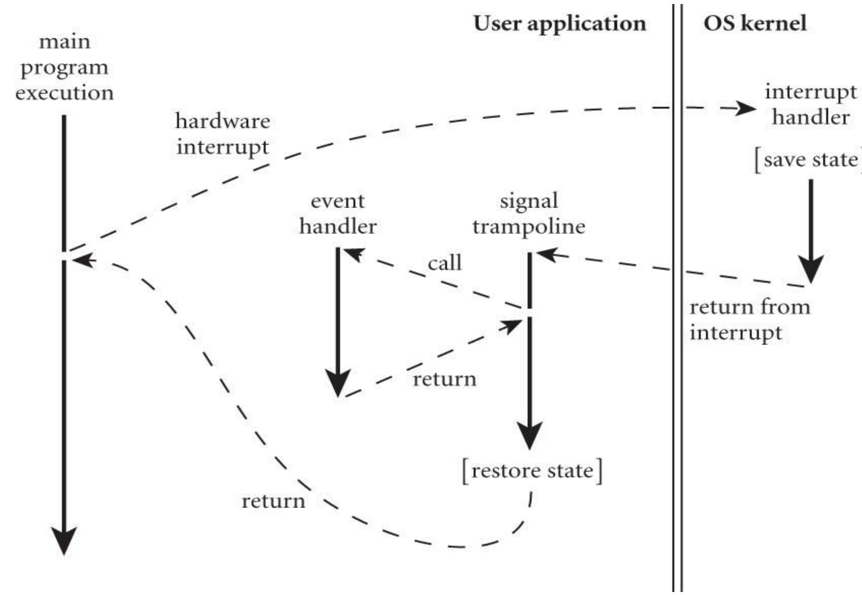
- Why design in exception handling facilities?
  - Allow users to explicitly handle errors in a uniform manner
  - Allow users to handle errors without having to check these conditions before
  - Explicitly in the program everywhere they might occur

Events

- What is an event?
  - Running programs need to respond to the events
  - Events occurs outside the programs at unpredictable times
- Examples
  - Inputs from users (keyboard, mouse motion/click)
  - I/O from network, disk
- Event handlers
  - A special callback function
  - A dedicated thread to handle

Event Handlers

- Sequential handlers
  - Works in an asynchronous way
    - Register *handler* and return
  - Use a hardware interrupt mechanism
  - OS calls handler routines
  - Return to the program



Signal delivery for sequential handler

- Thread-based handlers
  - Separate thread control thread
  - Works in a synchronous way
    - A dedicated thread is called
    - Makes a system call for the next event
    - Waits for it to occur

Coroutines

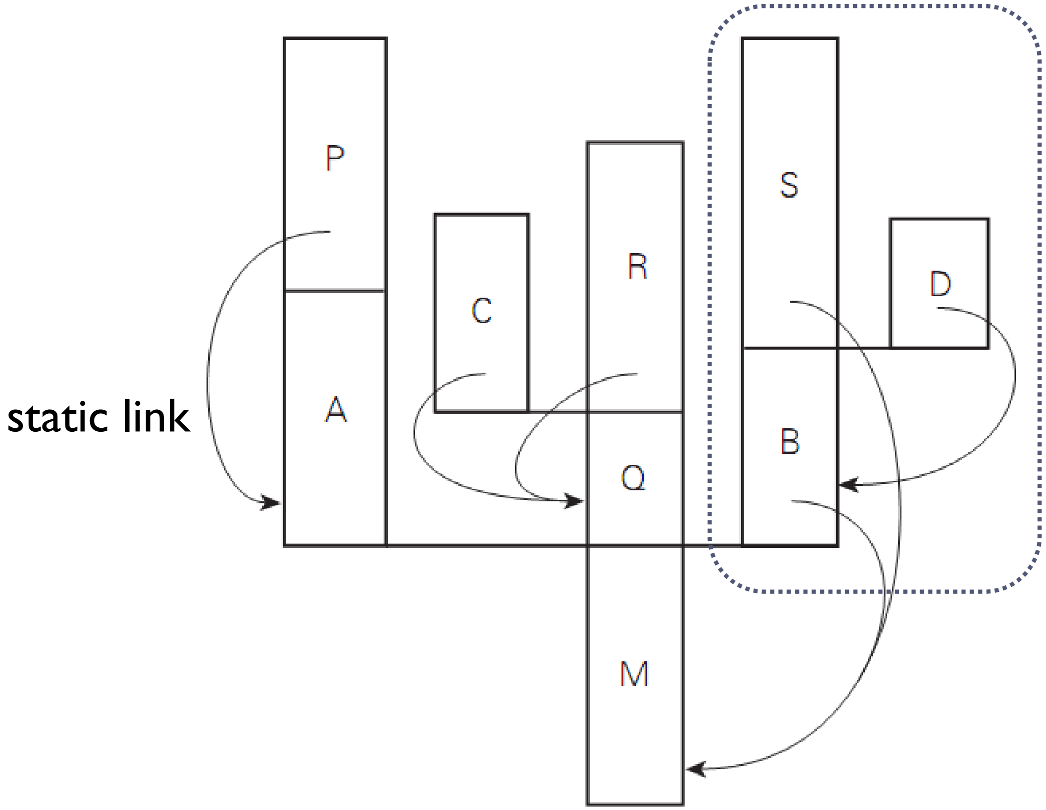
- Concurrently calling one another
  - Coroutines are execution contexts that exist concurrently, but that execute one at a time, and that *transfer* control to each other explicitly, by name

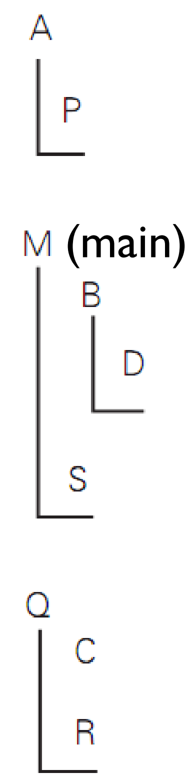
- Coroutines can be used to implement
  - Iterators
  - Threads

- Separate stack should be maintained
  - Because they are concurrent (i.e., simultaneously started but not completed), coroutines cannot share a single stack

Multiple Stacks for Coroutines

B calls subroutine S and created coroutine D





Cactus Stack

Summary

- Function
  - Stack frame
  - Passing parameters
- Exception
  - Unexpected/unusual HW/SW condition caused by current program
  - Try-catch (Java, C++)
- Event
  - HW/SW condition required to respond by current program
  - Event handling mechanism
- Coroutine
  - Concurrent execution of multiple sequences, but execute one at a time
  - Transfer:
    - *non-local goto* to jump to other coroutine's last transfer (continuation)
  - Cactus stack: Multiple concurrent stacks