CS 4100
Block Structured Languages

From *Principles of Programming Languages: Design, Evaluation, and Implementation (Third Edition),* by Bruce J. MacLennan, Chapter 6, and based on slides by Istvan Jonyer

Chapter 6:
Implementation of Block-Structure

- Addressing implementation aspects of block-structured languages (Pascal and Algol)
  - Fortran (and pseudocode) not block structured
  - We'll focus on Pascal, since most languages these days are Pascal-like
  - Algol is block structured

Activation Record

- Represents the state of a procedure

Fixed vs Variable

- Program has two major components
  - Fixed part
    - Code (the program itself)
    - Does not change during runtime
  - Variable part
    - Activation record
    - Dynamically created and deleted at runtime
    - We'll focus on this part

State of an Activation

- Point of execution (instruction pointer)
  - Stored in IP of activation record (and IP register of processor)
  - Usually points to next instruction
- Context of execution (scope/environment)
  - Environment pointer (EP)
  - Local context
    - Local activation record
  - Non-local context
    - Non-local activation record

Activation Records

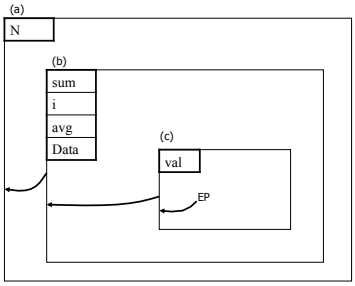
- Local variables and formal parameters are contained in the activation record
  - Create and delete correspond to entry and exit
- Context of a statement
  - Names declared in current procedure +
  - Names declared in surrounding procedures
    - For multiple bindings, innermost declaration is used (if name not found in current activation record, look to outer A/Rs successively)

Static Link

- How to keep track of outer scopes? (p214)
  - Static link points to outer activation record
  - Each context (A/R) has static link to outer scope
  - Static links form a chain all the way to top level (global scope, and beyond to OS)
  - Static chain reflects the static structure of the program
    - The way procedures are nested
    - Ends at global scope


```
program a(…);
  var N: integer;
  procedure b(sum: real);
      var   i: integer;
            avg: real;
            Data: array[1..10] of real;
      procedure c(val: real);
      begin
            writeln (Data[i]);
      end; // c
  begin // b
      ...
  end;  // b
begin // a
  ...
end;  // a
```

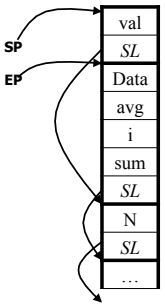

Contour Diagram of Static Structure of Previous Program



Pointers

- EP points to active local context
- SP points to register of active context
- IP points to next instruction
- SL outer activation record
  - Environment of declaration
  - Keeps track of outer scopes
- DL (coming soon) points to callers A/R
  - Talked about this in Fortran

Activation Record for Procedures



- Activation record of (c)
- Activation record of (b)
- Activation record of (a)

Variable Addressing

- Name lookup is done at compile time
  - Names are not actually looked up at runtime
  - Names are bound to addresses in activation record
- We need two addresses for accessing a variable
  - How far we have to follow the static link
    - Where the variable is defined
  - Offset of variable in activation record

Terminology

- Static nesting level
  - How deep the scope is where variable is defined (from global scope)
  - Number of contour lines surrounding declaration or use
- Static distance
  - Distance between the variable's declaration and use
- Offset
  - Variables position inside activation record

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Fetching a Variable

- Notation
  - M[i]: memory at address i
  - EP: environment pointer (how to get to A/R)
  - offset(v): relative offset of variable v in activation record (how to find in A/R)
  - reg.X: processor register (EP,IP,SP)
- General case (v is local)
  - **fetch** `M[reg.EP + offset(v)]`

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Examples

- Get variable `sum` (with offset 1) at static distance of 1
  - ARP: activation record pointer

```
ARP := M[reg.EP];
fetch M[ARP + 1];
```

- Get variable `N` (with offset 1) at static distance of 2

```
ARP := M[reg.EP];
ARP := M[ARP];
fetch M[ARP + 1];
```

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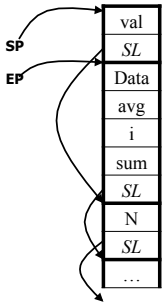
Activation Record for Procedures



- Activation record of (c)
- Activation record of (b)
- Activation record of (a)

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Dynamic Link

- How is dynamic link different from static link?
  - Can we do with just one?
    - Both are needed for static scoping
    - Dynamic link is enough for dynamic scoping
- Static link
  - Points to environment of declaration
- Dynamic link
  - Points to caller
    - Can restore caller's state on exit

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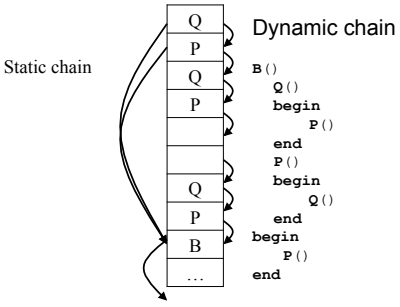
Dynamic vs Static Link



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Procedure Activation

- Three steps
  - Save state of caller
    - In local activation record
  - Create activation record of callee
    - Transmit parameters to callee
    - Establish dynamic link from caller
  - Enter callee
    - At its first instruction

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Saving the Caller's State

- Saving address where caller must resume after returning from call
- Saving locals and non-locals
  - No action is required
  - Locals are already stored in AR
  - Access to non-locals is already established (SL)
- Saving processor registers
  - Registers must be saved in AR
  - Platform-specific (not discussed)
  - Not visible to programmer

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Creating Callee's AR

- Callee's AR has following components
  - PAR: parameters
    - Parameters are placed here by caller
    - M[callee's AR].PAR[1] := evaluation of parameter 1;
  - IP: resumption address
    - Not used until making procedure call
  - SL: static link
    - Set to environment of definition
    - Computed from static nesting levels of procedures
    - M[callee's AR].SL := reg.EP (if defined in current scope)
  - DL: dynamic link
    - Set to caller's AR (EP register)
    - M[callee's AR].DL := reg.EP

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Final Steps

- Install callee's AR as current activation record

```
reg.EP := callee's AR;
```

- Include callee's AR in stack "officially"

```
reg.SP := reg.SP + size(callee's AR);
goto entry(callee);
```

- Both entry point and AR size are known at compile time
  - Goto = reg.IP := entry(callee)

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Procedure Exit

- We have to effectively reverse the entry procedure
  - Delete callee's activation record
    - Subtract size of AR from stack
      - reg.SP := reg.SP – size(callee's AR)
  - Restore the state of the caller
    - Reinstalling the caller's context
      - reg.EP := M[reg.EP].DL;
  - Resume execution of caller
    - reg.IP := M[reg.EP].IP (**goto** M[reg.EP].IP)

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Non-Local GOTOs

- Local GOTO
  - Simple machine jump to address
- Non-local GOTO
  - Requires restoration of environment
  - Must manipulate runtime stack
    - Analogous to returning from a procedure call

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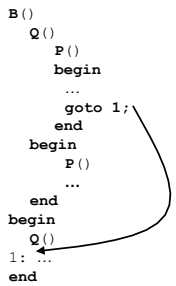
Example



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Implementation

- How do we find the scope for the label?
  - Static nesting level is kept in symbol table at compile time
  - Static difference *sd* can be computed and found runtime
- Steps involved:
  - Scan down static chain *sd* times
    - sd times: reg.EP := M[reg.EP].SL
  - Remove ARs from top of stack
    - reg.SP := reg.SP + size(AR of label)
  - Transfer execution to point of label (constant)
    - goto address(label)

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Displays

- Traversing static chains is proportional to length of chain
  - Would be nice if it was constant
- Solution
  - Store the address of activation record for each environment (not procedure call!) in array
  - This array is called the "display" D
  - Accessing static nesting levels is easy
    - D[snl]
  - Accessing variables is now only two steps, always!
    - **fetch** M[D[snl] + offset(variable)]

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Static Chains vs. Displays

Operation	Static Chain	Display
Local variable	1	2
Non-local variable	sd+1	2
Procedure call	sd+3	6
Procedure return	2	5

- SC values are estimates
- Displays
  - Better for variables
  - Worse for procedure calls

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Blocks

- Pascal does not have blocks…
- But Algol, C, Ada and many others do
- Blocks require activation records
  - Thus, entering and exiting a block is analogous with calling and returning from a procedure
  - Can they be implemented in the same way?
    - Yes!

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Block vs. Procedure

- Some efficiency hacks are possible with blocks
  - Blocks are always called from the same place! …and returns to the same place!
    - No need to save IP (resume address) of caller
    - No need to save processor registers
    - Environment is always the same
      - Environment of definition = Surrounding block
      - Static and dynamic links are the same
  - No parameters
    - No need to evaluate and copy parameters

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Improvements

- Simplified structure
  - LV: local variables
    - Block can have local variables
      - (vs. compound statements)
  - IP: resumption address
    - Block may call procedure
  - SL: static link
    - Remove dynamic link, since they are the same

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Entry-Exit

- Entry:

```
M[reg.SP].SL := reg.EP;
reg.EP := reg.SP;
reg.SP := reg.SP + size(block AR)
```

- Exit

```
reg.SP := reg.SP - size(block AR)
reg.EP := M[reg.EP].SL;
```

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