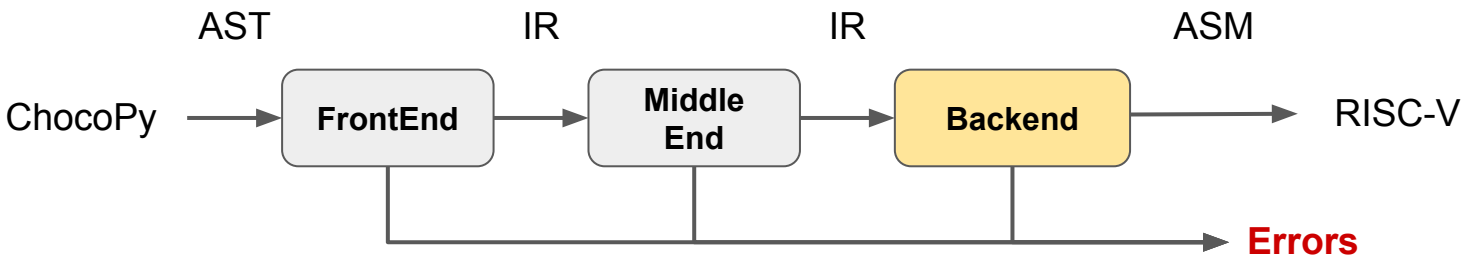
Compiling Techniques

Lecture 17: Introduction to Code Generation

Overview



Frontend: Lexer/Parser & AST Builder & Semantic Analyzer (CW 1 & 2)

Middle End: Optimizations

Representations

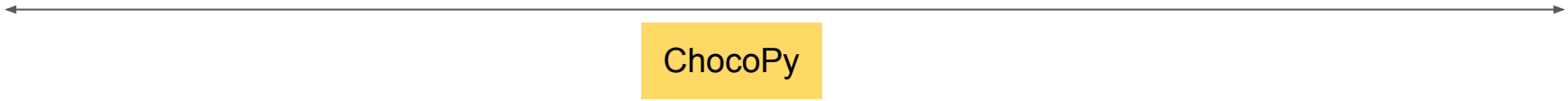
- How do we represent values from our program?

- Challenges:
  - Fixed-width registers
  - We only have bits (not e.g., characters)
  - Lack of high-level structure

Representing Values in Memory/Registers

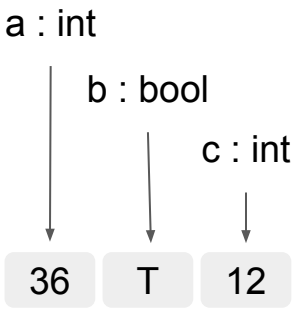
Statically Typed Languages (C/C++)

Dynamically Typed Languages (Python)

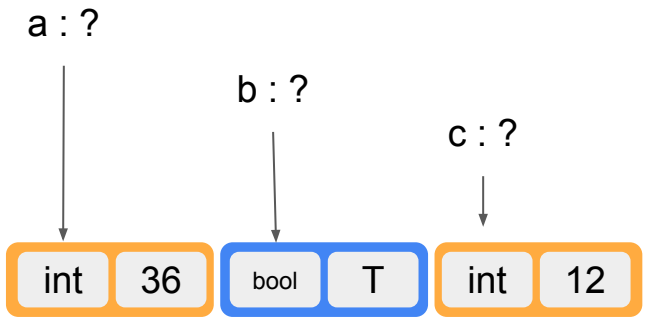


ChocoPy

Plain (Unboxed) Values



Boxed Values



Properties of Boxed Values

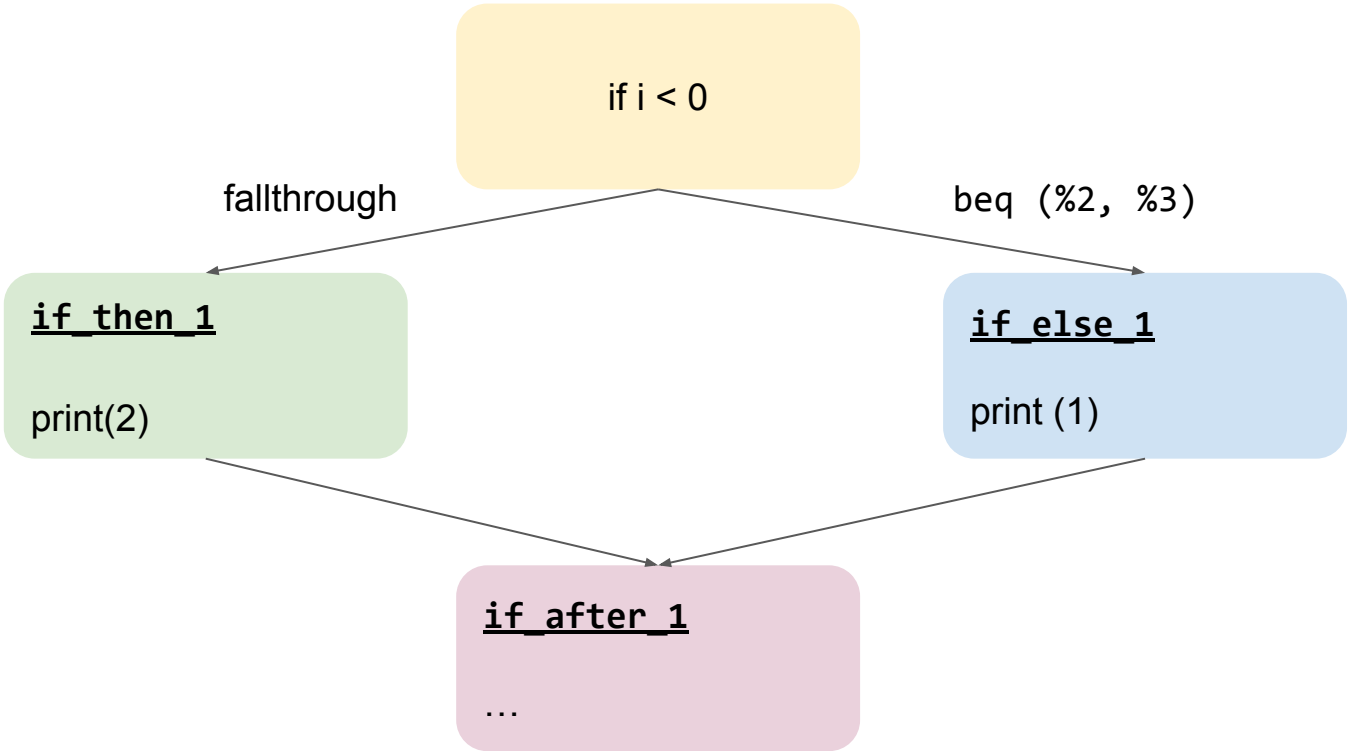
Advantages

- Better for
  - Dynamically Typed Languages
  - Dynamic Dispatch
- Can be Treated More Uniformly in The Compiler

Disadvantages

- Reduced Performance (Runtime)
- Higher Memory Cost
- Requires Complex Runtime System

Basic Blocks: Linear Sequences of Operations



Control Flow

```
if 1 < 0:
```

```
    %0 = "riscv_ssa.li"() <{"immediate" = 1 : i32}> : () -> !riscv_ssa.reg
    %1 = "riscv_ssa.li"() <{"immediate" = 0 : i32}> : () -> !riscv_ssa.reg
    %2 = "riscv_ssa.slt"(%0, %1) : (!riscv_ssa.reg, !riscv_ssa.reg) -> !riscv_ssa.reg
    %3 = "riscv_ssa.li"() <{"immediate" = 0 : i32}> : () -> !riscv_ssa.reg
    "riscv_ssa.beq"(%2, %3) <{"offset" = #riscv.label<if_else_1>}> : …
```

```
  print(1)
```

```
    "riscv_ssa.label"() <{"label" = #riscv.label<if_then_1>}> : () -> ()
    %4 = "riscv_ssa.li"() <{"immediate" = 1 : i32}> : () -> !riscv_ssa.reg
    "riscv_ssa.call"(%4) <{"func_name" = "_print_int"}> : (!riscv_ssa.reg) -> ()
    "riscv_ssa.j"() <{"offset" = #riscv.label<if_after_1>}> : () -> ()
```

```
else:
  print(2)
```

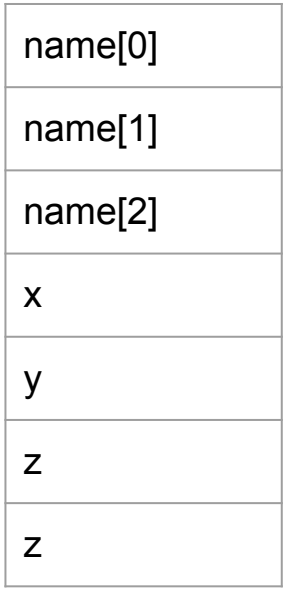
```
    "riscv_ssa.label"() <{"label" = #riscv.label<if_else_1>}> : () -> ()
    %5 = "riscv_ssa.li"() <{"immediate" = 2 : i32}> : () -> !riscv_ssa.reg
    "riscv_ssa.call"(%5) <{"func_name" = "_print_int"}> : (!riscv_ssa.reg) -> ()
```

```
…
```

```
    "riscv_ssa.label"() <{"label" = #riscv.label<if_after_1>}> : () -> ()
```

Representing Structs

```
struct {
    char name[3];
    int x;
    int y;
    double z;
};
```



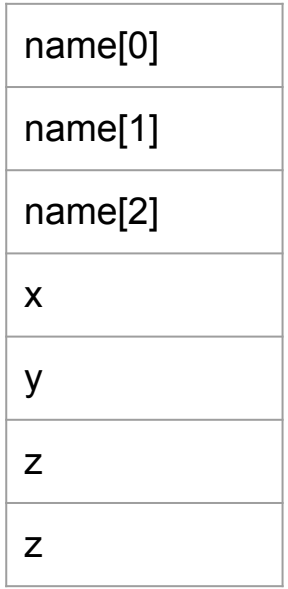
Representing Classes

What are classes?

- A number of fields
- Some associated functions

```
class Record {

std::array<char, 3> name_;

int x_; int y_; double z_;

void f() …

}
```

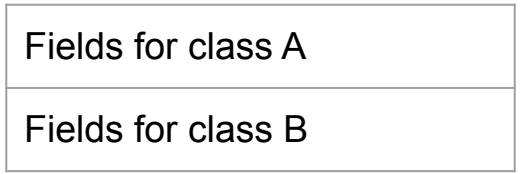
How to represent them? The same as structs!



Representing Classes: Inheritance

- How do we support inherited fields?
  - Stack classes
- How do we support dynamic dispatch?
  - VTable

Class A extends Class B



Representing Classes: Inheritance

- How do we support inherited fields?
  - Stack classes
- How do we support dynamic dispatch?
  - VTable

```
Class A {
   Void f()
   Void g()
}

Class B {
   Void f()
   Void h()
}
```

Function	Which Code
f	
g	
h	

Functions in Memory
A.f()
A.g()
B.f()
B.h()

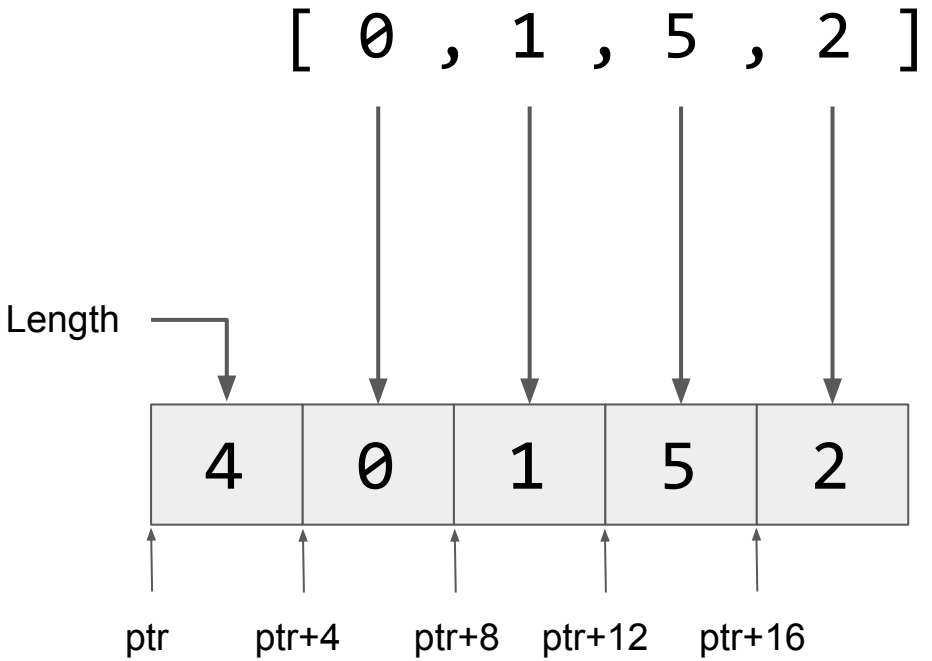
How do we access these? Constant offsets

- Always know that A.f() is at offset 0 in the vtable, no matter what the inheritance chain is
- Always know that A.x is at offset 3 into the class

Function	Which Code
f	0x0004142
g	0x0002144
h	0x0002131

name[0]
name[1]
name[2]
x
y
z
z

List Storage: Length + Data



Constructing a List:

1. Allocate `# of elements + 1` words of storage with _malloc.
   The ptr returned by _malloc represents the list.

2. Store length of list at the first word after ptr (offset zero).

3. Store the data elements at words 2 to length+1.

Iterating Over Lists

```
x: int = 0

for x in [1, 2, 3, 4]:
    print(x)
```

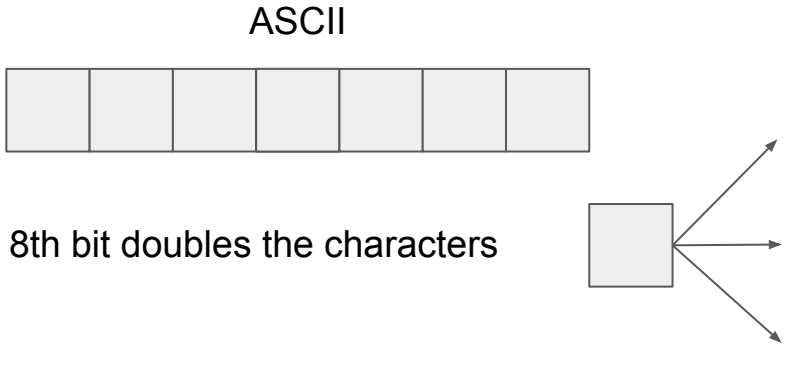
ASCII String Representation

Use ‘ord()’ function to translate a character to its ASCII value.

Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char
0	0	[NULL]	32	20	[SPACE]	64	40	@	96	60	`
1	1	[START OF HEADING]	33	21	!	65	41	A	97	61	a
2	2	[START OF TEXT]	34	22	"	66	42	B	98	62	b
3	3	[END OF TEXT]	35	23	#	67	43	C	99	63	c
4	4	[END OF TRANSMISSION]	36	24	$	68	44	D	100	64	d
5	5	[ENQUIRY]	37	25	%	69	45	E	101	65	e
6	6	[ACKNOWLEDGE]	38	26	&	70	46	F	102	66	f
7	7	[BELL]	39	27	'	71	47	G	103	67	g
8	8	[BACKSPACE]	40	28	(	72	48	H	104	68	h
9	9	[HORIZONTAL TAB]	41	29	)	73	49	I	105	69	i
10	A	[LINE FEED]	42	2A	*	74	4A	J	106	6A	j
11	B	[VERTICAL TAB]	43	2B	+	75	4B	K	107	6B	k
12	C	[FORM FEED]	44	2C	,	76	4C	L	108	6C	l
13	D	[CARRIAGE RETURN]	45	2D	-	77	4D	M	109	6D	m
14	E	[SHIFT OUT]	46	2E	.	78	4E	N	110	6E	n
15	F	[SHIFT IN]	47	2F	/	79	4F	O	111	6F	o
16	10	[DATA LINK ESCAPE]	48	30	0	80	50	P	112	70	p
17	11	[DEVICE CONTROL 1]	49	31	1	81	51	Q	113	71	q
18	12	[DEVICE CONTROL 2]	50	32	2	82	52	R	114	72	r
19	13	[DEVICE CONTROL 3]	51	33	3	83	53	S	115	73	s
20	14	[DEVICE CONTROL 4]	52	34	4	84	54	T	116	74	t
21	15	[NEGATIVE ACKNOWLEDGE]	53	35	5	85	55	U	117	75	u
22	16	[SYNCHRONOUS IDLE]	54	36	6	86	56	V	118	76	v
23	17	[ENG OF TRANS. BLOCK]	55	37	7	87	57	W	119	77	w
24	18	[CANCEL]	56	38	8	88	58	X	120	78	x
25	19	[END OF MEDIUM]	57	39	9	89	59	Y	121	79	y
26	1A	[SUBSTITUTE]	58	3A	:	90	5A	Z	122	7A	z
27	1B	[ESCAPE]	59	3B	;	91	5B	[	123	7B	{
28	1C	[FILE SEPARATOR]	60	3C	<	92	5C	\	124	7C	|
29	1D	[GROUP SEPARATOR]	61	3D	=	93	5D	]	125	7D	}
30	1E	[RECORD SEPARATOR]	62	3E	>	94	5E	^	126	7E	~
31	1F	[UNIT SEPARATOR]	63	3F	?	95	5F	_	127	7F	[DEL]

What about Other Characters?

Single Byte Encoding (128 or 256 characters)



¡¢£¤¥¦§¨©ª«¬-®¯°±²³´µ¶·¸¹º»¼½¾¿
ÀÁÂÃÄÅÆÇÈÉÊËÌÍÎÏÐÑÒÓÔÕÖ×ØÙÚÛÜÝÞß
àáâãäåæçèéêëìíîïðñòóôõö÷øùúûüýþÿ

Unicode Multibyte Encodings (today: 144,697 characters)

UTF-8: 1 - 4 bytes

UTF-16: 2 or 4 bytes

UTF-32: Always 4 bytes

Strings are Represented as Lists of Characters

“Hello”

[‘H’, ‘e’, ‘l’, ‘l’, ‘o’]

Characters Storage

- Each character is encoded as ASCII code
  (use ord() function)
- Each character is stored as a full word
  (despite only needing a byte)

What about If-Conditions / Loops

```
a: int = 0

if True:
        a = 42
else:
        a = 41
```

Do we need basic blocks

Advantages

- Facilitate reordering of control flow

Disadvantages

- Pattern rewrites become more difficult
- Not as easy to reason about