Appendix C
Architectural Alternatives: the Number of Addresses

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Overview

Slide 1

- basic characterizations
  - counting memory references
  - 3 explicit addresses
  - 2 explicit addresses
  - 1 explicit address
  - 0 explicit addresses
- adding registers to a
  - 3-address machine
  - 2-address machine
  - 1-address machine
  - 0-address machine
  - load/store machine

Preliminaries

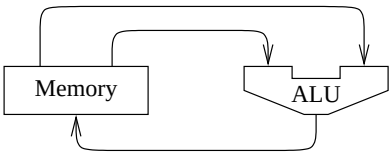
Slide 2

- all operands in memory: operand ≡ memory address
- assume that each address is stored in an instruction extension word
- memory addresses use the notation "[*address*]"
- accounting:
  - instruction references
  - data references

3-Address Architecture

Slide 3

- all three addresses are explicit
- data paths



An example

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$$a = a * b + c * d * e$$

a	100
b	108
c	116
d	124
e	132

mulx	[100], [108], [100]	! $a * b \rightarrow a$	4 instr. refs	3 data refs
mulx	[116], [124], [200]	! $c * d \rightarrow t$	4 instr. refs	3 data refs
mulx	[200], [132], [200]	! $t * e \rightarrow t$	4 instr. refs	3 data refs
add	[100], [200], [100]	! $a + t \rightarrow a$	4 instr. refs	3 data refs
			16 instr. refs	12 data refs

2-Address Architecture

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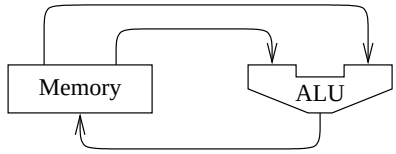
- 2 explicit addresses
- one address is a simple source
- the other is a source and destination
- data paths



An Example

$$a = a * b + c * d * e$$

a	100
b	108
c	116
d	124
e	132

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mulx	[108], [100]	! $b * a \rightarrow a$	3 instr. refs	3 data refs
mov	[116], [200]	! $c \rightarrow t$	3 instr. refs	2 data refs
mulx	[124], [200]	! $d * t \rightarrow t$	3 instr. refs	3 data refs
mulx	[132], [200]	! $e * t \rightarrow t$	3 instr. refs	3 data refs
add	[200], [100]	! $t + a \rightarrow a$	3 instr. refs	3 data refs
			15 instr. refs	14 data refs

1-Address Architecture

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- one explicit address
- the *accumulator* provides the second source and the destination
- *ldx* load the accumulator
- *stx* store the accumulator

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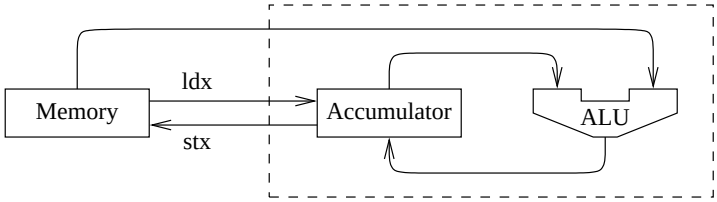
Data Paths



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An Example

$$\mathrm{a} = \mathrm{a} * \mathrm{b} + \mathrm{c} * \mathrm{d} * \mathrm{e}$$

ldx	[100]	! acc = a	2 instr. refs	1 data ref
mulx	[108]	! acc = acc $* b$	2 instr. refs	1 data ref
stx	[100]	! a = acc	2 instr. refs	1 data ref
ldx	[116]	! acc = c	2 instr. refs	1 data ref
mulx	[124]	! acc = acc $* d$	2 instr. refs	1 data ref
mulx	[132]	! acc = acc $* e$	2 instr. refs	1 data ref
add	[100]	! acc = acc $+ a$	2 instr. refs	1 data ref
stx	[100]	! a = acc	2 instr. refs	1 data ref
			16 instr. refs	8 data refs

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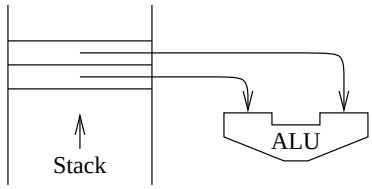
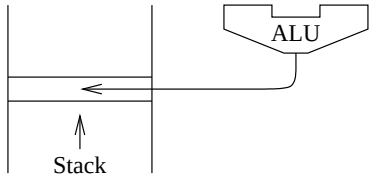
0-Address Architecture

- the *stack* provides sources and destination
- *pushx* and *popx*
- fetching the operands



- saving the result



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An Example

$$\mathrm{a = a * b + c * d * e}$$

pushx	[100]	! $\langle a \rangle$	2 instr. refs	1 data ref
pushx	[108]	! $\langle a \rangle \langle b \rangle$	2 instr. refs	1 data ref
mulx		! $\langle a * b \rangle$	1 instr. ref	
pushx	[116]	! $\langle a * b \rangle \langle c \rangle$	2 instr. refs	1 data ref
pushx	[124]	! $\langle a * b \rangle \langle c \rangle \langle d \rangle$	2 instr. refs	1 data ref
mulx		! $\langle a * b \rangle \langle c * d \rangle$	1 instr. ref	
pushx	[132]	! $\langle a * b \rangle \langle c * d \rangle \langle e \rangle$	2 instr. refs	1 data ref
mulx		! $\langle a * b \rangle \langle c * d * e \rangle$	1 instr. ref	
add		! $\langle a * b + c * d * e \rangle$	1 instr. ref	
popx	[100]	2 instr. refs	1 data ref	
			16 instr. refs	6 data refs

Registers

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- reduce data references (intermediate results)
- reduce instruction references (small addresses)

Data Paths for 2- and 3-Address

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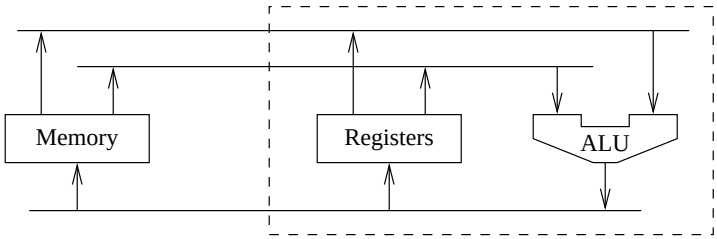

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3-Address Example

mulx	[100], [108], %r2	! $a * b \rightarrow$ %r2	3 instr. refs	2 data refs
mulx	[116], [124], %r3	! $c * d \rightarrow$ %r3	3 instr. refs	2 data refs
mulx	[132], %r3, %r3	! $e *$ %r3 $\rightarrow$ %r3	2 instr. refs.	1 data ref
add	%r3, %r2, [100]	! %r3 + %r2 $\rightarrow a$	2 instr. refs	1 data ref
			10 instr. refs	6 data refs

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2-Address Example

mulx	[108], [100]	! $b * a \rightarrow a$	3 instr. refs	3 data refs
mov	[116], %r2	! $c \rightarrow$ %r2	2 instr. refs	1 data ref
mulx	[124], %r2	! $d *$ %r2 $\rightarrow$ %r2	2 instr. refs	1 data refs
mulx	[132], %r2	! $e *$ %r2 $\rightarrow$ %r2	2 instr. refs	1 data ref
add	%r2, [100]	! %r2 + $a \rightarrow a$	2 instr. refs	2 data refs
			11 instr. refs	8 data refs

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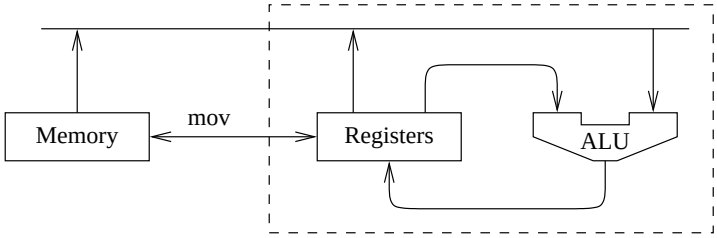
1 1/2-Address



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1 1/2-Address Example

mov	[100], %r2	! $a \rightarrow$ %r2	2 instr. refs	1 data ref
mulx	[108], %r2	! $b *$ %r2 $\rightarrow$ %r2	2 instr. refs	1 data ref
mov	[116], %r3	! $c \rightarrow$ %r3	2 instr. refs	1 data ref
mulx	[124], %r3	! $d *$ %r3 $\rightarrow$ %r3	2 instr. refs	1 data ref
mulx	[132], %r3	! $e *$ %r3 $\rightarrow$ %r3	2 instr. refs	1 data ref
add	%r3, %r2	! %r3 + %r2 $\rightarrow$ %r2	1 instr. ref	
mov	%r2, [100]	! %r2 $\rightarrow a$	2 instr. refs	1 data ref
			13 instr. refs	6 data refs

1-Address Example

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ldx	[100]	! acc = a	2 instr. refs	1 data ref
mulx	[108]	! acc = acc $* b$	2 instr. refs	1 data ref
stx	%r2	! %r2 = acc	1 instr. ref	
ldx	[116]	! acc = c	2 instr. refs	1 data ref
mulx	[124]	! acc = acc $* d$	2 instr. refs	1 data ref
mulx	[132]	! acc = acc $* e$	2 instr. refs	1 data ref
add	%r2	! acc = acc + %r2	1 instr. ref	
stx	[100]	! a = acc	2 instr. refs	1 data ref
			14 instr. refs	6 data refs

Load/Store Example

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ldx	[100], %r2	! *load a*	2 instr. refs	1 data ref
ldx	[108], %r3	! *load b*	2 instr. refs	1 data ref
mulx	%r3, %r2, %r2	! $a * b \rightarrow$ %r2	1 instr. ref	
ldx	[116], %r4	! *load c*	2 instr. refs	1 data ref
ldx	[124], %r5	! *load d*	2 instr. refs	1 data ref
mulx	%r4, %r5, %r4	! $c * d \rightarrow$ %r4	1 instr. ref	
ldx	[132], %r6	! *load e*	2 instr. refs	1 data ref
mulx	%r4, %r6, %r4	! $c * d * e \rightarrow$ %r4	1 instr. ref	
add	%r4, %r2, %r2	! $c * d * e + a * b \rightarrow$ %r2	1 instr. ref	
stx	%r2, [100]		2 instr. refs	1 data ref
			16 instr. refs	6 data refs

Summary

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