

Check-In

Review – Runtime Environments

Give an example of a language and its runtime environment

Announcements

Administrivia

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ECCS 665 **COMPILER** ***CONSTRUCTION***

Intermediate
Representations

Last Time

Lecture Review – Runtime Environments

Runtimes

- Runtime Environments
- Hardware Intuition

You Should Know

- What a runtime environment is
- Basic notions of how we might execute programs
 - OS mediation
 - Virtual machine
 - Accessing memory / registers



Runtimes



Today's Outline

Lecture Outline – Intermediate Representations

Introduce IRs

- What they are
- How they're used

Three Address Code (3AC)

- Introduction
- Inventory



**Intermediate
Representations**

Compiler Construction

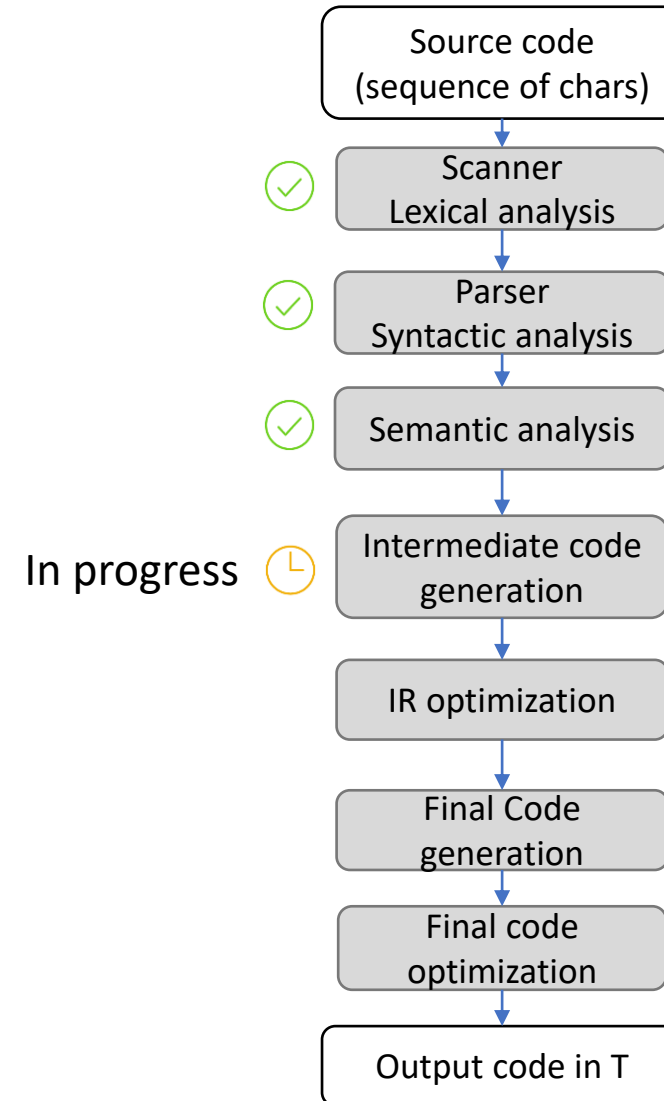
Progress Pics

Done:

- Derived an AST, augmented with types and identifier symbols
- Ensured the program is legal to the best of our abilities

ToDo:

- Get that sucker to run!



IRs: The Big Idea

Intermediate Representations

A big, basic concept

- “Encoding of a program”
- “The output of a compiler frontend and input of a compiler backend”
- “What a compiler knows about a program”
- “A simpler language to which the source language is mapped”



Intermediate Representation Benefits

Introducing IRs

Abstraction

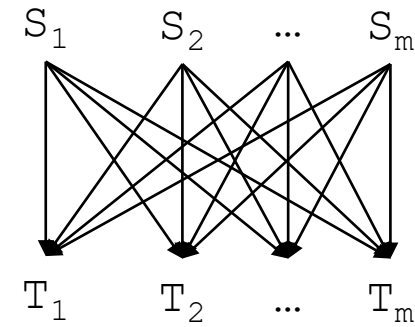
- Decouple compiler frontend from the backend

Analysis

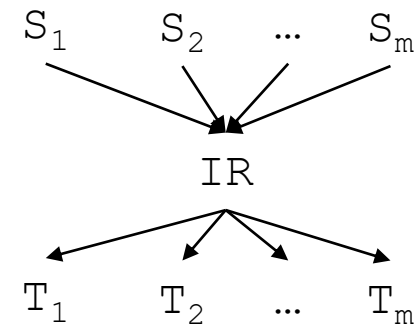
M source languages

N target languages

Write $M \times N$ compilers



or $M+N$ compiler modules



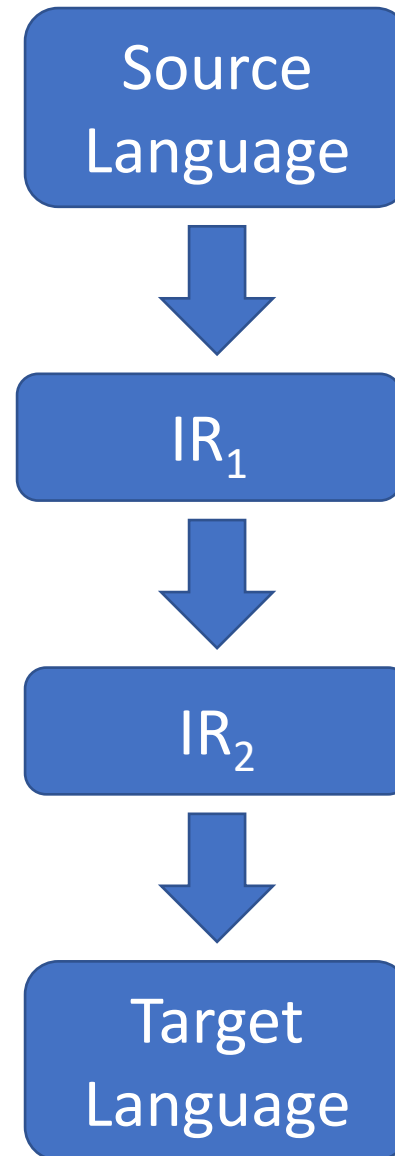
Intermediate Representation Benefits

Introducing IRs

Abstraction

- Decouple compiler frontend from the backend
- Break down source language constructs over several small steps towards target

Analysis



Intermediate Representation Benefits

Introducing IRs

Abstraction

- Decouple compiler frontend from the backend
- Break down source language constructs over several small steps towards target

Analysis

- Optimize programs

Improve...

- Runtime
- Memory usage
- Power usage
- Security

Intermediate Representation Benefits

Introducing IRs

Abstraction

- Decouple compiler frontend from the backend
- Break down source language constructs over several small steps towards target

Analysis

- Optimize programs
- Predict faults

For example...

- typechecking



But isn't this an analysis on the AST?

Intermediate Representation Benefits

Introducing IRs

Abstraction

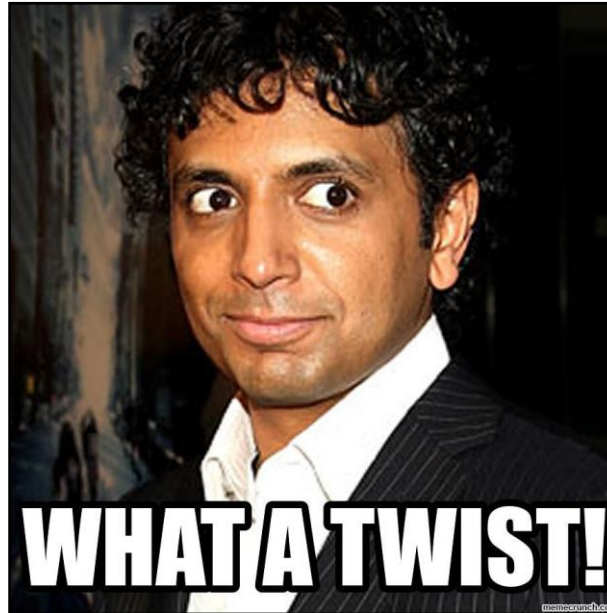
- Decouple
- from the
- Break down
- construction
- steps to

Analysis

- Optimiz
- Predict

For example

ASTs are an example of an IR!!



*M. Night Shyamalan, famous for
(ill-considered) plot twists in
movies he writes/directs*

ST?

Classes of IR

Introducing IRs

Structural

- Abstract-Syntax Tree (AST)
- Abstract Syntax DAG

Linear

- Three-Address Code (3AC)
- Stack machine code

Hybrid

- Control-Flow Graph

Limitations of Trees

Introducing IRs

- AST is great for some things, but not everything
 - Doesn't represent control flow very well
- Compilers *could* go directly from AST to machine code
- Let's consider a different IR



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Introduce IRs

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Three Address Code (3AC)

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**Intermediate
Representations**

Introducing 3AC

3AC Description

A Simplified Instruction Set Architecture (ISA)

- A family of pseudocode notations



Disclaimer

Like ASTs, there's no canonical 3AC

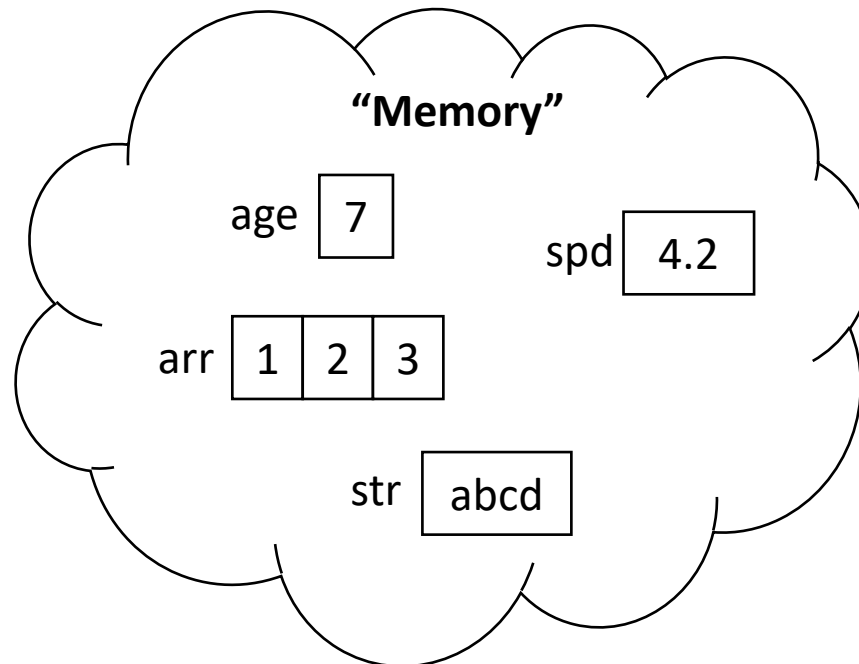
We're more interested in the general idea

Introducing 3AC

3AC Description

A Simplified Instruction Set Architecture (ISA)

- A family of pseudocode notations
- Memory model: infinite “symbolic store”



- Naming a variable adds a location in the store
- We'll assume that the store can handle scope

Introducing 3AC

3AC Description

A Simplified Instruction Set Architecture (ISA)

- A family of pseudocode notations
- Memory model: infinite “symbolic store”
- Instruction model: linear instructions divided into *procedures*

Discrete code listings

From Variables to Locations (“locs”)

3AC Description


A loc is...

- An address in memory
- A container for a value

Use [] around loc to denote value at that location

- [a] is the “value at a”

(sort of like adding a pointer level into every access)

int a;		int * a;
int * b;		int ** b;
a = 1;		*a = 1;
*b = 2;		**b = 2;

3AC: What's With the Name?

3AC Description

Instructions have *at most 3* operands

$a = b + c * d - e$



`[tmp1] := [c] * [d];`

`[tmp2] := [b] + [tmp1];`

`[tmp3] := [tmp2] - [e];`

`[a] := [tmp3];`

3AC: Instruction Classes

3AC Description

Data flow

- Assignment
- Math/Logic

Control flow

- Labels
- Jumps

Interprocedural

- Boundaries
- Bodies
- Calls

$\langle \text{opd} \rangle := \langle \text{opd} \rangle$

Opd stands for “operand”
Literals, variables, etc.

Example:

```
[a] := 1  
[b] := [a]
```

3AC: Instruction Classes

3AC Description

Data flow

- Assignment
- Math/Logic

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- Boundaries
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- Calls

`<opd> := <opd> <opr> <opd>`
`<opd> := <opr> <opd>`

Opd stands for “operand”
Literals, variables, etc.

Opr stands for “operator”
MULT64, DIV64, SUB64, ADD64, etc.

Example:

```
[a] := 1 MULT64 2  
[b] := [a] SUB64 4
```


3AC: Instruction Classes

3AC Description

Data flow

- Assignment
- Math/Logic

Control flow

- Labels
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Interprocedural

- Boundaries
- Bodies
- Calls

<lbl>: <instr>

Example:

Label1: [a] := 1

nop

Example:

Label1: nop

3AC: Instruction Classes

3AC Description

Data flow

- Assignment
- Math/Logic

Control flow

- Labels

- Jumps

Interprocedural

- Boundaries
- Bodies
- Calls

goto <lbl>

Example:

```
Label12: goto Label12
```

ifz <opd> goto <lbl>

Example:

```
ifz [a] goto Label11
[a] := 1
Label11: [a] := 2
```

3AC: Instruction Classes

3AC Description

Data flow

- Assignment
- Math/Logic

Control flow

- Labels
- Jumps

Interprocedural

- Boundaries
- Bodies
- Calls

enter <proc>
leave <proc>

Example:

```
enter fn  
[global] := 7  
leave fn
```

3AC: Instruction Classes

3AC Description

Data flow

- Assignment
- Math/Logic

Control flow

- Labels
- Jumps

Interprocedural

- Boundaries
- Bodies
- Calls

getarg <idx> <opd>
setret <opd>

Example:

```
int fn(int a, int b){  
    a = b;  
    return 42;  
}
```

Example:

```
enter fn  
getarg 1, [a]  
getarg 2, [b]  
[a] := [b]  
setret 42  
leave fn
```

3AC: Instruction Classes

3AC Description

Data flow

- Assignment
- Math/Logic

Control flow

- Labels
- Jumps

Interprocedural

- Boundaries
- Bodies
- Calls

call <proc>

setarg <int> <opd>

getret <opd>

Example:

```
int fn(int a, int b){
    a = b;
    return 42;
}

int v(){
    int k;
    k = fn(7, 9);
}
```

Example:

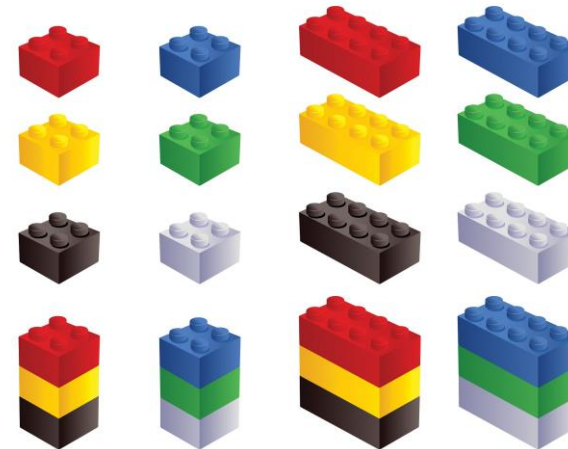
```
enter fn
getarg 1, [a]
getarg 2, [b]
[a] := [b]
setret 42
leave fn
enter v
setarg 1, 7
setarg 2, 9
call fn
getret [k]
leave v
```


That's All we Need!

3AC Description

We can build complex behavior out of these simple building blocks

- One minor loose end to tie up...



Dealing with Scope

3AC Description

```
void fn() {  
  int a;  
  a = 9;  
  if (true) {  
    int a;  
    a = 6;  
  }  
}
```

```
enter fn  
[ a1 ] := 9  
...  
[ a2 ] := 6  
...  
leave fn
```

*Name
clash?*

Only in notation!

These assignment connect to different symbols

We can use superscripts if needed

3AC Data Structures

AST Translation to 3AC – Implementation

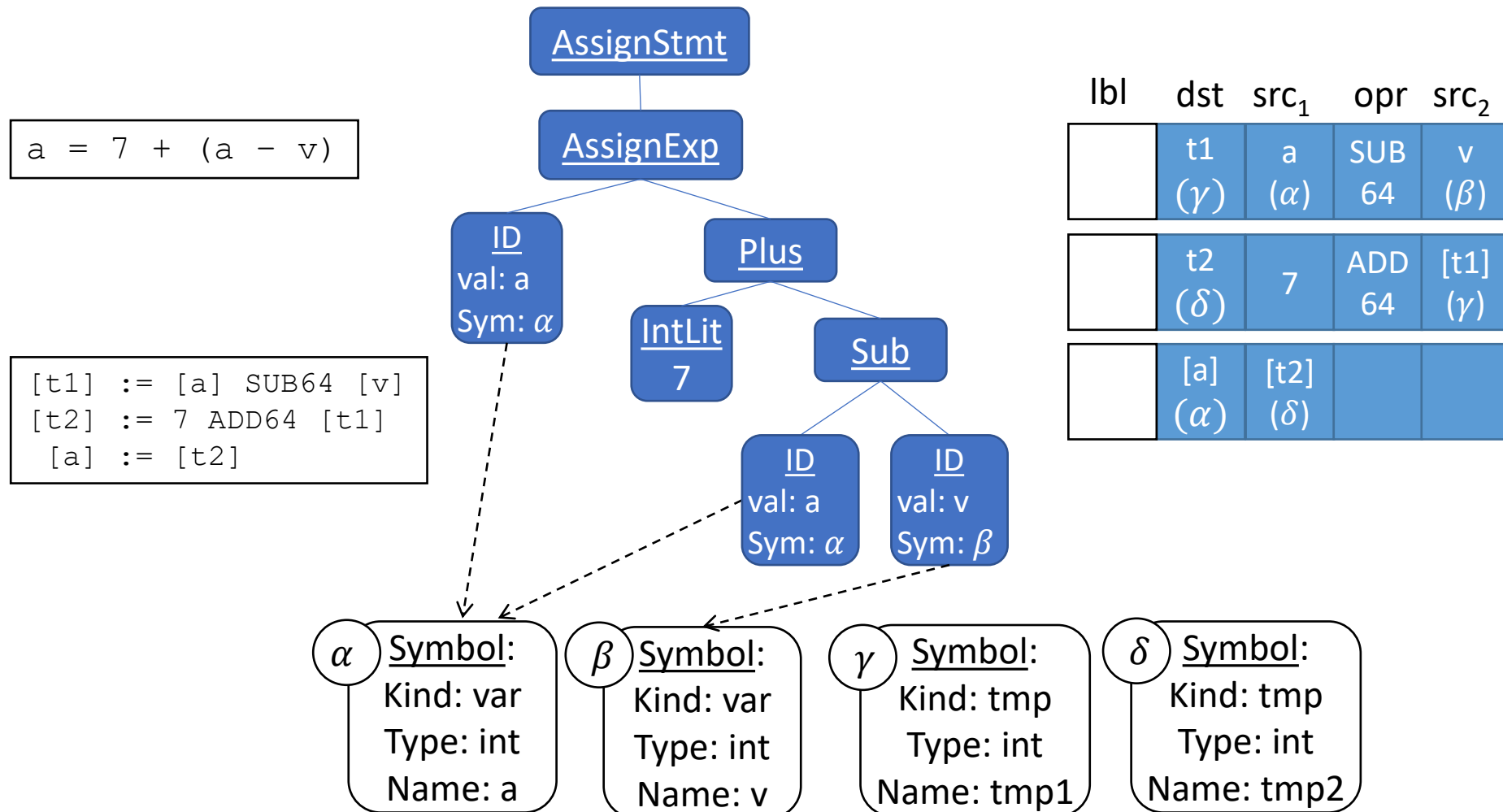
- One class per 3AC node type
 - Often referred to as “Quads” – has at most 4 fields (+ label)
 - Each procedure maintains a list of its quads

lbl	dst	src1	opr	src2
L1	[t1]	[a]	SUB 64	2

Translation Implementation

AST Translation to 3AC – Implementation

Propagate context to parent & generate 3AC instruction(s)



Next Time

3AC Translation

Translating AST code into 3AC

- A final walk of the AST

