Final code generation

- Write a set of auxiliary procedures for generating labels and temporaries.
- Find types of variables. (Hopefully you found this in earlier part).
- Find all temporaries that you might need (GenCode for each expression can find all temporaries).
- Make a map of how stack and heap is going to look like. That is, how are specific variables going to get mapped in the memory.
- Associate an offset for all variables and parameters.
- Establish a protocol for calling a function and returning from a function.
- For every expression type, find a correspondence between the expression and its corresponding implementation in assembly. (Check GenCode related handout)
- For every statement type, find a corresponding implementation (Check GenCode related handout)

Class

- Find size of class
- Determine all fields: include its fields and field of class classes.
- Assign an offset for members of fields (including those that you receive from superclass). You will need type for every class:
- Arrange for code generation for every method:

```
ClassType::CodeGen(){
 Fields *fl= Fields(); // find the fields of this class
 Methods *mt = Methods(); // methods of this class
 int offset = 0; // initial offset

 // assume that fit is an iternator
 for (fit = fl->begin(); fit!= fl->end(); fit++) {
   // assign offset
   (*fit).Offset = offset;
   class_size = class_size + (*fit).Size();
   // set offset for next field
   offset = offset+(*it).Size();
 }
 // assume that iterator mit will go over all methods of class
 for (mit = mt->begin(); mit!= ml->end(); mit++) {
   // generate code for method
   (*mit)->GenCode();
 }
}
```

Allocation of space for variables

- Every variable (including instance and local) has an offset associated with it.
- Two kinds of variables:
  1. Primitive types: Allocate space for primitive types on stack
     Allocate 1 word for each primitive type
  2. Reference types:
     - Allocate space for reference on stack (1 word)
     - Allocate space for object on heap (equal to size of class)
- Example:

```
void func() {
   // create an object
   ClassC x = new ClassC();
   ...
   // store a value in x.c
   x.c = 4;
   ...
}
```

  - `func`'s activation record will allocate space for x. The space for x is, thus, allocated when func is executed.
  - Generate code that will invoke `sbrk` to allocate space on heap for x. Use the size of `ClassC` to determine amount of space (can be determined by compiler).
  - Store the address returned by `sbrk` on stack at an offset for the reference (say, xoffset).

Generation of code for variable access

- What kind of code should be generated to refer to a specific name?
- Remember: every variable gets mapped to a memory location: either in stack or heap.
- Local variable: Data is on stack:
  - Find offset for each variable
  - Can find variable by \$fp + offset.
- Reference type:
  - Find address for data on heap
  - Find offset within heap
  - Example:
    1. Read the value of x into register r1 to get address on data associated with x on heap.
    2. Add offset of c to content of r1 to get address of x.c into register r2.
    3. Store value 4 into the address specified in register r2.

    So generated code for the assignment will look something like the following:

```
# load reference for x in register 16
lw $16, $fp(xoffset)
# load value 4 in register 17
lw $17, 0x04
# store $17 in address specified by 16+coffset.
sw $17, $16(coffset)
```

Method declaration

- For `R p(T1 a1, T2 a2, ..)` , do the following.
- Make the implicit parameter explicit: `R p(Class this, T1 a1, T2 a2, ...)`
- Assign an offset for each parameter. The first parameter will be nearest to the framepointer.
- Layout space for local variables: lvarsize = size of local + temporary variables
- Find registers that you want to save: `rsize := size of registers.`
- Determine stack frame size: `stack frame size := lvarsize + rsize;`
- Generate an assembly routine of the form:

```
    .global   _p_C_asm
    .ent      _p_C_asm
_p_C_asm:
```

- Use stack frame size to generate code that will allocate space on stack: Generate code of the form `sp := sp - stack frame size;`
- Generate code for saving registers at specific offsets with AR
- Generate code for the body
- Generate code for loading registers from the current activation record.
- Generate code for jumping to routine that called this routine.

Method activation: `x.p(f1, f2, ..., fn)`

- Generate code for pushing value of `fi` on stack. Note: you should generate code for evaluating and pushing the parameters on stack in such a way that `fn` is pushed first, and `f1` last.
- generate code for pushing value of `x` on stack.
- generate code for jumping to the assembly routine generated for `p`
- Save any registers that you want to save

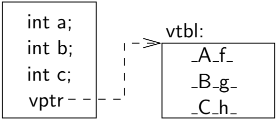
```
// Assumption: m stores information about a method
MethodInvocationExpression *m;

// get parameters of method
ParamList p = m->GetParams();

// object on which method is invoked
Object *o = m->Object();

// Traverse parameter list in reverse order
// assume that this is how it is stored
for (pit = p.begin(); pit != p.end(); pit++) {
  (*pit).GenCode(); // generate code for each parameter
}
for (pit = p.begin(); pit != p.end(); pit++) {
  // push the symbtab that stores value for each
  // parameter on stack
  Print(``push (*pit).symtab on stack'');}
}
// push the object on stack
Print(``push o->symtab on stack'');
// construct assembly name for p
String asmFunc = AssemblyName(o->ClassName(), m->MethodName());
Print(``jump to asmFunc'');
```

Implementation of dynamic functions

- Define a table, say `vtbl`, for a class. The table contains pointers to virtual functions of the class. Each object of a class contains pointer to the virtual function table of the class.

```
class A {
    int a;
    void f(int);
    void g(int);
    void h(char);
};
class B extend A {
    int b;
    void g(int);
};
class C extends B {
    int c;
    void h(int);
}
```

- Class C layout:

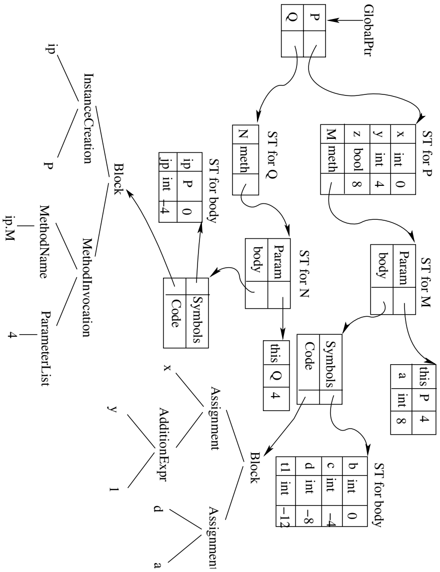


- Invoke a method `f`:
  - push arguments on stack
  - find f's index in virtual function table
  - jump to the label in table.

Example: input program

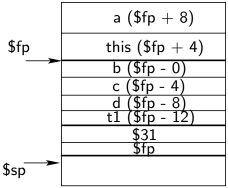
```
class P {
  int x;
  int y;
  boolean z;
  void M(int a) {
     int b, c;
     int d;

     x = y+1;
     d = a;
  }
}
class Q {
  void N() {
    P ip;
    int jp;

    ip = new P;
    ip.M(4);
  }
}
```

A compact parse tree

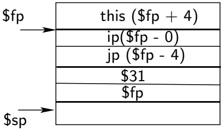


Code Generation for program

- Code generation for example = code generation for class P and code generation for class Q.
- The following computations need to be done:
  - Class: Offsets for all instances variables + size of class. Offset will be used for accessing a specific instance variable in heap.
    For instance, in order to access instance variable x of an object X (through expression X.x) of P, we need offset of x.
  - Parameters: offsets for all parameters + total space taken by parameters. Offset will be used for accessing specific parameter on stack.
  - Block (local and temp) variables: Offsets for all local variables + total size. Total size will be used for builiding AR, and offset for accessing local variables within activation record.
- How will stack look for procedures?



Layout for P.M



Layout for Q.N

General Approach

- Remember: $sp points to first free location in stack.
  $fp: points to first local variable.
- For each method, generate a unique assembly routine.
- All local variables (primitives and references) and parameters of a program or procedure will go on stack.
  - Local variable: -offset($fp) (offset of local variable)
  - Parameter: offset($fp) (offset of parameter)
- Use a load - compute - store model.
- Global data: For every global variable, say GL, generate code like the following:

```
      .data
GL: .word 0
```

  Initialize GL to 0, and now GL can be accessed symbolically.
- Literal: Literals like strings, float, and double values can be stored in following manner:

```
      .data
astr: .asciiz "this is a string"
temp1:  .double 4.56, 0.4e-25
temp2:  .float 2.34, 0.5e-20
```

Code generation for methods of P

- Find the temporaries that you need for P.M: 1.
- Compute various sizes for P.M:
  - Variables: 4+4+4+4: 16 bytes (var size)
  - Registers: 4 bytes ($31) + 4 bytes ($fp)
  - Framesize = 16 + 4 + 4 =24
- Code generation of P.M = prologue + body + epilogue.
  We first look at prologue.
- Generate header for P.M:

```
    .text
    .ent      _P_M_asm
_P_M_asm:
```

- Generate code that will construct an activation frame for P.M:

```
    subu $sp, 24 # 24 = size of activation frame.
```

- Generate code for saving registers: save $31 and $fp only.

```
    sw $31, 24-16($sp) # $sp+framesize-var size
    sw $fp 24-16-4($sp) # store after $31
```

- Generate code for setting new frame pointer:

```
    addu $fp, $sp, 24 # 24 = framesize
```

- This should take care of prologue for P.M

Code generation for body of P.M

- Code generation here will involve generating body for statements of P.M.
- generate code for evaluating `x := y+1;`
  - First evaluate the right hand side y+1;
  - Store this value in a temp.
  - Generated code should first find y in memory, and change its value. So the compiler must first find where y comes from. By looking at symbol tables, it finds that y is an instance variable of P. So y is a component of object `this` passed to M. Generated code can find y in two steps
    - Find "this" on stack using $fp (it should be the first argument):
      ```
      lw $19, 4($fp) # 4 = offset of object
      ```
    - Now access y from this
      ```
      lw $20, 4($19) # 4 = offset of y on heap
      ```
      Register 20 contains the value of y.
  - Add 1 to $20. Then store it in temp:
    ```
    addi $20, $20, 1 # add 1
    sw $20, -12($fp) # store in temp (at offset 20)
    ```
  - Generate code for assigning `temp` to x. (Note that x will need to be accessed in the same manner as y as above):
    ```
    lw $19, -12($fp) # load temp; offset for temp=12
    lw $20, 4($fp) # 4 = offset of this
    sw $19, 0($20) # store $19 into x(at offset 0)
    ```
- generate code for evaluating `d = a`: Load content of a into register and store it into d.
  ```
  lw $19, 8($fp) # 8 = offset of a
  sw $19, -8($fp) # store in d (at offset -8)
  ```

Epilogue for P.M

- Generate code for restoring $31 and $fp:

```
lw $31, 24-16($sp) # 24-16 = offset for 31
lw $fp 24-16-4($sp) # 24-16-4 = offset for for sp
```

- generate code for cleaning up stack

```
addu  $sp, 24
```

- generate code for returning:

```
j     $31
```

- Generated end:

```
.end  _P_M_asm
```

Code Generation for Q.N

- Computations by compiler:
  - Variables: 4 bytes (for ip) + 4 bytes (for jp) = 8 bytes
  - Registers: 4 (register 31) + 4 bytes (register $fp)
    Framesize = 8 + 4 + 4 = 16
- Generate header for Q.N:
```
.ent    _Q_N_asm
_Q_N_asm:
```
- generate code for constructing activation frame for Q:
```
subu $sp, 16 # 16 = size of activation frame.
```
- Generate code for saving registers: save $31 and $fp only.
```
sw $31, 16-8($sp)
sw $fp 16-8-4($sp)
```
- Generate code for setting new frame pointer:
```
addu $fp, $sp, 16 # 16 = framesize
```

Generate body for Q.N

- Generate code for `ip := new P`
  1. Allocate space for an object. Size of space defined by size of P. This is done by calling sbrk
  2. Store the address returned by sbrk in ip.

     ```
     li $v0, 9 # 9 = sbrk code
     li $a0, 12 # 12 = sizeof(P)
     syscall # system call
     sw $v0, -0($fp) # store returned address($2) on stack
     ```
  3. The address of space allocated is stored on stack in location $fp=0. (that is, first local variable).
  4. This is the place where a constructor should be called. It will involve the following:
     - Evaluate arguments of constructor
     - Push arguments on stack
     - Call constructor

Generate body for Q.N - cont'd.

- Generate code for method invocation: `ip.M(4)`
  1. generate code for evaluating parameters and store the evaluated values on stack.
  2. Note that there are two parameters to M: i) object on which method is being invoked (ip in this case) and ii) int parameter with value 4.
  3. Push first argument (ip):
     ```
     subu $sp, 4 # allocate 4 bytes for first arg
     li $19, -0($fp) # load content of ip (at offset -0)
     sw $19, 4($sp) # store value of arg into stack
     ```
  4. Evaluate second argument and push it on stack:
     ```
     subu $sp, 4 # allocate 4 bytes for first arg
     li $19, 4 # load 4 in register $19
     sw $19, 4($sp) # store val of arg into stack
     ```
  5. Now jump to assembly routine _P_M_asm:
     ```
     jal _P_M_asm
     ```
  6. After returning from procedure, need to take back space which was allocated for arguments. So generate code for deallocating argument space (two arguments)
     ```
     addu $sp, 8 # 8 = size of arguments
     ```

Generate body for Q.N - cont'd.

- Epilogue for Q.N:
  1. Generate code for restoring $31 and $fp:

     ```
     lw $31, 16-8($sp) # restore $31
     lw $fp 16-8-4($sp) # restore $fp
     ```
  2. generate code for cleaning up stack

     ```
     addu  $sp, 16
     ```
  3. generate code for returning:

     ```
     j     $31
     ```
  4. Generated end:

     ```
     .end  _Q_N_asm
     ```