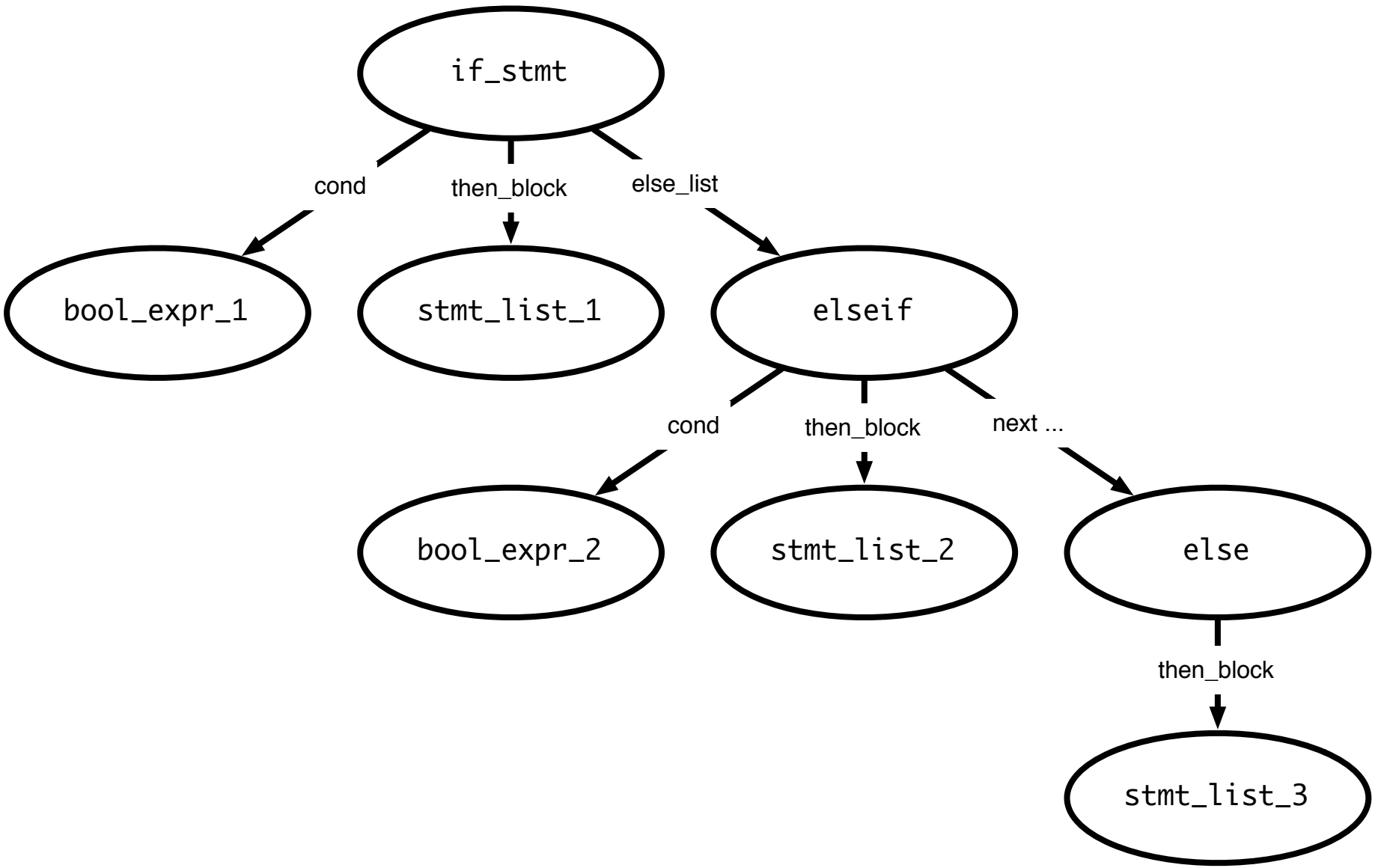
Processing control structures

If statements

```
if <bool_expr_1> then
  <stmt_list_1>
elseif <bool_expr_2> then
  <stmt_list_2>
...
else
  <stmt_list_3>
endif
```

If statements



Generating code for ifs

```
if <bool_expr_1> then
  <stmt_list_1>
elseif <bool_expr_2> then
  <stmt_list_2>
else
  <stmt_list_3>
endif
```

```
  <code for bool_expr_1>
  j<!op> ELSE_1
  <code for stmt_list_1>
  jmp OUT
ELSE_1:
  <code for bool_expr_2>
  j<!op> ELSE
  <code for stmt_list_2>
  jmp OUT
ELSE:
  <code for stmt_list_3>
OUT:
```

Notes on code generation

- The <op> in j<!op> is dependent on the type of comparison you are doing in <bool_expr>
- When you generate JUMP instructions, you should also generate the appropriate LABELs
  - But you may not put the LABEL into the code immediately
    - *e.g.*, the OUT label (when should you create this? When should you put this in code?)
  - Instead, generate the labels when you first process the if statement (i.e., before you process the children) so that it's available when necessary
- Remember: labels have to be unique!

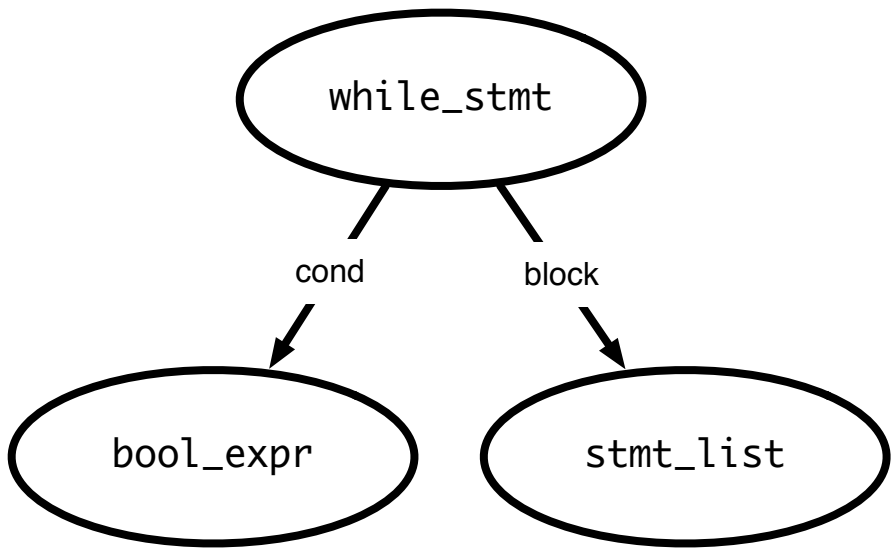
Directly generating binary code

- Recall difference between assembly code and machine code
  - Assembly code must be processed by assembler, machine code directly executable
  - One job of assembler: decide actual addresses to jump to instead of labels
- So what happens if we generate binary directly?
  - Need to insert JMP instructions before knowing where the label will be
- Solution: *backpatching*
  - Store offset of JMP instruction in semantic record
  - When label is created, access JMP instruction and "patch up" jump target

Processing Loops

While loops

```
while <bool_expr> do
  <stmt_list>
end
```



Generating code for do-while loops

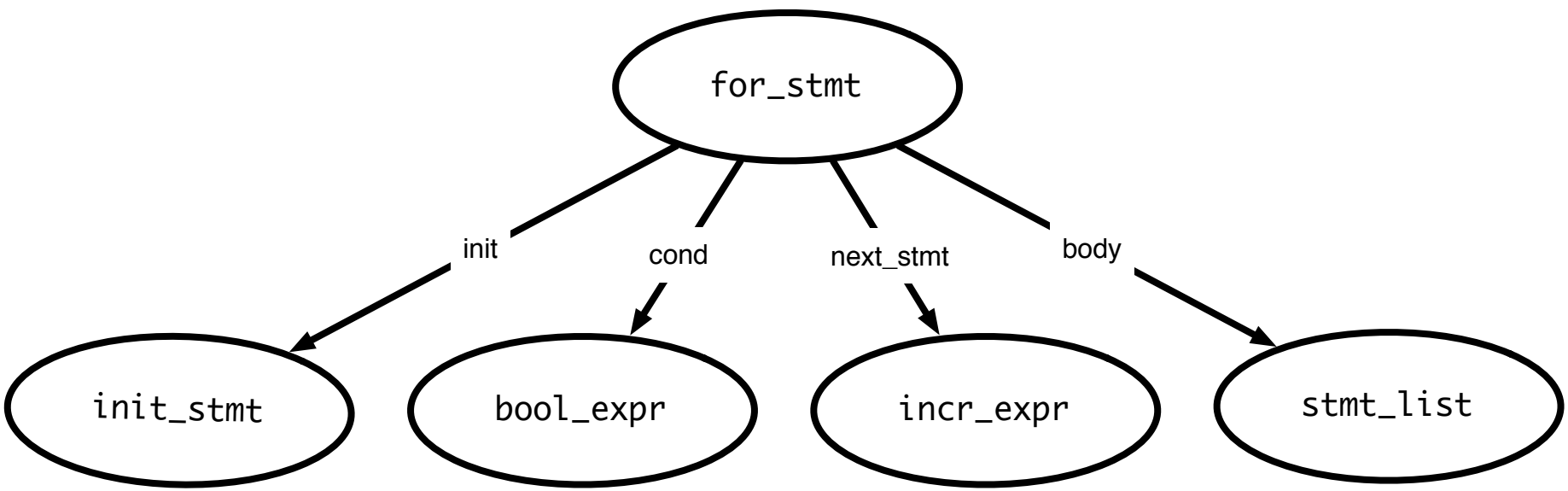
```
do
  <stmt_list>
while <bool_expr>;
```

```
LOOP:
  <stmt_list>
  <bool expr>
  j<op> LOOP
OUT:
```

- Note that we j<op> instead of j<!op>
  - Jump when the expression is *true*
- Re-evaluate expression each time
- Question: what would code for "while" loop look like?

For loops

```
for (<init_stmt>;<bool_expr>;<incr_stmt>)
  <stmt_list>
end
```



Generating code: for loops

```
for (<init_stmt>;<bool_expr>;<incr_stmt>)
  <stmt_list>
end
```

```
  <init_stmt>
LOOP:
  <bool_expr>
  j<!op> OUT
  <stmt_list>
INCR:
  <incr_stmt>
  jmp LOOP
OUT:
```

- Execute init_stmt first
- Jump out of loop if bool_expr is false
- Execute incr_stmt after block, jump back to top of loop
- Question: Why do we have the INCR label?

continue and break statements

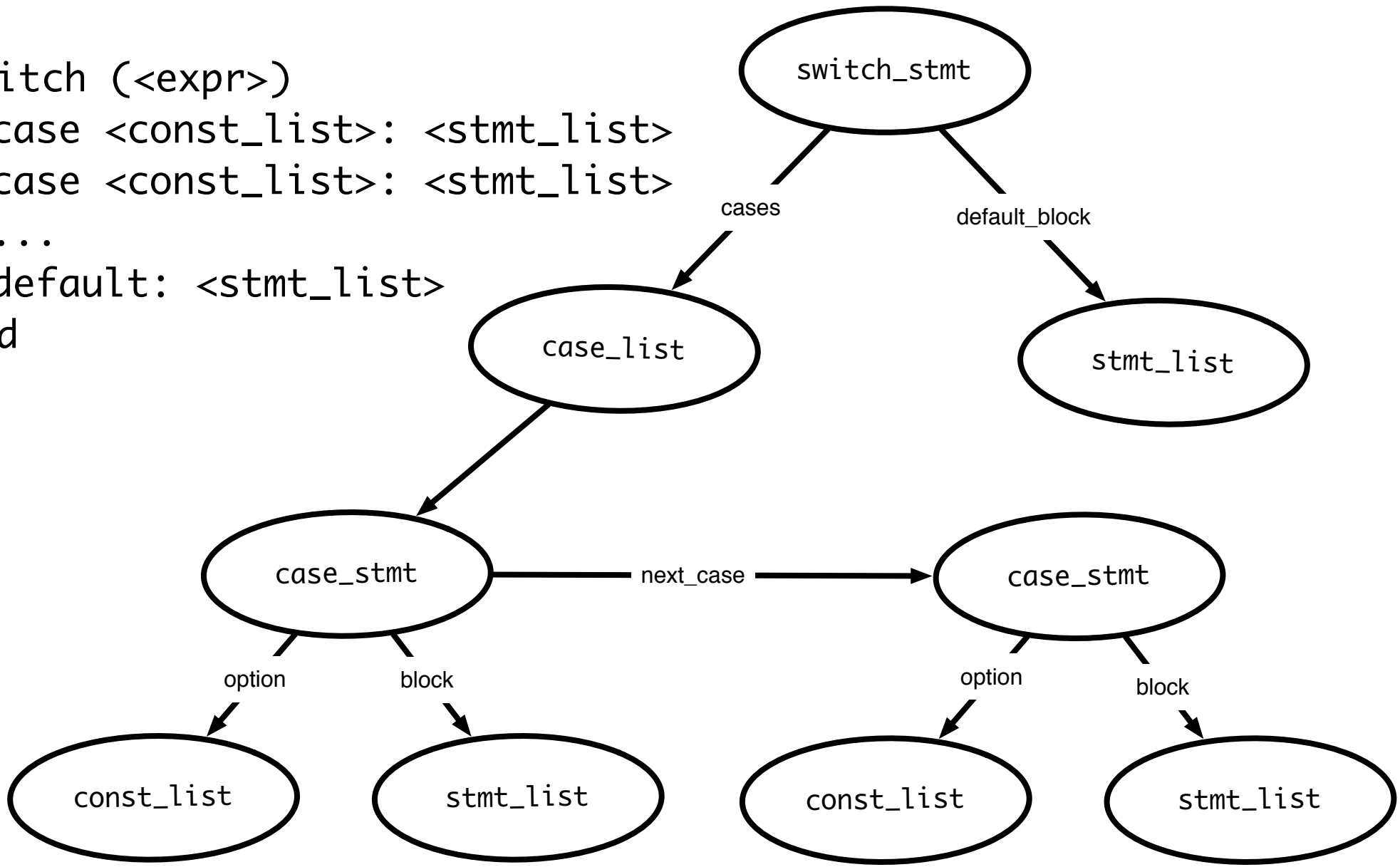
```
for (<init_stmt>;<bool_expr>;<incr_stmt>)
  <stmt_list>
end
```

```
  <init_stmt>
LOOP:
  <bool_expr>
  j<!op> OUT
  <stmt_list>
INCR:
  <incr_stmt>
  jmp LOOP
OUT:
```

- Continue statements: skip past rest of block, perform incr_stmt and restart loop
- Break statements: jump out of loop (do not execute incr_stmt)
- Caveats:
  - Code for stmt_list is generated earlier–where do we jump?
  - Keep track of "loop depth" as you descend through AST

Switch statements

```
switch (<expr>)
  case <const_list>: <stmt_list>
  case <const_list>: <stmt_list>
  ...
  default: <stmt_list>
end
```



Switch statements

```
switch (<expr>)
  case <const_list>: <stmt_list>
  case <const_list>: <stmt_list>
  ...
  default: <stmt_list>
end
```

- Generated code should evaluate <expr> and make sure that some case matches the result
- Question: how to decide where to jump?

Deciding where to jump

- Problem: do not know *which label* to jump to until switch expression is evaluated
- Use a jump table: an array indexed by case values, contains address to jump to
  - If table is not full (i.e., some possible values are skipped), can point to a default clause
    - If default clause does not exist, this can point to error code
  - Problems
    - If table is sparse, wastes a lot of space
    - If many choices, table will be very large

Jump table example

Consider the code:
((xxxx) is address of code)

Case x is
(0010) When 0: stmts
(0017) When 1: stmts
(0192) When 2: stmts
(0198) When 3 stmts;
(1000) When 5 stmts;
(1050) Else stmts;

Table only has one
Unnecessary row
(for choice 4)

Jump table has 6 entries:

0	JUMP 0010
1	JUMP 0017
2	JUMP 0192
3	JUMP 0198
4	JUMP 1050
5	JUMP 1000

Jump table example

Consider the code:
((xxxx) Is address of code)

Case x is
(0010) When 0: stmts0
(0017) When 1: stmts1
(0192) When 2: stmts2
(0198) When 3 stmts3
(1000) When 987 stmts4
(1050) When others stmts5

Jump table has 6 entries:

0	JUMP 0010
1	JUMP 0017
2	JUMP 0192
3	JUMP 0198
4	JUMP 1050
. . .	JUMP 1050
986	JUMP 1050
987	JUMP 1000

Table only has 983 unnecessary rows. Doesn't appear to be the right thing to do! ***NOTE: table size is proportional to range of choice clauses, not number of clauses!***

Do a binary search

Consider the code: ((xxxx) Is address of code)

Case x is
(0010) When 0: stmts0
(0017) When 1: stmts1
(0192) When 2: stmts2
(0198) When 3 stmts3
(1000) When 987 stmts4
(1050) When others stmts5

Jump table has 6 entries:

0	JUMP 0010
1	JUMP 0017
2	JUMP 0192
3	JUMP 0198
987	JUMP 1000

Perform a binary search on the table. If the entry is found, then jump to that offset. If the entry isn't found, jump to others clause. *O(log n)* time, n is the size of the table, for each jump.

Linear search example

Consider the code:
(xxxx) Is offset of local
Code start from the
Jump instruction

Case x is
(0010) When 0: stmts
(0017) When 1: stmts
(0192) When 2: stmts
(1050) When others stmts;

If there are a small number of choices, then do an in-line linear search. A straightforward way to do this is generate code analogous to an IF THEN ELSE.

If (x == 0) then stmts1;
Elseif (x = 1) then stmts2;
Elseif (x = 2) then stmts3;
Else stmts4;

O(n) time, n is the size of the table, for each jump.

Dealing with jump tables

```
switch (<expr>)
  case <const_list>: <stmt_list>
  case <const_list>: <stmt_list>
  ...
  default: <stmt_list>
end
```

```
    <expr>
    <code for jump table>
  LABEL0:
    <stmt_list>
  LABEL1:
    <stmt_list>
  ...
  DEFAULT:
    <stmt_list>
  OUT:
```

- Generate labels, code, then build jump table
  - Put jump table after generated code
- Why do we need the OUT label?
  - In case of `break` statements

Case statements

- As in LITTLE
- What makes them different from switch statements?
  - Arbitrary expressions in each CASE
- How should you generate code for this?