CMPT 755
Compilers

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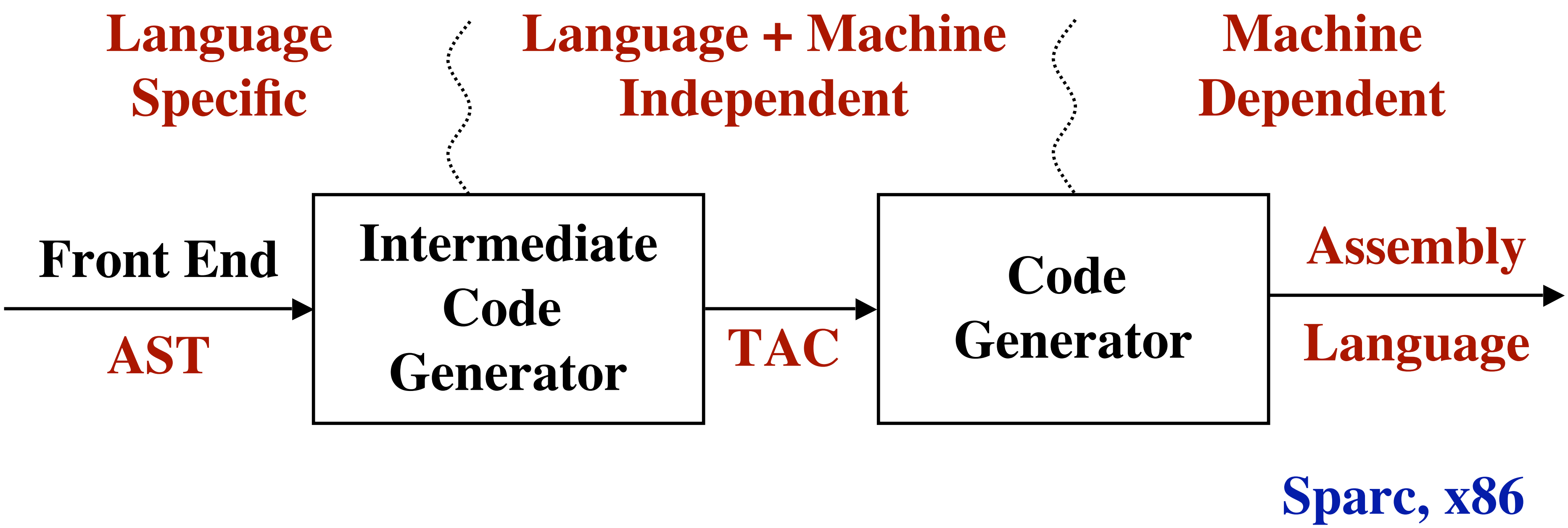
TAC: Intermediate Representation

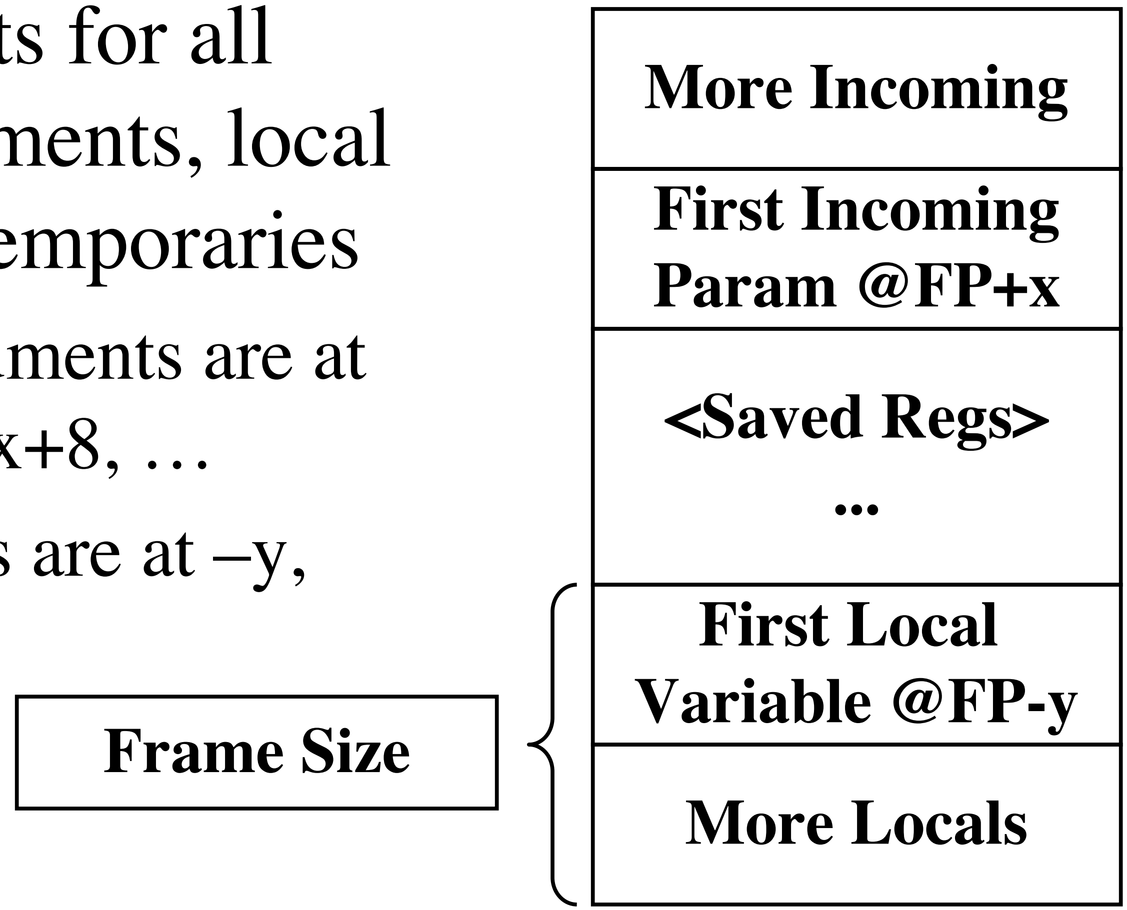


TAC: 3-Address Code

- Instructions that operate on named locations and labels
  - Mini-ISA or “generic assembly”
- Locations
  - Every location is some place to store 4 bytes
    - Pretend we can make infinitely many of them
  - Either on stack frame:
    - You assign offset (plus other information possibly)
  - Or global variable
    - Referred to by global name
- Labels (you generate as needed)

Function arguments

- Compute offsets for all incoming arguments, local variables and temporaries
  - Incoming arguments are at offset x, x+4, x+8, …
  - Locals+Temps are at –y, -y-4, -y-8,…
- Compute →



Computing Location Offsets

```
class A {
  void f (int a /* @x+4 */,
          int b /* @x+8 */,
          int c /* @ x+12 */) {
    int s; // @-y-4
    if (c > 0) {
          int t; … // @-y-8
    } else {
          int u;    // @-y-12
          int t; … // @-y-16
    }
  }
}
```

Location offsets for temporaries are ignored on this slide

← You could reuse @-y-8 here, but okay if you don't

TAC Instructions (I)

- Assignment
- rhs can be
  - Location
  - String Constant
  - Integer Constant
  - Label

- Example:

```
t2 := t1;
t3 := "Hello"
t5 := 42;
t7 := _L1;
```

```
Code.Append(
   new LoadStringConstant(
        /*t3=*/GenTempVar(), "Hello"));
```

TAC Instructions (II)

- Arithmetic
  - Binary add, sub, multiply, divide, modulo
- Equality (eq)
- Relational (lt)
- Logical (and, or)

- Labels and branches:
  - Insert label in TAC stream

    _L4:
  - Unconditional branch

    goto _L4
  - Conditional branch

    ifz t1 **goto** _L3

TAC Instructions (III)

- Preparing function calls
  - param t1;
  - (eval left to right)
  - (push right to left)
  - pop n
- Calling methods
- Label vs. Address
  - call
- Void vs. nonvoid
  - T1 = call _L3
  - call t3 (akin to jump return)

TAC Instructions (IV)

- Defining functions
  - BeginFunc <n>
    - Enter function, specify or forward-declare stack frame size
  - EndFunc
  - Return
  - Return t3
- Loads and Stores
  - Optional integer offset
  - Examples:

    t2 = *(t4)

    *(t5+4) = t6
- Unary minus, logical not

  t2 := not t3

What TAC doesn't give you

- Array indexing (bounds check)
- Two or n-dimensional arrays
- Relational <=, >=, >, …
- Conditional branches other than **ifz**
- Field names in records/structures
  - Use base+offset load/store
- Object data and method access

```
int gcd(int x, int y)
{
    int d;
    d = x - y;
    if (d > 0)
        return gcd(d, y);
    else if (d < 0)
        return gcd(x, -d);
    else
        return x;
}
```

```
_gcd:
    BeginFunc 32 ;
    _tmp0 := x - y ;
    d := _tmp0 ;
    _tmp1 := 0 ;
    _tmp2 := _tmp1 < d ;
    ifz _tmp2 goto _L0 ;
    param y #1 ;
    param d #0 ;
    _tmp3 := call _gcd ;
    pop 8 ;
    return _tmp3 ;
    goto _L1 ;
_L0:
    _tmp4 := 0 ;
        ….
_L1:
    EndFunc ;
```

```
int factorial(int n)
{
 if (n <=1 ) return 1;
 return n*factorial(n-1);
}

void main()
{
   Print(factorial(6));
}
```

```
_factorial:
        BeginFunc 32 ;
        _tmp0 := 1 ;
        _tmp1 := n lt _tmp0 ;
        _tmp2 := n eq _tmp0 ;
        _tmp3 := _tmp1 or _tmp2 ;
        ifz _tmp3 goto _L0 ;
        _tmp4 := 1 ;
        Return _tmp4 ;
_L0:
        _tmp5 := 1 ;
        _tmp6 := n minus _tmp5 ;
        param _tmp6 #0 ;
        _tmp7 := call _factorial ;
        pop 4 ;
        _tmp8 := n * _tmp7 ;
        return _tmp8 ;
        EndFunc ;
```

Short-circuiting Booleans

- More complex if statements:
  - if (a or b and not c) { … }
- Typical sequence:

```
_t1 := not c
_t2 := b and _t1
_t3 := a or _t2
```

- Short-circuit is possible in this case:
  - if (a and b and c) { … }
- Short-circuit sequence:

```
_t1 := a
ifz _t1 goto _L0 /* sckt */
goto _L4
_L0: _t2 := b
ifz _t2 goto _L1
```

```
void main() {
  int i;
  for (i = 0; i < 10; i = i + 1)
    Print(i);
}
```

```
main:
    BeginFunc 24 ;
    _tmp0 := 0 ;
    i := _tmp0 ;
_L0:
    _tmp1 := 10 ;
    _tmp2 := i < _tmp1 ;
    ifz _tmp2 goto _L1 ;
    param i #0 ;
    call _PrintInt ;
    pop 4 ;
    _tmp3 := 1 ;
    _tmp4 := i + _tmp3 ;
    i := _tmp4 ;
    goto _L0 ;
_L1:
    EndFunc ;
```

```
void foo(int[] arr)
      { arr[1] = arr[0] * 2; }
```

```
_foo:
   BeginFunc 48 ;
    _tmp0 := 1 ;
   _tmp1 := 4 ;
   _tmp2 := _tmp1 * _tmp0 ;
   _tmp3 := arr + _tmp2 ;
   _tmp4 := *(_tmp3) ;
   _tmp5 := 0 ;
   _tmp6 := 4 ;
   _tmp7 := _tmp6 * _tmp5 ;
   _tmp8 := arr + _tmp7 ;
   _tmp9 := *(_tmp8) ;
   _tmp10 := 2 ;
   _tmp11 := _tmp9 * _tmp10 ;
   _tmp4 := _tmp11 ;
   EndFunc ;
```

Wrong

```
_foo:
   BeginFunc 44;
   _t0 := 1;
   _t1 := 4;
   _t2 := _t1 * _t0;
   _t3 := arr + _t2;
   _t4 := 0;
   _t5 := 4;
   _t6 := _t5 * _t4;
   _t7 := arr + _t6;
   _t8 := *(_t7);
   _t9 := 2;
   _t10 := _t8 * _t9;
   *(_t3) := _t10;
   EndFunc;
```

Correct

Backpatching

- Easiest way to implement the translations is to use two passes
- In one pass we may not know the target label for a jump statement
- *Backpatching* allows us to do it in one pass
- Generate branching statements with the targets of the jumps temporarily unspecified
- Put each of these statements into a list which is then filled in when the proper label is determined

Correctness vs. Optimizations

- When writing backend, correctness is paramount
  - Efficiency and optimizations are secondary concerns at this point
- Don’t try optimizations at this stage

Basic Blocks

- Functions transfer control from one place (the caller) to another (the called function)
- Other examples include any place where there are branch instructions
- A *basic block* is a sequence of statements that enters at the start and ends with a branch at the end
- Remaining task of code generation is to create code for basic blocks and branch them together