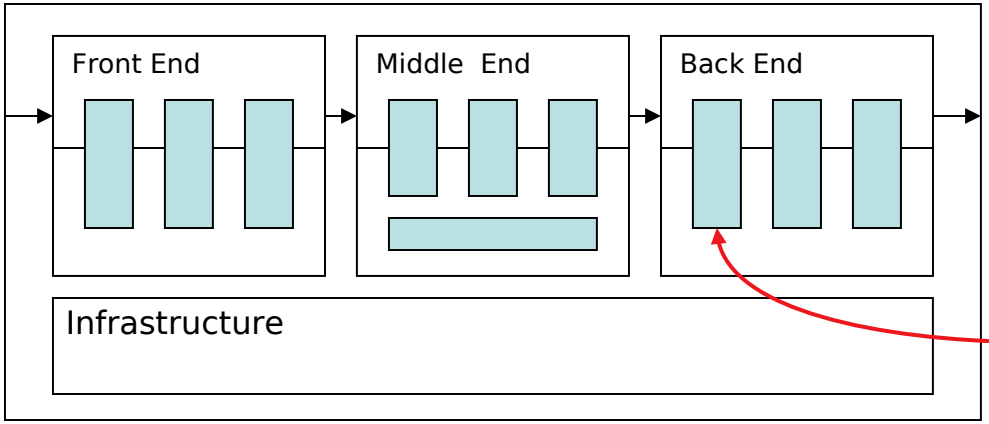
Instruction Selection: Peephole Matching

The Problem

Writing a compiler is a lot of work

- Would like to reuse components whenever possible
- Would like to automate construction of components



Today's lecture:
Automating
Instruction
Selection

- Front end construction is largely automated
- Middle is largely hand crafted
- (Parts of) back end can be automated

Definitions

Instruction selection

- Mapping *IR* into assembly code
- Assumes a fixed storage mapping & code shape
- Combining operations, using address modes

Instruction scheduling

- Reordering operations to hide latencies
- Assumes a fixed program *(set of operations)*
- Changes demand for registers

Register allocation

- Deciding which values will reside in registers
- Changes the storage mapping, may add false sharing
- Concerns about placement of data & memory operations

The Problem

Modern computers (still) have many ways to do anything

Consider register-to-register copy

- Obvious operation is `i2i` $r_i \Rightarrow r_j$
- Many others exist

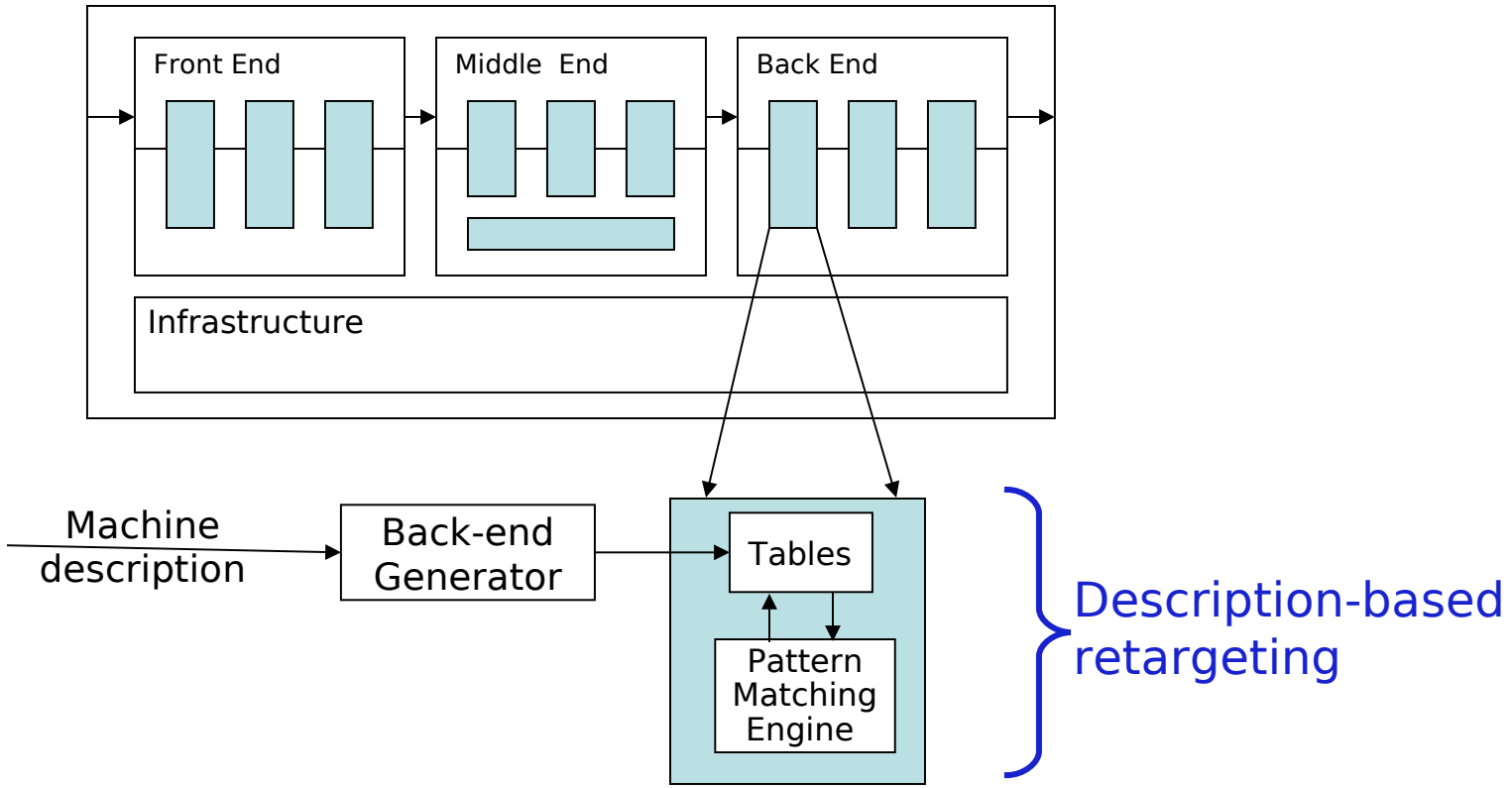
`addI` r_i,0 $\Rightarrow$ r_j	`subI` r_i,0 $\Rightarrow$ r_j	`lshiftI` r_i,0 $\Rightarrow$ r_j
`multI` r_i,1 $\Rightarrow$ r_j	`divI` r_i,1 $\Rightarrow$ r_j	`rshiftI` r_i,0 $\Rightarrow$ r_j
`orI` r_i,0 $\Rightarrow$ r_j	`xorI` r_i,0 $\Rightarrow$ r_j	**…** and others **…**

- Human would ignore all of these
- Algorithm must look at all of them & find low-cost encoding
  - → Take context into account (*busy functional unit?*)

And this is an overly-simplified example

The Goal

Want to automate generation of instruction selectors



Machine description should also help with scheduling & allocation

The Big Picture

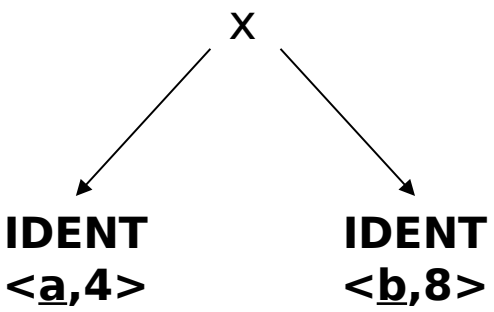
Need pattern matching techniques

- Must produce good code (*some metric for good*)
- Must run quickly

Our treewalk (visitor) code generator ran quickly

How good was the code?

Tree



Treewalk Code

```
loadI   4      ⇒ r5
loadA   r5     ⇒ r6
loadI   8      ⇒ r7
loadA   r7     ⇒ r8
mult    r6,r8  ⇒ r9
```

Desired Code

```
loadAI  4      ⇒ r5
loadAI  8      ⇒ r6
mult    r5,r6  ⇒ r7
```

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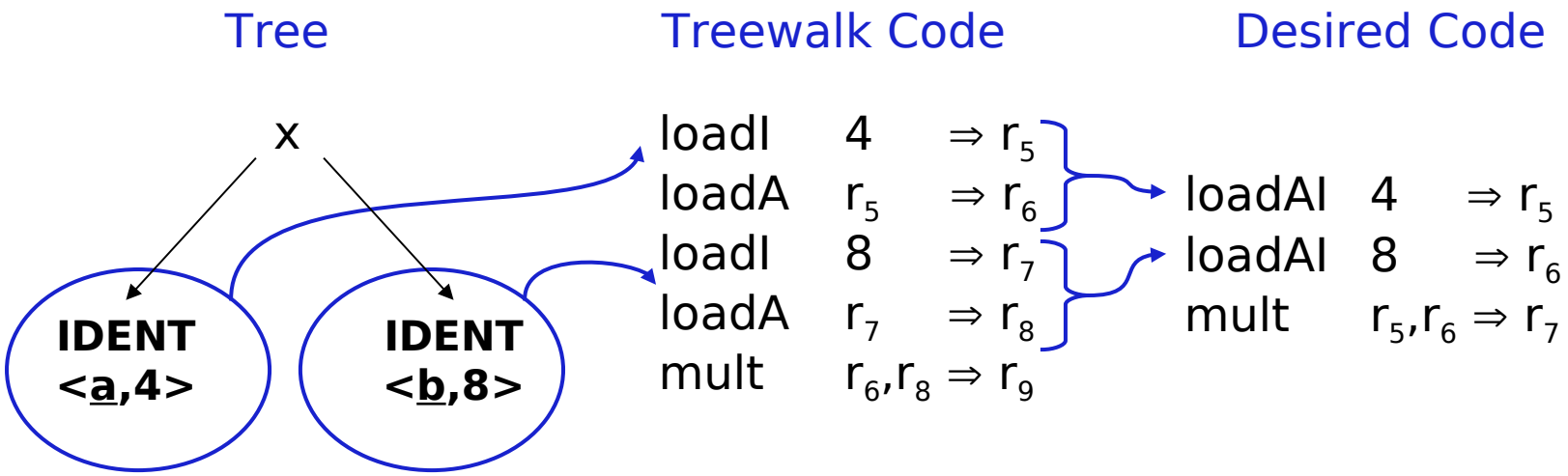

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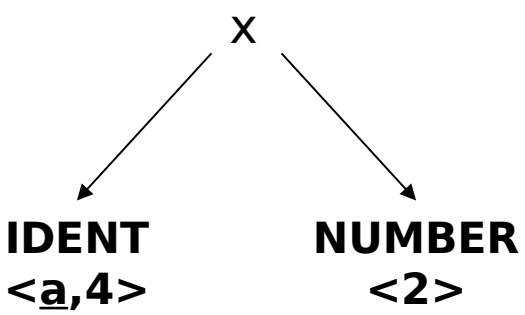

Treewalk Code

```
loadI   4     ⇒ r5
loadA   r5    ⇒ r6
loadI   2     ⇒ r7
mult    r6,r7 ⇒ r8
```

Desired Code

```
loadAI  4     ⇒ r5
multI   r5,2  ⇒ r7
```

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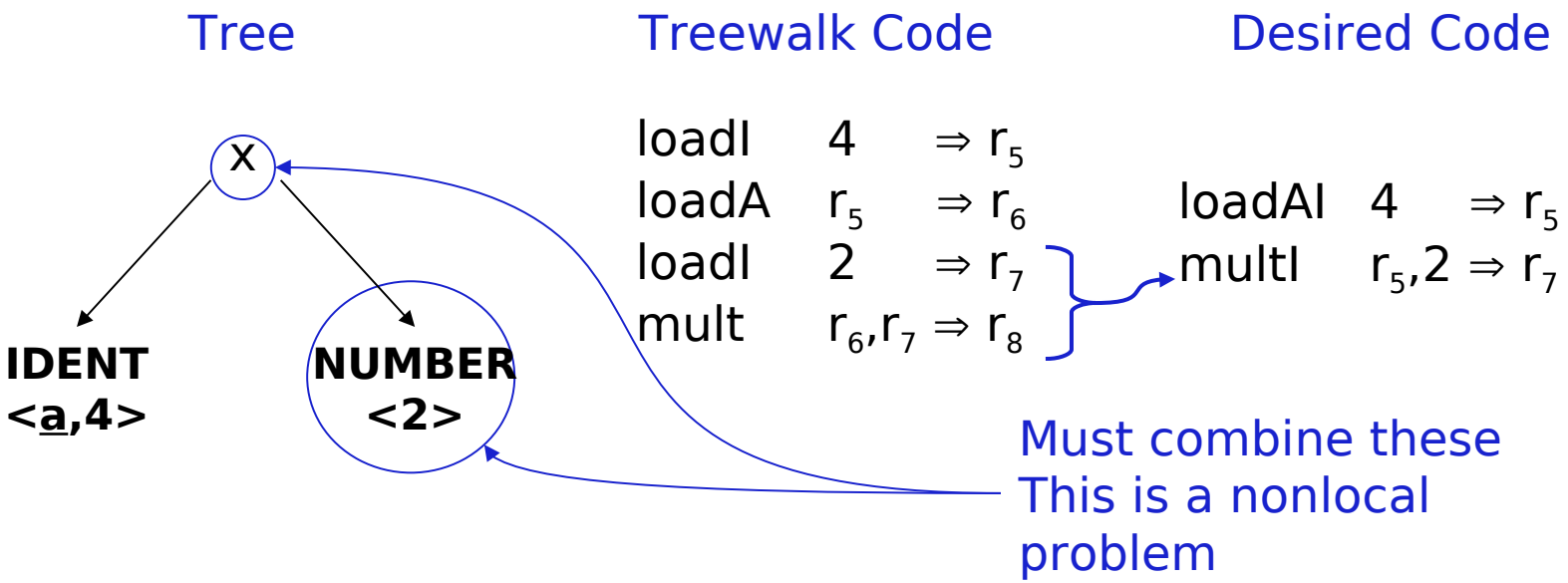

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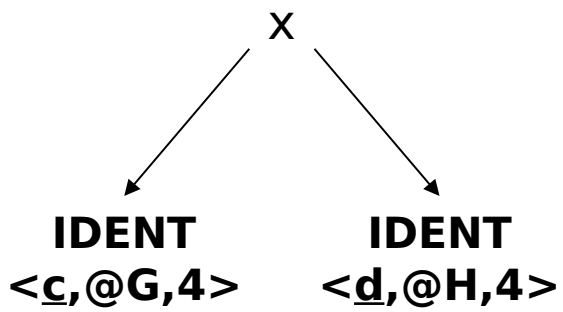


Treewalk Code

```
loadI   @G  ⇒ r5
loadI   4   ⇒ r6
loadAO  r5,r6 ⇒ r7
loadI   @H  ⇒ r7
loadI   4   ⇒ r8
loadAO  r8,r9 ⇒ r10
mult    r7,r10⇒ r11
```

Desired Code

```
loadI   4       ⇒ r5
loadAI  r5,@G   ⇒ r6
loadAI  r5,@H   ⇒ r7
mult    r6,r7   ⇒ r8
```

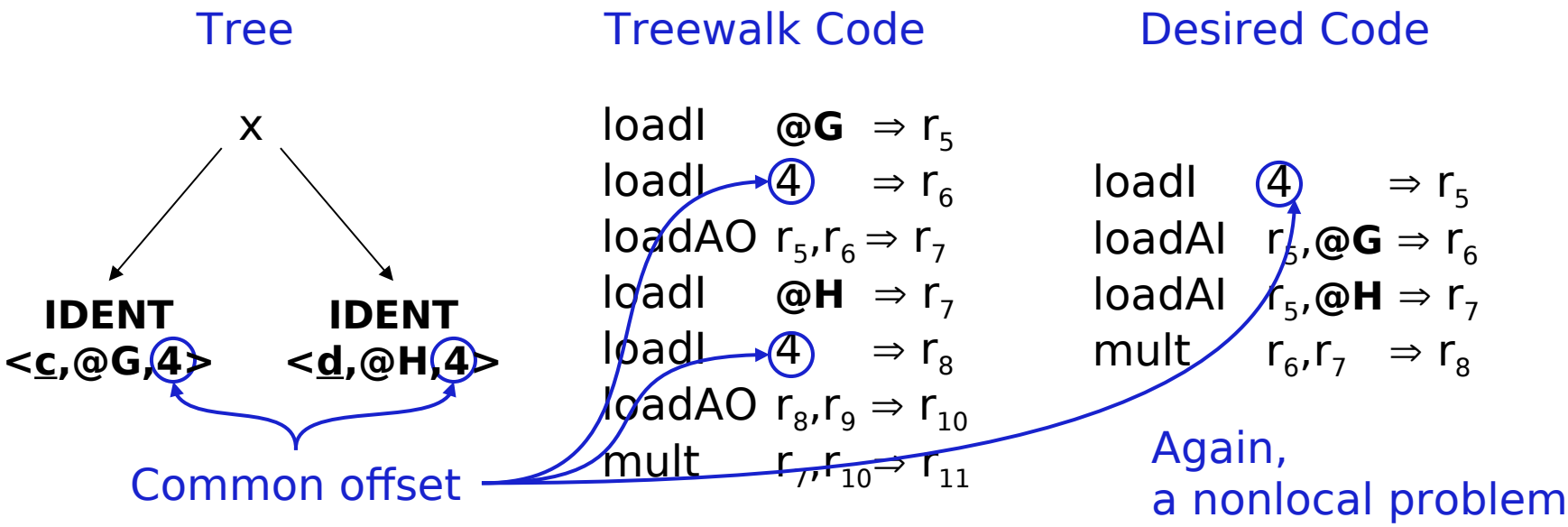
The Big Picture

Need pattern matching techniques

- Must produce good code (*some metric for good*)
- Must run quickly

Our treewalk code generator met the second criteria

How did it do on the first ?



How do we perform this kind of matching ?

Tree-oriented IR suggests pattern matching on trees

- Tree-patterns as input, matcher as output
- Each pattern maps to a target-machine instruction sequence
- Use dynamic programming or bottom-up rewrite systems

Linear IR suggests using some sort of string matching

- Strings as input, matcher as output
- Each string maps to a target-machine instruction sequence
- Use text matching (Aho-Corasick) or peephole matching

In practice, both work well; matchers are quite different

Peephole Matching

- Basic idea
- Compiler can discover local improvements locally
  - → Look at a small set of adjacent operations
  - → Move a “peephole” over code & search for improvement
- Classic example was store followed by load

Original code				Improved code			
storeAI	r_1	⇒	8	storeAI	r_1	⇒	8
loadAI	8	⇒	r_{15}	i2i	r_1	⇒	r_{15}

Peephole Matching

- Basic idea
- Compiler can discover local improvements locally
  - → Look at a small set of adjacent operations
  - → Move a “peephole” over code & search for improvement
- Classic example was store followed by load
- Simple algebraic identities

Original code	Improved code
addI r_2,0 ⇒ r_7 mult r_4,r_7 ⇒ r_{10}	mult r_4,r_2 ⇒ r_{10}

Peephole Matching

- Basic idea
- Compiler can discover local improvements locally
  - → Look at a small set of adjacent operations
  - → Move a “peephole” over code & search for improvement
- Classic example was store followed by load
- Simple algebraic identities
- Jump to a jump

Original code	Improved code
jumpI → L_{10} L_{10}: jumpI → L_{11}	L_{10}: jumpI → L_{11}

Peephole Matching

Implementing it

- Early systems used limited set of hand-coded patterns
- Window size ensured quick processing

Modern peephole instruction selectors

- Break problem into three tasks

- Apply symbolic interpretation & simplification systematically

Peephole Matching

Expander

- Turns IR code into a low-level IR (LLIR) such as RTL*
- Operation-by-operation, template-driven rewriting
- LLIR form includes all direct effects
- Significant, albeit constant, expansion of size

*RTL = Register transfer language

Peephole Matching

Simplifier

- Looks at LLIR through window and rewrites is
- Uses forward substitution, algebraic simplification, local constant propagation, and dead-effect elimination
- Performs local optimization within window

- This is the heart of the peephole system
  - → Benefit of peephole optimization shows up in this step

Peephole Matching

Matcher

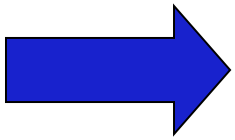
- Compares simplified LLIR against a library of patterns
- Picks low-cost pattern that captures effects
- Must preserve LLIR effects, may add new ones (*e.g., set cc*)
- Generates the assembly code output

Example

Original IR Code

OP	Arg_1	Arg_2	Result
mult	2	Y	t_1
sub	x	t_1	w

Expand



LLIR Code

$r_{10} \leftarrow 2$
$r_{11} \leftarrow @y$
$r_{12} \leftarrow r_0 + r_{11}$
$r_{13} \leftarrow \text{MEM}(r_{12})$
$r_{14} \leftarrow r_{10} \times r_{13}$
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Each register is single use

Example

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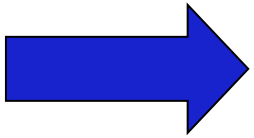
Simplify



LLIR Code

$r_{13} \leftarrow \text{MEM}(r_0 + @y)$
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Example

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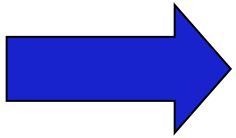
Match



ILOC Code

loadAI r_0,@y $\Rightarrow r_{13}$
multI 2 x $r_{13} \Rightarrow r_{14}$
loadAI r_0,@x $\Rightarrow r_{17}$
sub $r_{17} - r_{14} \Rightarrow r_{18}$
storeAI r_{18} $\Rightarrow r_0$,@w

- Introduced all memory operations & temporary names
- Turned out pretty good code

Steps of the Simplifier (*3-operation window*)

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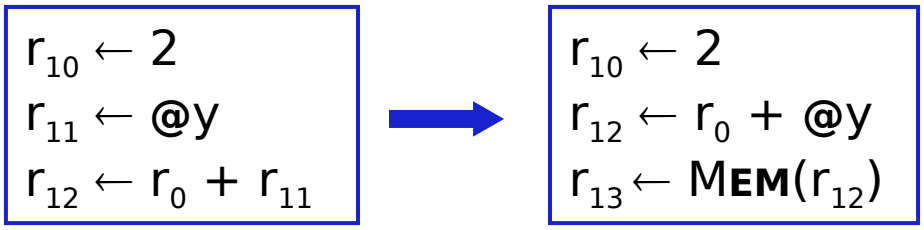

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this instruction disappear
(r10 not needed)

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1st op rolling out of window

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Example

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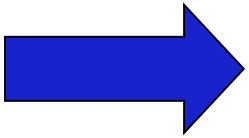
$\text{MEM}(r_{20}) \leftarrow r_{18}$

Simplify



LLIR Code

$r_{13} \leftarrow \text{MEM}(r_0 + @y)$

$r_{14} \leftarrow 2 \times r_{13}$

$r_{17} \leftarrow \text{MEM}(r_0 + @x)$

$r_{18} \leftarrow r_{17} - r_{14}$

$\text{MEM}(r_0 + @w) \leftarrow r_{18}$

Making It All Work

Details

- LLIR is largely machine independent (RTL)
- Target machine described as LLIR → ASM pattern
- Actual pattern matching
  - → Use a hand-coded pattern matcher (gcc)
  - → Turn patterns into grammar & use LR parser (VPO)
- Several important compilers use this technology
- It seems to produce good portable instruction selectors

Key strength appears to be late low-level optimization

Next lecure

Instruction selection

- Tree-based pattern matching