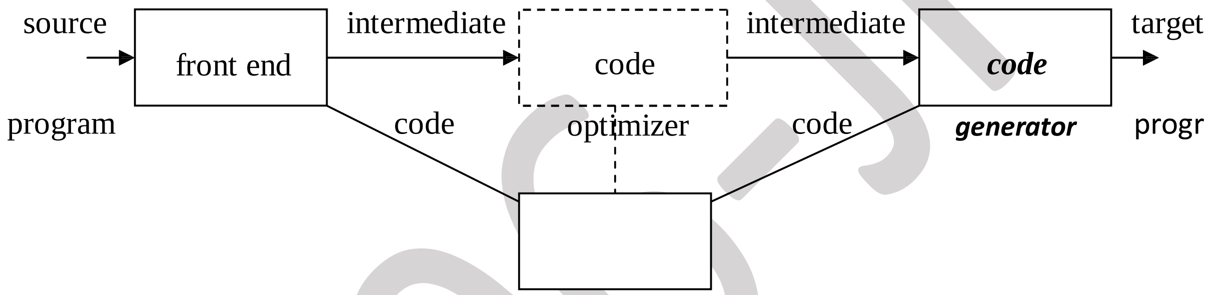
UNIT IV RUN-TIME ENVIRONMENT AND CODE GENERATION **8**

Storage Organization, Stack Allocation Space, Access to Non-local Data on the Stack, Heap Management - Issues in Code Generation - Design of a simple Code Generator.

The final phase in compiler model is the code generator. It takes as input an intermediate representation of the source program and produces as output an equivalent target program. The code generation techniques presented below can be used whether or not an optimizing phase occurs before code generation.

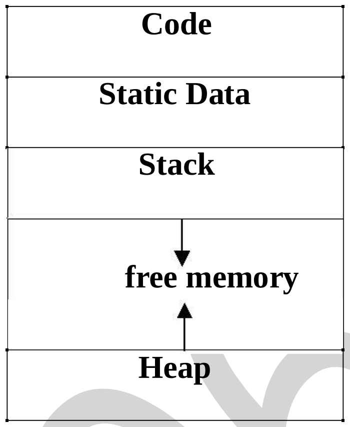
Position of code generator



STORAGE ORGANISATION

- The executing target program runs in its own logical address space in which each program value has a location.
- The management and organization of this logical address space is shared between the complier, operating system and target machine. The operating system maps the logical address into physical addresses, which are usually spread throughout memory.

Typical subdivision of run-time memory:



- Run-time storage comes in blocks, where a byte is the smallest unit of addressable memory. Four bytes form a machine word. Multibyte objects are stored in consecutive bytes and given the address of first byte.

  This run-time storage might be subdivided to hold:

  1. The generated target code,
  2. Data objects, and
  3. A counterpart of the control stack to keep track of procedure activations.

- The storage layout for data objects is strongly influenced by the addressing constraints of the target machine.
- A character array of length 10 needs only enough bytes to hold 10 characters, a compiler may allocate 12 bytes to get alignment, leaving 2 bytes unused.
- This unused space due to alignment considerations is referred to as padding.
- The size of some program objects may be known at run time and may be placed in an area called static.
- The dynamic areas used to maximize the utilization of space at run time are stack and heap.

Activation records:

- Procedure calls and returns are usually managed by a run time stack called the *control stack.*
- Each live activation has an activation record on the control stack, with the root of the activation tree at the bottom, the latter activation has its record at the top of the stack.
- The contents of the activation record vary with the language being implemented. The diagram below shows the contents of activation record.

Temporaries
Local Data
Machine Status
Control Link
Access Link
Actual Parameters
Return Value

- Temporary values such as those arising from the evaluation of expressions.
- Local data belonging to the procedure whose activation record this is.
- A saved machine status, with information about the state of the machine just before the call to procedures.
- An access link may be needed to locate data needed by the called procedure but found elsewhere.
- A control link pointing to the activation record of the caller.
- Space for the return value of the called functions, if any. Again, not all called procedures return a value, and if one does, we may prefer to place that value in a register for efficiency.
- The actual parameters used by the calling procedure. These are not placed in activation record but rather in registers, when possible, for greater efficiency.

STORAGE ALLOCATION STRATEGIES

The different storage allocation strategies are :

1. **Static allocation** – lays out storage for all data objects at compile time

2. **Stack allocation** – manages the run-time storage as a stack.
3. **Heap allocation** – allocates and deallocates storage as needed at run time from a data area known as heap.

Static allocation

- In static allocation, names are bound to storage as the program is compiled, so there is no need for a run-time support package.
- Since the bindings do not change at run-time, everytime a procedure is activated, its names are bound to the same storage locations.
- Therefore values of local names are *retained* across activations of a procedure. That is, when control returns to a procedure the values of the locals are the same as they were when control left the last time.
- From the type of a name, the compiler decides the amount of storage for the name and decides where the activation records go. At compile time, we can fill in the addresses at which the target code can find the data it operates on.

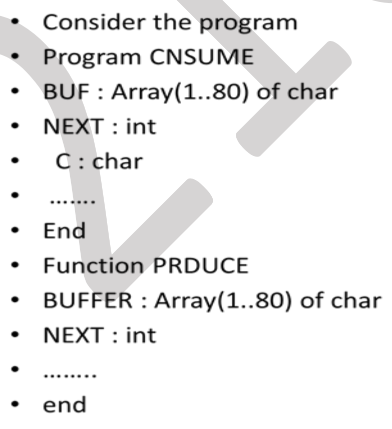
Some limitations of using static allocation:

1. The size of a data object and constraints on its position in memory must be known at compile time.

2. Recursive procedures are restricted, because all activations of a procedure use the same bindings for local names.

3. Data structures cannot be created dynamically, since there is no mechanism for storage allocation at run time.

FORTRAN use static storage allocation



- Consider the program
- Program CNSUME
- BUF : Array(1..80) of char
- NEXT : int
-   C : char
- …….
- End
- Function PRDUCE
- BUFFER : Array(1..80) of char
- NEXT : int
- ……..
- end

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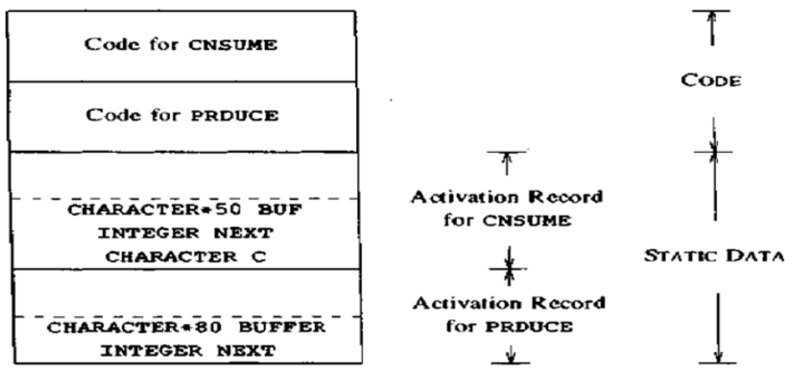

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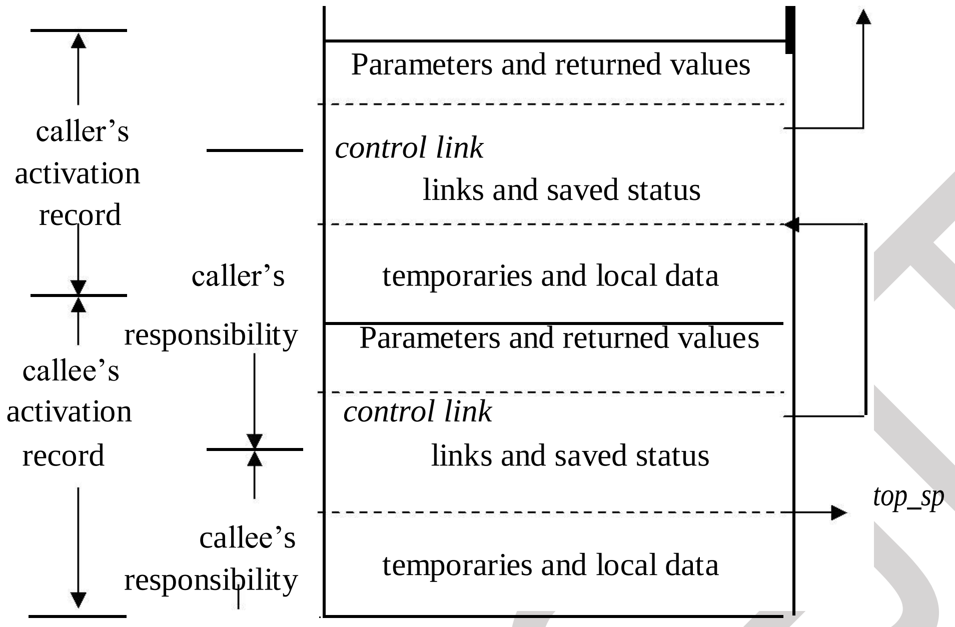
Stack allocation

- All compilers for languages that use procedures, functions or methods as units of user-defined actions manage at least part of their run-time memory as a stack.
- Each time a procedure is called , space for its local variables is pushed onto a stack, and when the procedure terminates, that space is popped off the stack.

Calling sequences:

- Procedures called are implemented in what is called as calling sequence, which consists of code that allocates an activation record on the stack and enters information into its fields.
- A return sequence is similar to code to restore the state of machine so the calling procedure can continue its execution after the call.
- The code in calling sequence is often divided between the calling procedure (caller) and the procedure it calls (callee).
- When designing calling sequences and the layout of activation records, the following principles are helpful:
  - ➢ Values communicated between caller and callee are generally placed at the beginning of the callee's activation record, so they are as close as possible to the caller's activation record.
- ➢ Fixed length items are generally placed in the middle. Such items typically include the control link, the access link, and the machine status fields.
- ➢ Items whose size may not be known early enough are placed at the end of the activation record. The most common example is dynamically sized array, where the value of one of the callee's parameters determines the length of the array.
- ➢ We must locate the top-of-stack pointer judiciously. A common approach is to have it point to the end of fixed-length fields in the activation record. Fixed-length data can then be accessed by fixed offsets, known to the intermediate-code generator, relative to the top-of-stack pointer.


caller's activation record
callee's activation record
caller's responsibility
callee's responsibility
Parameters and returned values
control link
links and saved status
temporaries and local data
Parameters and returned values
control link
links and saved status
top_sp
temporaries and local data

Division of tasks between caller and callee

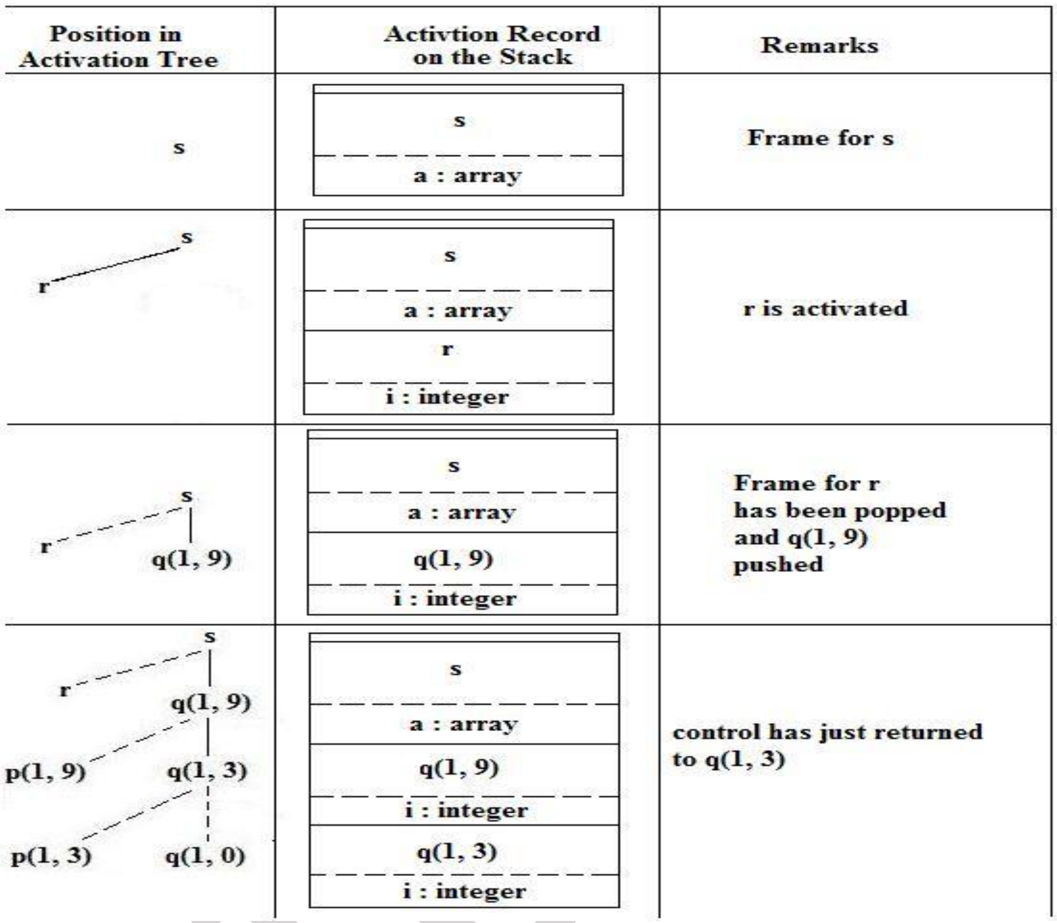
- The calling sequence and its division between caller and callee are as follows.
    - The caller evaluates the actual parameters.
    - The caller stores a return address and the old value of *top_sp* into the callee's activation record. The caller then increments the *top_sp* to the respective positions.
    - The callee saves the register values and other status information.
    - The callee initializes its local data and begins execution.
- A suitable, corresponding return sequence is:
    - The callee places the return value next to the parameters.
    - Using the information in the machine-status field, the callee restores *top_sp* and other registers, and then branches to the return address that the caller placed in the status field.
    - Although *top_sp* has been decremented, the caller knows where the return value is, relative to the current value of *top_sp*; the caller therefore may use that value.

Variable length data on stack:

- The run-time memory management system must deal frequently with the allocation of space for objects, the sizes of which are not known at the compile time, but which are local to a procedure and thus may be allocated on the stack.
- The reason to prefer placing objects on the stack is that we avoid the expense of garbage collecting

their space.

- The same scheme works for objects of any type if they are local to the procedure called and have a size that depends on the parameters of the call.



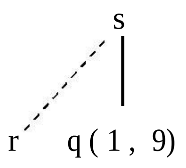
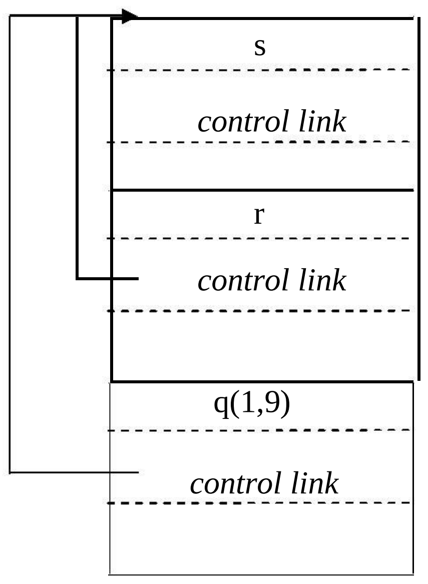
Position in Activation Tree	Activtion Record on the Stack	Remarks
s	s / a : array	Frame for s
s, r	s / a : array / r / i : integer	r is activated
s, r, q(1, 9)	s / a : array / q(1, 9) / i : integer	Frame for r has been popped and q(1, 9) pushed
s, r, q(1, 9), p(1, 9), q(1, 3), p(1, 3), q(1, 0)	s / a : array / q(1, 9) / i : integer / q(1, 3) / i : integer	control has just returned to q(1, 3)

Heap allocation

Stack allocation strategy cannot be used if either of the following is possible :

1. The values of local names must be retained when an activation ends.
2. A called activation outlives the caller.

- Heap allocation parcels out pieces of contiguous storage, as needed for activation records or other objects.
- Pieces may be deallocated in any order, so over the time the heap will consist of alternate areas that are free and in use.

Position in the activation tree	Activation records in the heap	Remarks
	 s control link r control link q(1,9) control link	Retained activation record for r

- The record for an activation of procedure r is retained when the activation ends.
- Therefore, the record for the new activation q(1 , 9) cannot follow that for s physically.
- If the retained activation record for r is deallocated, there will be free space in the heap between the activation records for s and q.
- For large blocks of storage use the heap manager.This approach results in fast allocation and deallocation of small amounts of storage, since taking and returning a block from linked list are efficient operations.

ISSUES IN THE DESIGN OF A CODE GENERATOR

The following issues arise during the code generation phase :

1. Input to code generator
2. Target program
3. Memory management
4. Instruction selection
5. Register allocation

6. Evaluation order

1. **Input to code generator:**
   - The input to the code generation consists of the intermediate representation of the source program produced by front end , together with information in the symbol table to determine run-time addresses of the data objects denoted by the names in the intermediate representation.

   - Intermediate representation can be :
     a. Linear representation such as postfix notation
     b. Three address representation such as quadruples
     c. Virtual machine representation such as stack machine code
     d. Graphical representations such as syntax trees and dags.

   - Prior to code generation, the front end must be scanned, parsed and translated into intermediate representation along with necessary type checking. Therefore, input to code generation is assumed to be error-free.

2. **Target program:**
   - The output of the code generator is the target program. The output may be :
     a. Absolute machine language
        - It can be placed in a fixed memory location and can be executed immediately.

     b. Relocatable machine language
        - It allows subprograms to be compiled separately.

     c. Assembly language
        - Code generation is made easier.

3. **Memory management:**
   - Names in the source program are mapped to addresses of data objects in run-time memory by the front end and code generator.

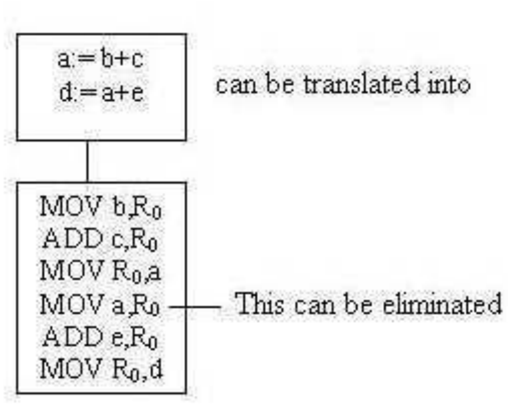
   - It makes use of symbol table, that is, a name in a three-address statement refers to a symbol-table entry for the name.

   - Labels in three-address statements have to be converted to addresses of instructions. For example,
     j :**goto***i*generates jump instruction as follows :
     - if*i*<*j*, a backward jump instruction with target address equal to location of code for quadruple *i* is generated.
     - if*i*>*j*, the jump is forward. We must store on a list for quadruple*i* the location of the first machine instruction generated for quadruple*j*. When *i*is processed, the machine locations for all instructions that forward jumps to *i* are filled.

4. **Instruction selection:**
   - The instructions of target machine should be complete and uniform.

   - Instruction speeds and machine idioms are important factors when efficiency of target program is considered.

- The quality of the generated code is determined by its speed and size.
- The former statement can be translated into the latter statement as shown below:



5. Register allocation

- Instructions involving register operands are shorter and faster than those involving operands in memory.
- The use of registers is subdivided into two subproblems :

Register allocation – the set of variables that will reside in registers at a point inthe program is selected.

➢ ***Register assignment*** – the specific register that a variable will reside in ispicked.

- Certain machine requires even-odd *register pairs* for some operands and results. For example , consider the division instruction of the form :

D x, y

where, x – dividend even register in even/odd register pair y –
divisor
even register holds the remainder odd
register holds the quotient

6. Evaluation order

- The order in which the computations are performed can affect the efficiency of the target code. Some computation orders require fewer registers to hold intermediate results than others.

A SIMPLE CODE GENERATOR

- A code generator generates target code for a sequence of three- address statements and effectively uses registers to store operands of the statements.

For example: consider the three-address statement **a := b+c**

It can have the following sequence of codes:

ADD R_j, R_i Cost = 1 // if R_i contains b and R_j contains c

(or)

ADD c, R_i Cost = 2 // if c is in a memory location

(or)

MOV c, R_j Cost = 3 // move c from memory to Rj and add

ADD R_j, R_i

Register and Address Descriptors:

- A register descriptor is used to keep track of what is currently in each registers. The register descriptors show that initially all the registers are empty.
- An address descriptor stores the location where the current value of the name can be found at run time.

A code-generation algorithm:

The algorithm takes as input a sequence of three -address statements constituting a basic block. For each three-address statement of the form x : = y op z**,** perform the following actions:

1. Invoke a function *getreg* to determine the location L where the result of the computation y op z should be stored.

2. Consult the address descriptor for y to determine y', the current location of y. Prefer the register for y' if the value of y is currently both in memory and a register. If the value of y is not already in L, generate the instruction **MOV y' , L** to place a copy of y in L.

3. Generate the instruction **OP z' , L** where z' is a current location of z. Prefer a register to a memory location if z is in both. Update the address descriptor of x to indicate that x is in location L. If x is in L, update its descriptor and remove x from all other descriptors.

4. If the current values of y or z have no next uses, are not live on exit from the block, and are in registers, alter the register descriptor to indicate that, after execution of x : = y op z , those registers will no longer contain y or z.

The algorithmic sequence of *getreg* function can be,

1. if x value is in register that register is returned.
2. If (1) fails, new register is returned.
3. If (2) fails, and the operation needs a special register, that register value is temporarily moved to the memory and the register is returned.
4. If (3) fails, finally memory location is returned.

Generating Code for Assignment Statements:

- The assignment d : = (a-b) + (a-c) + (a-c) might be translated into the following three-address code sequence:

```
 t : = a – b         u : =
a – c         v : = t + u
d : = v + u
```

with d live at the end.

Code sequence for the example is:

Statements	**Code Generated**	**Register descriptor**	**Address descriptor**
		Register empty	
t : = a - b	MOV a, R_0 SUB b, R0	R_0 contains t	t in R_0
u : = a - c	MOV a , R1 SUB c , R1	R_0 contains t R1 contains u	t in R_0 u in R1
v : =t + u	ADD R_1, R_0	R_0 contains v R_1 contains u	u in R_1 v in R_0
d : = v + u	ADD R_1, R_0 MOV R_0, d	R_0 contains d	d in R_0 d in R_0 and memory

Generating Code for Indexed Assignments

The table shows the code sequences generated for the indexed assignment statements **a : = b [i]** and **a [i] : = b**

Statements	**Code Generated**
a : = b[i]	MOV b(Ri), R
a[i] : = b	MOV b, a(Ri)

Generating Code for Pointer Assignments

The table shows the code sequences generated for the pointer assignments **a : = *p** and ***p : = a**

Statements	**Code Generated**
a : = *p	MOV *R_p, a
*p : = a	MOV a, *R_p

Generating Code for Conditional Statements

Statement	Code
if x < y goto z	CMP x, y CJ<z /* jump to z if condition code is negative */
x : = y +z if x <0 goto z	MOV y, R_0 ADD z, R_0 MOV R_0,x CJ<Z