Check-In 20

Review – Runtime Environments

Give an example of a programming language and its runtime environment

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Review – Runtime Environments

Give an example of a programming language and its runtime environment

Announcements

Administrivia

University of Kansas | Drew Davidson

Intermediate Representations

Last Time

Lecture Review – Runtime Environments

Runtimes

- Runtime Environments

You Should Know

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

Runtimes


COMPILER
Code Generation
Optimization
Architecture
Runtimes
Intermediate Code
SDD
Parsing
Semantics
Lexical Analysis
Syntactic Definiton

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

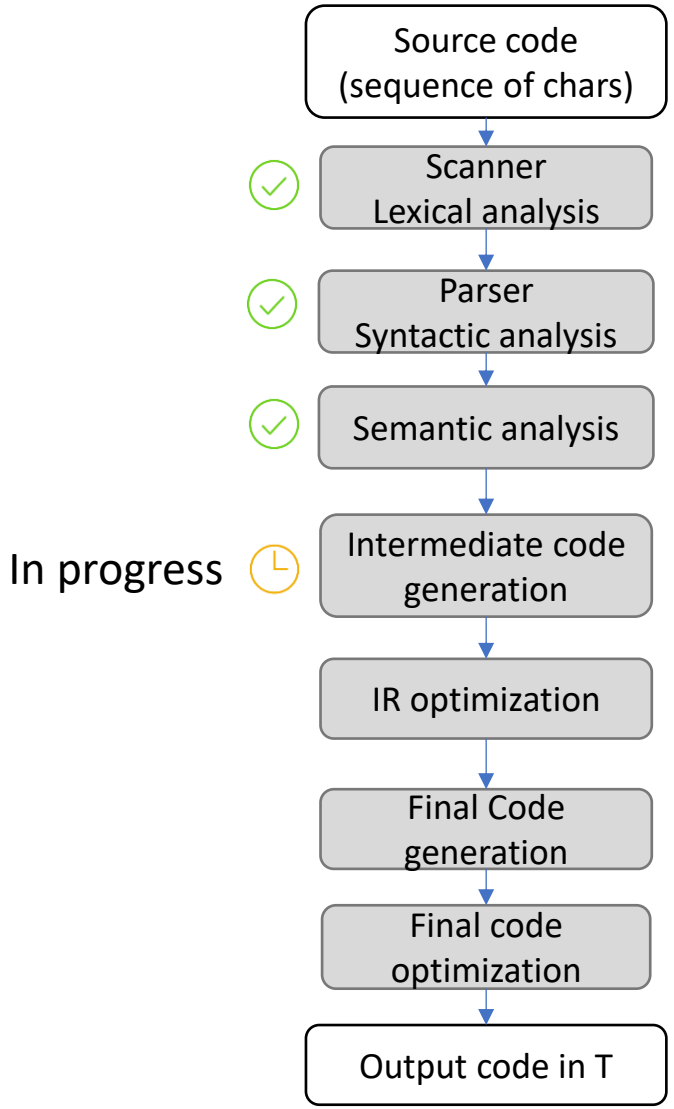
Progress Pics

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

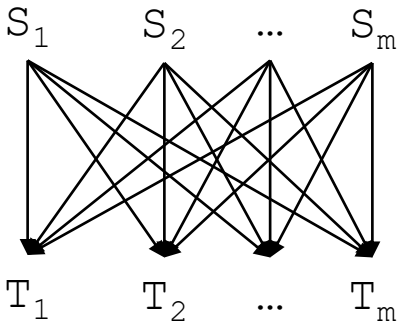
- Decouple compiler frontend from the backend

Analysis

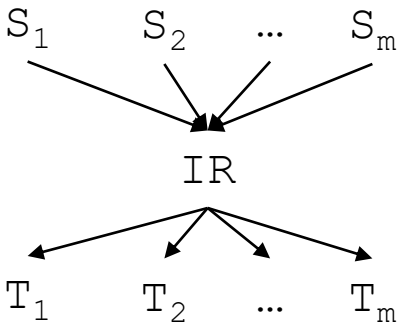
M source languages

N target languages

Write M×N compilers



or M+N compiler modules



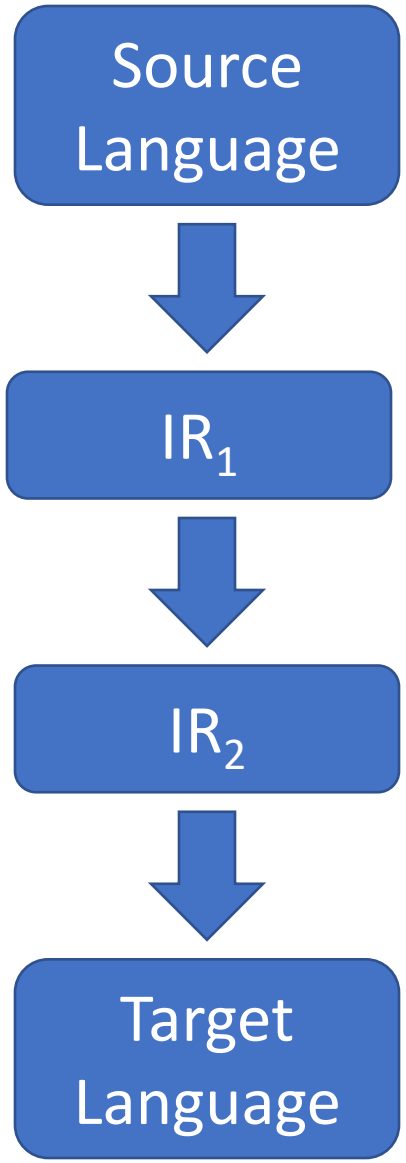
Intermediate Representation Benefits

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…

- Run time
- 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

- Decoup
  from th
- Break d
  constru
  steps to

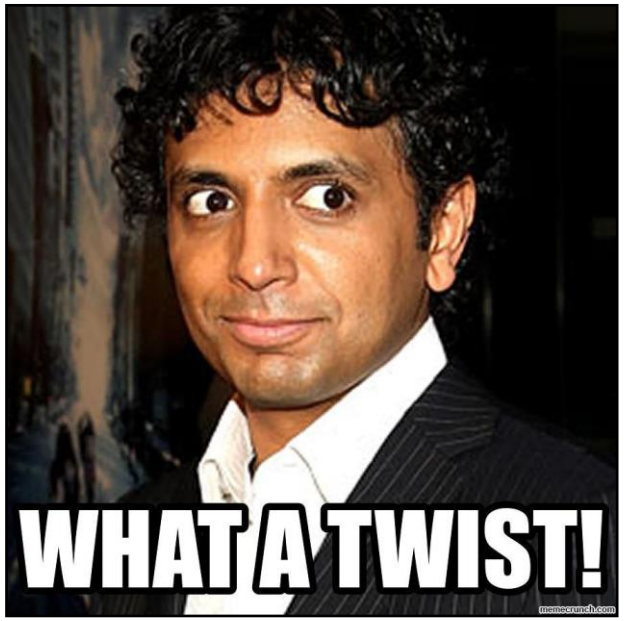
Analysis

- Optimi

- 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

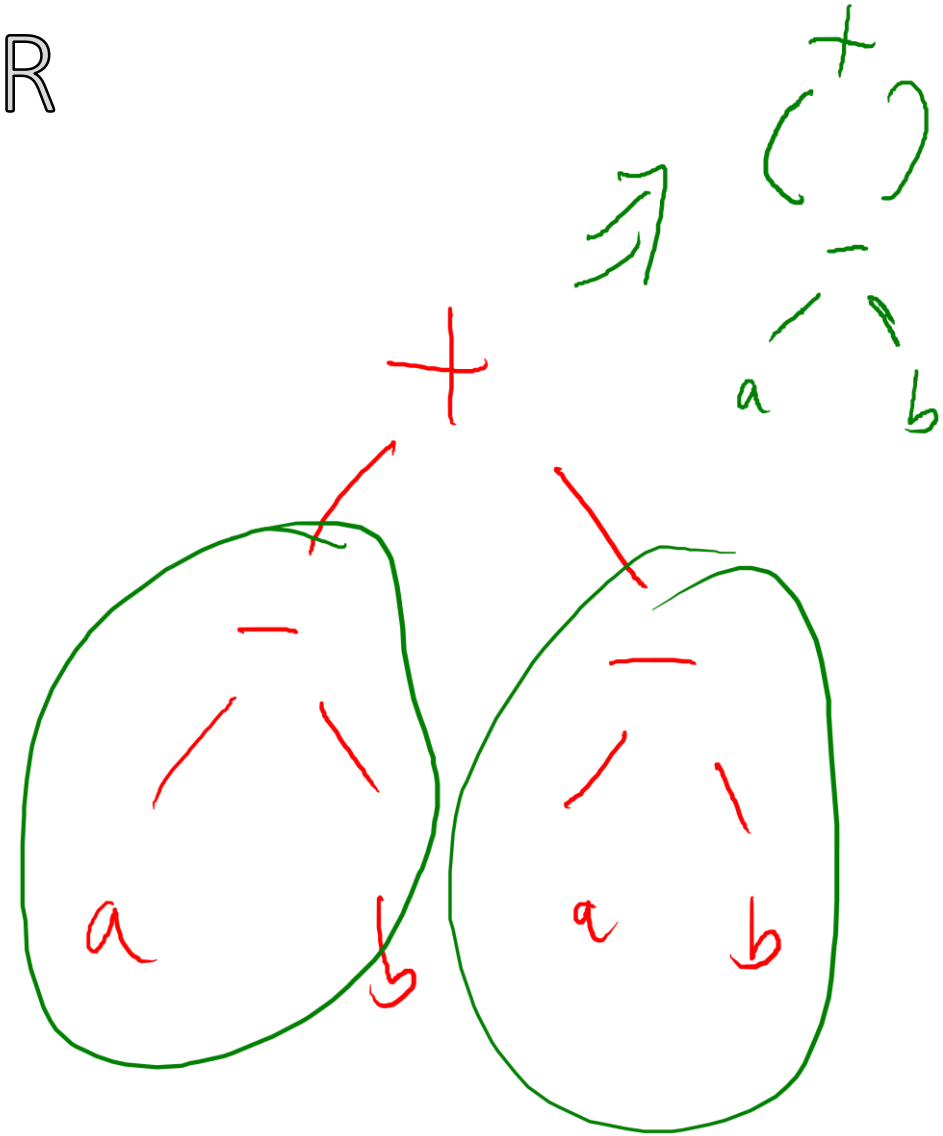
- Abstract-Syntax Tree (AST)
- Abstract Syntax DAG

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

Today's Outline

Lecture Outline – Intermediate Representations

Introduce IRs

- What they are
- How they're used

Three Address Code (3AC)

- Introduction
- Inventory

Intermediate Representations

Introducing 3AC

3AC Description

A Simplified Instruction Set Architecture (ISA)

- A family of pseudocode notations

Like ASTs, there's no canonical 3AC

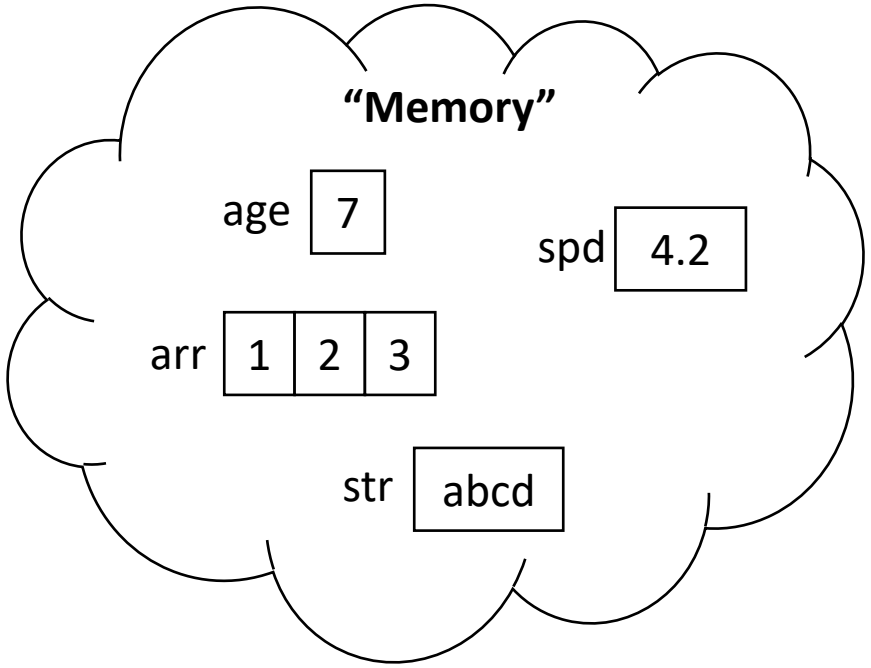
We're more interested in the general idea

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 * b;
a = 1;
*b = 2;
```

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

3AC: What's With the Name?

3AC Description

Instructions have *at most 3* operands

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

becomes

```
[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

<opd> := <opd>

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

Example:

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

3AC: Instruction Classes

3AC Description

Data flow

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- Math/Logic

Control flow

- Labels
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Interprocedural

- Boundaries
- Bodies
- 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
- Jumps

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:

```
Label2: goto Label2
```

ifz <opd> goto <lbl>

Example:

```
        ifz [a] goto Label1
        [a] := 1
Label1: [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:

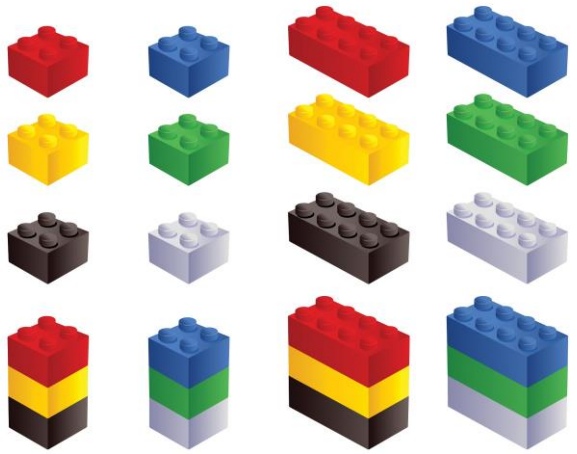
```
enter fn
getarg 1, [a]
getarg 2, [b]
[a] := [b]
setret 42
leave fn
enter v
setarg 1, 7
setarg 2, 9
call fn
getret [k]
leave v
```

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?

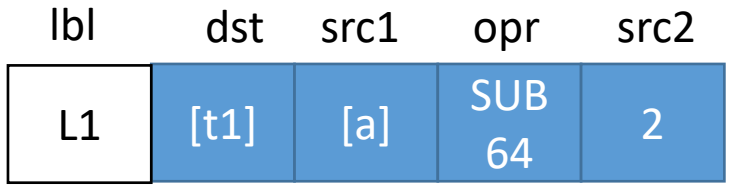
Only in notation!
These assignment connect to different symbols

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



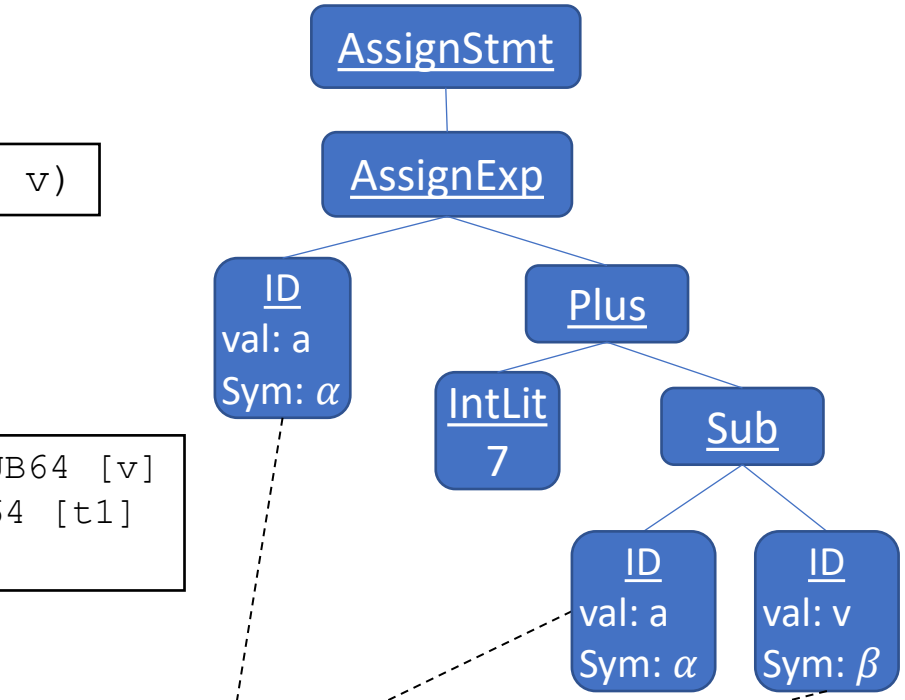
Translation Implementation

AST Translation to 3AC – Implementation

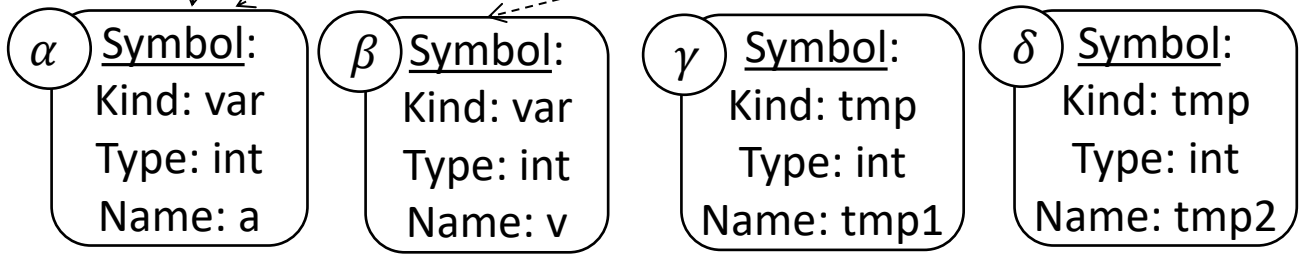
Propagate context to parent & generate 3AC instruction(s)

```
a = 7 + (a - v)
```

```
[t1] := [a] SUB64 [v]
[t2] := 7 ADD64 [t1]
 [a] := [t2]
```



lbl	dst	src_1	opr	src_2
	t1 (γ)	a (α)	SUB 64	v (β)
	t2 (δ)	7	ADD 64	[t1] (γ)
	[a] (α)	[t2] (δ)		



Next Time

3AC Translation

Translating AST code into 3AC

- A final walk of the AST