Lecture 11 – Code Generation

THEORY OF COMPILATION

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www.cs.technion.ac.il/~yahave/tocs2011/compilers-lec11.pptx

Reference: Dragon 8. MCD 4.2.4

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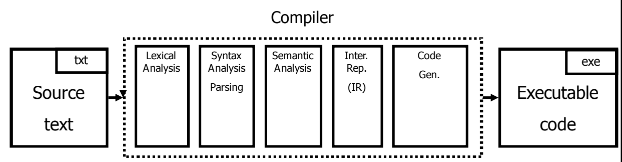
You are here



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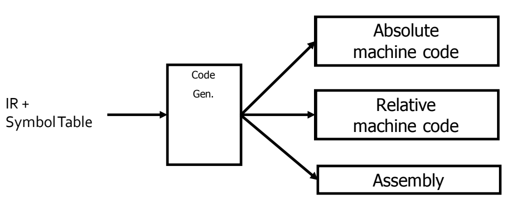
target languages



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From IR to ASM: Challenges

- mapping IR to ASM operations
  - what instruction(s) should be used to implement an IR operation?
  - how do we translate code sequences
- call/return of routines
  - managing activation records
- memory allocation
- register allocation
- optimizations

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Intel IA-32 Assembly

- Going from Assembly to Binary…
  - Assembling
  - Linking
- AT&T syntax vs. Intel syntax
- We will use AT&T syntax
  - matches GNU assembler (GAS)

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IA-32 Registers

- Eight 32-bit general-purpose registers
  - EAX – accumulator for operands and result data. Used to return value from function calls.
  - EBX – pointer to data. Often use as array-base address
  - ECX – counter for string and loop operations
  - EDX – I/O pointer (GP for us)
  - ESI – GP and source pointer for string operations
  - EDI – GP and destination pointer for string operations
  - EBP – stack frame (base) pointer
  - ESP – stack pointer
- EFLAGS register
- EIP (instruction pointer) register
- Six 16-bit segment registers
- … (ignore the rest for our purposes)

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Not all registers are born equal

- EAX
  - Required operand of MUL,IMUL,DIV and IDIV instructions
  - Contains the result of these operations
- EDX
  - Stores remainder of a DIV or IDIV instruction (EAX stores quotient)
- ESI, EDI
  - ESI – required source pointer for string instructions
  - EDI – required destination pointer for string instructions
- Destination Registers of Arithmetic operations
  - EAX, EBX, ECX, EDX
- EBP – stack frame (base) pointer
- ESP – stack pointer

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IA-32 Addressing Modes

- Machine-instructions take zero or more operands
- Source operand
  - Immediate
  - Register
  - Memory location
  - (I/O port)
- Destination operand
  - Register
  - Memory location
  - (I/O port)

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Immediate and Register Operands

- Immediate
  - Value specified in the instruction itself
  - GAS syntax – immediate values preceded by $
  - add $4, %esp
- Register
  - Register name is used
  - GAS syntax – register names preceded with %
  - mov %esp,%ebp

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Memory and Base Displacement Operands

- Memory operands
  - Value at given address
  - GAS syntax - parentheses
  - mov (%eax), %eax
- Base displacement
  - Value at computed address
  - Address computed out of
    - base register, index register, scale factor, displacement
  - offset = base + (index*scale) + displacement
  - Syntax: disp(base,index,scale)
  - movl $42, $2(%eax)
  - movl $42, $1(%eax,%ecx,4)

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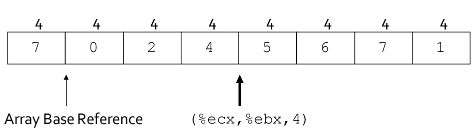
Base Displacement Addressing




```
Mov (%ecx,%ebx,4), %eax
```

```
%ecx = base
%ebx = 3
```

offset = base + (index*scale) + displacement

offset = base + (3*4) + 0 = base + 12

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How do we generate the code?

- break the IR into basic blocks
- basic block is a sequence of instructions with
  - single entry (to first instruction), no jumps to the middle of the block
  - single exit (last instruction)
  - code execute as a sequence from first instruction to last instruction without any jumps
- edge from one basic block B1 to another block B2 when the last statement of B1 may jump to B2

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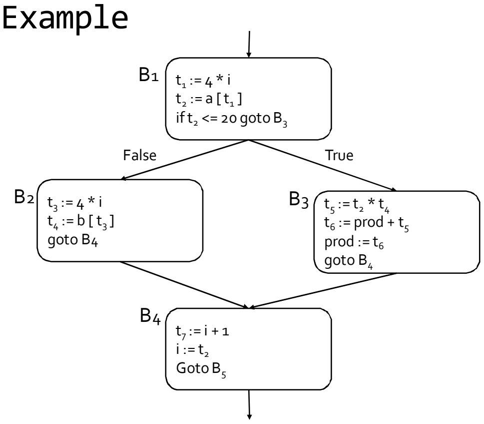
Example



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creating basic blocks

- Input: A sequence of three-address statements
- Output: A list of basic blocks with each three-address statement in exactly one block
- Method
  - Determine the set of leaders (first statement of a block)
    - The first statement is a leader
    - Any statement that is the target of a conditional or unconditional jump is a leader
    - Any statement that immediately follows a goto or conditional jump statement is a leader
  - For each leader, its basic block consists of the leader and all statements up to but not including the next leader or the end of the program

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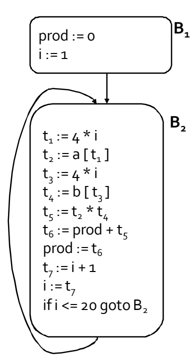
control flow graph

- A directed graph G=(V,E)
- nodes V = basic blocks
- edges E = control flow
  - (B1,B2) ∈E when control from B1 flows to B2



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example

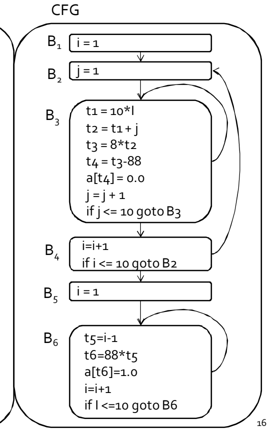
source

```
for i from 1 to 10 do
  for j from 1 to 10 do
    a[i, j] = 0.0;
for i from 1 to 10 do
  a[i, i] = 1.0;
```

IR

```
1)  i = 1
2)  j =1
3)  t1 = 10*I
4)  t2 = t1 + j
5)  t3 = 8*t2
6)  t4 = t3-88
7)  a[t4] = 0.0
8)  j = j + 1
9)  if j <= 10 goto (3)
10) i=i+1
11) if i <= 10 goto (2)
12) i=1
13) t5=i-1
14) t6=88*t5
15) a[t6]=1.0
16) i=i+1
17) if I <=10 goto (13)
```

CFG



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Variable Liveness

- A statement x = y + z
  - defines x
  - uses y and z
- A variable x is live at a program point if its value is used at a later point

y = 42	x undef, y live, z undef
z = 73	x undef, y live, z live
x = y + z	x is live, y dead, z dead
print(x);	x is dead, y dead, z dead

(showing state after the statement)

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Computing Liveness Information

- between basic blocks – dataflow analysis (next lecture)
- within a single basic block?
- idea
  - use symbol table to record next-use information
  - scan basic block backwards
  - update next-use for each variable

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Computing Liveness Information

- INPUT: A basic block B of three-address statements. symbol table initially shows all non-temporary variables in B as being live on exit.
- OUTPUT: At each statement i: x = y + z in B, liveness and next-use information of x, y, and z at i.
- Start at the last statement in B and scan backwards
  - At each statement i: x = y + z in B, we do the following:
  1. Attach to i the information currently found in the symbol table regarding the next use and liveness of x, y, and z.
  2. In the symbol table, set x to "not live" and "no next use."
  3. In the symbol table, set y and z to "live" and the next uses of y and z to i

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Computing Liveness Information

- Start at the last statement in B and scan backwards
  - At each statement i: x = y + z in B, we do the following:
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  3. In the symbol table, set y and z to "live" and the next uses of y and z to i

```
x = 1
y = x + 3
z = x * 3
x = x * z
```

can we change the order between 2 and 3?

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common-subexpression elimination

- common-subexpression elimination

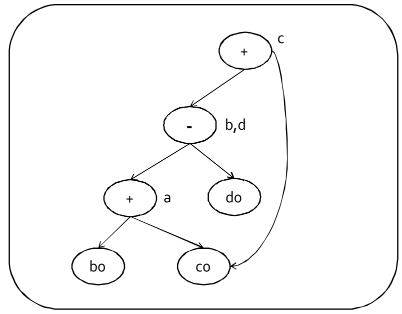
a = b + c
b = a – d
c = b + c
d = a - d

⇒

a = b + c
b = a – d
c = b + c
d = b

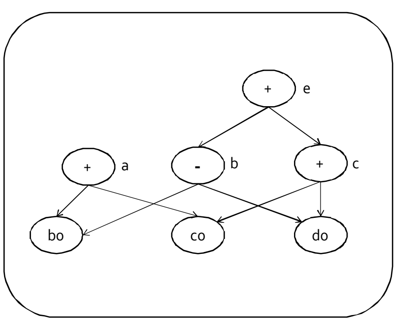
DAG Representation of Basic Blocks

a = b + c
b = a - d
c = b + c
d = a - d



DAG Representation of Basic Blocks

a = b + c
b = b - d
c = c + d
e = b + c



algebraic identities

a = x^2
b = x*2
c = x/2
d = 1*x

⇒

a = x*x
b = x+x
c = x*0.5
d = x

coming up next

- register allocation

The End