Location for Activation Record

- Depending upon language, activation record can be created in the static, stack or heap area
- Creation in Static Area:
  - Early languages, like FORTRAN
  - Address of all arguments, local variables etc. are preset at compile time itself
  - To pass parameters, values are copied into these locations at the time of invoking the procedure and copied back on return
  - There can be a single activation of a procedure at a time
  - Recursive procedures cannot be implemented

Location for Activation Record

- Creation in Stack Area:
  - Used for languages like C, Pascal, Java etc.
  - As and when a procedure is invoked, corresponding activation record is pushed onto the stack
  - On return, entry is popped out
  - Works well if local variables are not needed beyond the procedure body
- For languages like LISP, in which a full function may be returned, activation record created in the heap

Processor Registers

- Also a part of the runtime environment
- Used to store temporaries, local variables, global variables and some special information
- Program counter points to the statement to be executed next
- Stack pointer points to the top of the stack
- Frame pointer points to the current activation record
- Argument pointer points to the area of the activation record reserved for arguments

Environment Types

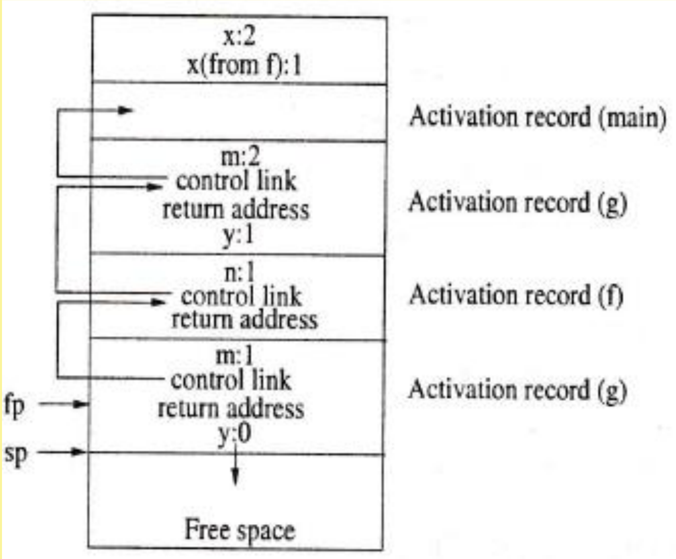
- Stack based environment without local procedures – common for languages like C
- Stack based environment with local procedures – followed for block structured languages like Pascal

Environment without Local Procedures

- For languages where all procedures are global
- Stack based environment needs two things about activation records
  - Frame pointer: Pointer to the current activation record to allow access to local variables and parameters
  - Control link / Dynamic link: Kept in current activation record to record position of the immediately preceding activation record

Environment without Local Procedures

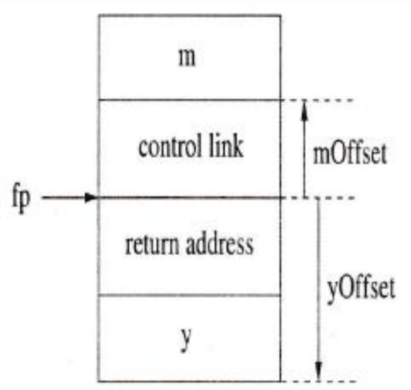
```
int x = 2;
void f( int n ) {
    static int x = 1;
    g(n);
    x--;
}
void g( int m ) {
    int y = m – 1;
    if (y > 0) {
        f(y);
        x--;
    }
}
main() {
    g(x); return 0;
}
```



Snapshot of program execution after main has called g, g has called f and f has in turn called g

Accessing Variables

- Parameters and local variables found by offset from the current frame pointer
- Offsets can be calculated statically by the compiler
- Consider procedure g with parameter m and local variable y



mOffset = size of control link = +4 bytes
yOffset = - (size of y + size of return address) = -6
Hence, m and y can be accessed by 4(fp) and -6(fp)

Activation Record Creation

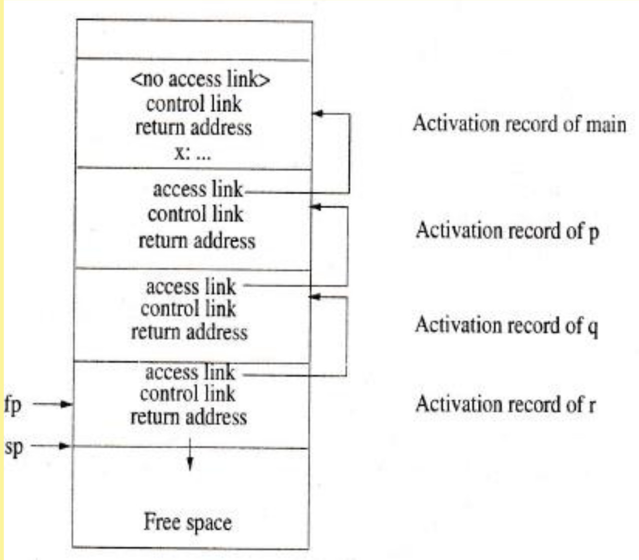
At a call	
Caller	**Callee**
1. Allocate basic frame 2. Store parameters 3. Store return address 4. Save caller-saved registers 5. Store self frame pointer 6. Set frame pointer for child 7. Jump to child	1. Save callee saved registers, state 2. Extend frame for locals 3. Initialize locals 4. Fall through to code
At a return	
Caller	**Callee**
1. Copy return value 2. Deallocate basic frame 3. Restore caller-saved registers	1. Store return value 2. Restore callee-saved registers, state 3. Unextend frame 4. Restore parent's frame pointer 5. Jump to return address

Environment with Local Procedures

- For supporting local procedures, variables may have various scopes
- To determine the definition to be used for a reference to a variable, it is needed to access non-local, non-global variables
- These definitions are local to one of the procedures nesting the current one – need to look into the activation records of nesting procedures
- Solution is to keep extra bookkeeping information, called *access link*, pointing to the activation record for the defining environment of a procedure

Environment with Local Procedures

```
program chaining;
 procedure p;
 var x: integer;
 procedure q;
    procedure r
    begin
       x := 2;
       ...
       if ... Then p;
    end {of r}
 begin
    r;
 end {of q}
 begin
    q;
 end {of p}
 begin {of main}
    p;
 end.
```



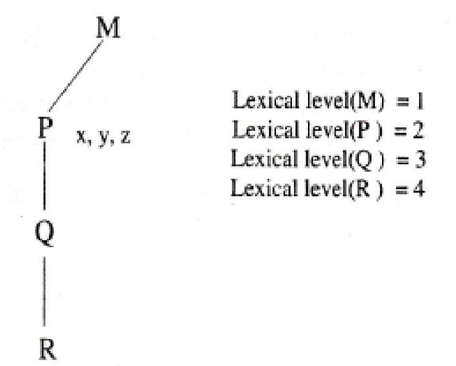
- Current procedure r
- To locate definition of x, it has to traverse through the activation records using access links
- When the required procedure containing definition of x is reached, it is accessed via offset from the corresponding frame pointer

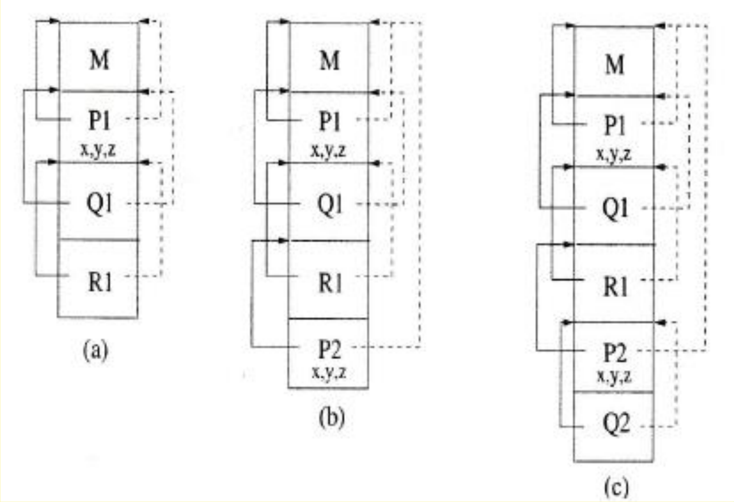
Compiler's Responsibility

- Proper code to access the correct definitions:
  - Find difference *d* between the lexical nesting level of declaration of the name and the lexical nesting level of the procedure referring to it
  - Generate code for following *d* access links to reach the right activation record
  - Generate code to access the variable through offset mechanism

Example

```
program M;
    procedure P;
        var x, y, z;
        procedure Q;
            procedure R;
            begin
                ...  z = P; ...
            end R;
        begin
            ...  y = R; ...
        end Q;
    begin
        ...  x = Q; ...
    end P;
begin
    ...  P; ...
end M;
```





DISPLAY

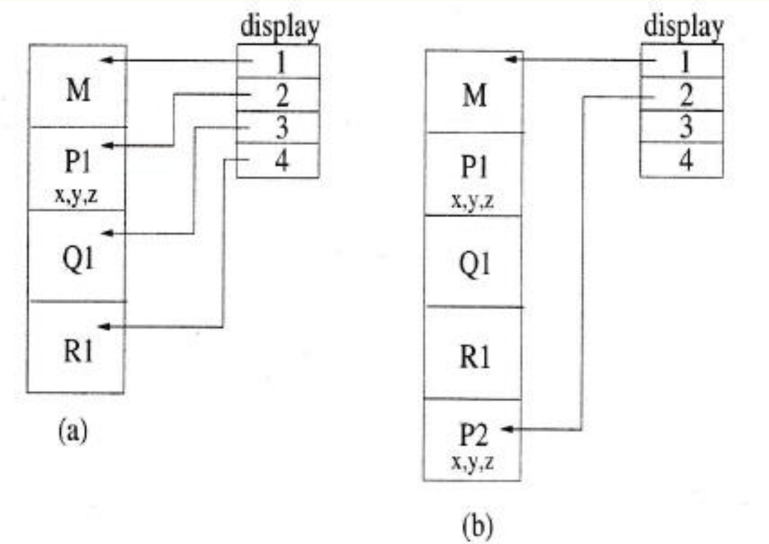
- Difficulty in non-local definitions is to search by following access links
- Particularly for virtual paging environment, certain portion of the stack containing activation records may be swapped out, access may be very slow
- To access variables without search, *display* is used

Display

- Display *d* is a global array of pointers to activation records, indexed by the lexical nesting depth
- Element *d*[*i*] points to the most recent activation of the block at nesting depth *i*
- A nonlocal X is found as follows:
  - If the most closely nested declaration of X is at nesting depth i, then d[i] points to activation record containing the location for X
  - Use relative address within the activation record to access X

Example

- Maximum nesting depth 4, so 4 entries in the display
- In Fig (a), M has called P, P has called Q and Q has in turn called R
- Compiler knows that x is in procedure P at lexical level 2
- Code is generated to access second entry of the display to reach the activation record of P directly
- Same is in Fig (b)



Maintaining Display

- When a procedure P at nesting depth i is called, following actions are taken:
  - Save value of d[i] in the activation record for P
  - Set d[i] to point to new activation record
- When a procedure P finishes:
  - d[i] is reset to the value stored in the activation record of P

Example

```
1.  Program X
2.  var x, y, z;
3.   Procedure P
4.         var a;
5.   begin (of P)
6.      a = Q
7.   end (of P)
8.   Procedure Q
9.      Procedure R
10.     begin (of R)
11.        P
12.     end (of R)
13.  begin (of Q)
14.        R
15.   end (of Q)
16.  begin (of X)
17.      P
18.      Q
19.  end (of X)
```

- Show the snapshots of the stack of activation records at the time of executing line nos. 6, 11, 14, 17, 18
- Show the corresponding displays

Conclusion

- Data structure activation record contains necessary information to control program execution
- Compiler writer must generate appropriate code for operations
- A small array, display, helps in the process
- Display management becomes a part of compiler's responsibility

NPTEL ONLINE CERTIFICATION COURSES

Thank you!

Compiler Design

Intermediate Code Generation

Santanu Chattopadhyay
Electronics and Electrical Communication Engineering

- Intermediate Languages
- Intermediate Language Design Issues
- Intermediate Representation Techniques
- Statements in Three-Address Code
- Implementation of Three-Address Instructions
- Three-Address Code Generation
- Conclusion

Intermediate Code

- Compilers are designed to produce a representation of input program in some hypothetical language or data structure
- Representations between the source language and the target machine language programs
- Offers several advantages
  - Closer to target machine, hence easier to generate code from
  - More or less machine independent, makes it easier to retarget the compiler to various different target processors
  - Allows variety of machine-independent optimizations
  - Can be implemented via syntax-directed translation, can be folded into parsing by augmenting the parser

Intermediate Languages

- Can be classified into – High-level representation and Low-level representation

High-level Representation
- Closer to source language program
- Easy to generate from input program
- Code optimization difficult, since input program is not broken down sufficiently

Low-level Representation
- Closer to target machine
- Easy to generate final code from
- Good amount of effort in generation from the source code

Intermediate Language Design Issues

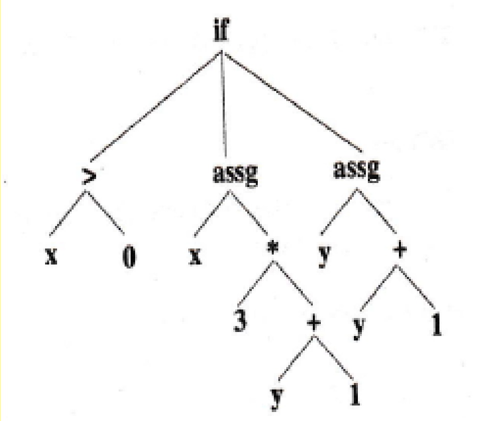
- Set of operators in intermediate language must be rich enough to allow the source language to be implemented
- A small set of operations in the intermediate language makes it easy to retarget
- Intermediate code operations that are closely tied to a particular machine or architecture can make it harder to port
- A small set of intermediate code operations may led to long instruction sequences for some source language constructs. Implies more work during optimization

Intermediate Representation Techniques

- High-level Representation
  - Abstract Syntax Trees
  - Directed Acyclic Graphs
  - P-code
- Low-level Representation

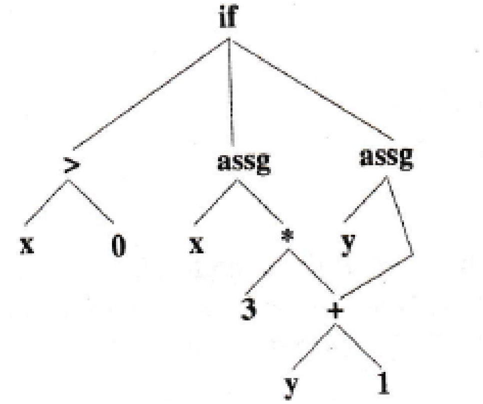
Abstract Syntax Tree

- Compact form of parse tree
- Represents hierarchical structure of a program
- Nodes represent operators, children of a node the operands
- Example: “if x>0 then x = 3*(y+1) else y = y+1”



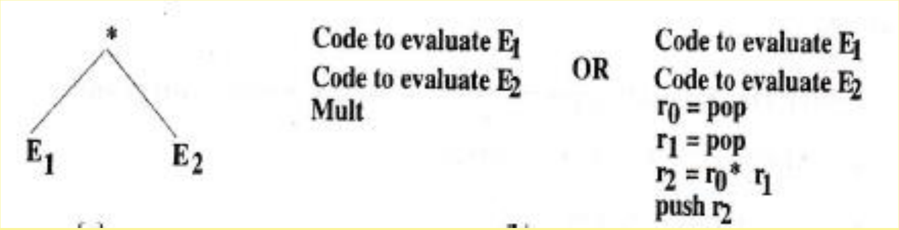
Directed Acyclic Graph (DAG)

- Similar to syntax tree
- Common subexpressions represented by single node



P-code

- Used for stack based virtual machines
- Operands are always found on the top of the stack
- May need to push operands to the stack first
- Syntax tree to P-code:



Low-level Representation – Three Address Code

- Sequence of instructions of the form "x = y op z"
- Only one operator permitted in the right hand side
- Due to its simplicity, offers better flexibility in terms of target code generation and code optimization

$x = y*z + w*a \rightarrow$

$t_1 = y*z$
$t_2 = w*a$
$x = t_1 + t_2$

Statements in Three-Address Code

- Intermediate languages usually have the following types of statements
  - Assignment
  - Jumps
  - Address and Pointer Assignments
  - Procedure Call/Return
  - Miscellaneous

Assignment Statement

- Three types of assignment statements
  - x = y op z, op being a binary operator
  - x = op y, op being a unary operator
  - x = y
- For all operators in the source language, there should be a counterpart in the intermediate language

Jump Statement

- Both conditional and unconditional jumps are required
  - goto L, L being a label
  - if x relop y goto L

Indexed Assignment

- Only one-dimensional arrays need to be supported
- Arrays of higher dimensions are converted to one-dimensional arrays
- Statements to be supported
  - x = y[i]
  - x[i] = y

Address and Pointer Assignments

- Statements required are of following types
  - x = &y, address of y assigned to x
  - x = *y, content of location pointed to by y is assigned to x
  - x = y, simple pointer assignment, where x and y are pointer variables

Procedure Call/Return

- A call to the procedure P(x1, x2, …, xn) is converted as

  param x1

  param x2

  …

  param xn

- A procedure is implemented using the following statements

  enter f,   Setup and initialization

  leave f,   Cleanup actions (if any)

  return

  return x

  retrieve x, Save returned value in x