

Part 5

Type Checking

Type Systems

- Programming languages have different types of data and objects

```
a = 42          # int
b = 4.2         # float
c = "fortytwo"  # str
d = [1,2,3]     # list
e = {'a':1, 'b':2} # dict
...
```

- Each type has different capabilities

```
>>> a - 10
```

```
32
```

```
>>> c - "ten"
```

```
Traceback (most recent call last):
```

```
  File "<stdin>", line 1, in <module>
```

```
TypeError: unsupported operand type(s) for -: 'str' and 'str'
```

```
>>>
```

What is a Type?

- It partly relates to data representation

```
int a = 42;  
short b = 42;  
long c = 42;  
float d = 4.2;
```

			00	00	00	2a	
					00	2a	
00	00	00	00	00	00	00	2a
40	10	cc	cc	cc	cc	cc	cd

- Must map to low-level operations on hardware
- Different kinds of instructions (int vs. float)
- Also: Input/Output encoding

Error Checking

- A type system also encodes semantic rules
- A lot of it is common sense
 - Can't perform operations (+,-,*,/) if not supported by the underlying type
 - Can't overwrite immutable data
 - Array indices must be positive integers

Dynamic Typing

- Rules are enforced at run-time
- Objects carry their type during execution

```
>>> a = 42
>>> a.__class__
<class 'int'>
>>> a + 10
52
>>> a.__add__(10)
52
>>> a.__add__('hello')
NotImplemented
>>> a + 'hello'
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unsupported operand type(s) for +: 'int'
and 'str'
>>>
```

Static Typing

- Rules are enforced at compile-time
- Code is annotated with explicit types

```
/* C */  
int fact(int n) {  
    int result = 1;  
    while (n > 0) {  
        result *= n;  
        n--;  
    }  
}
```

- Compiler executes a "proof of correctness"
- Types are discarded (erased) during execution

Note

- Most programming languages involve some mix of both techniques (static/dynamic)
- Compiler checks as much as possible
- Certain checks may be forced to run-time
- Example: Array-bounds checking

Elements of a Type System

- A Few Minimal Requirements:
 - Must be able to specify types
 - Must be able to compare types
 - Must be able to compose types
 - Must be able to check capabilities

Type Specification

- There is a set of "primitive" given types
- They are labels that you attach to values

```
var x float;  
func fact(n int) int {  
    if n == 1 {  
        return 1;  
    } else {  
        return n*fact(n-1);  
    }  
}
```

- Implicitly present in literals

```
42      (int)  
4.2     (float)
```

Type Comparison

- Types must be comparable

```
int != float
```

- A major part of checking is finding type-mismatches in the code (type errors)
- Common solution: compare type names
- "Nominal Typing"

Type Composition

- Can define new types from existing types

```
struct Position {  
    float x;  
    float y;  
};
```

- Example: Structures/Records
- Sometimes known as a "product type"
- "Product" terminology refers to the total number of possible values (all floats * all floats)

Type Composition

- Enums/Unions

```
enum MaybeInt {  
    Nothing;  
    Just(int);  
}
```

- An instance contains only one of the values

```
x = MaybeInt::Nothing;  
y = MaybeInt::Just(42);
```

- Sometimes called a "sum type".
- Refers to the total number of possible values (sum of possible values for each choice).

Function Types

- Functions may also represent a type

```
func mul(x int, y int) int {  
    return x * y;  
}
```

- Type consists of argument types and result type

```
(int, int) -> int
```

- Note: Functions might be first-class objects just like integers, floats, etc.

```
var m = mul;  
...  
z = m(x, y);      # Requires x=int, y=int, z=int
```

Structural Typing

- Are these two types the same type?

```
struct Position {  
    float x;  
    float y;  
};
```

```
struct Velocity {  
    float x;  
    float y;  
};
```

- If the same structure implies the same type, then that's "structural typing"

Type Capabilities

- Types have different capabilities (operators)

```
int:
    binary_ops = { '+', '-', '*', '/' },
    unary_ops = { '+', '-' }
```

```
string:
    binary_ops = { '+' },
    unary_ops = { }
```

- A type checker will consult

```
231 * 42          # OK!
'a' * 'b'         # ERROR!
```

Type Coercion

- There may be well-defined type conversions

`bool -> int -> float`

- Explicit casts

```
var x int = 42;  
var y float = float(x);           // y = 42.0
```

- Implicit casts

`3 + 2.5 -> float(3) + 2.5 -> 5.5`

Type Hierarchies

- There may be a concept of inheritance

```
class Parent:  
    ...  
  
class Child(Parent):  
    ...
```

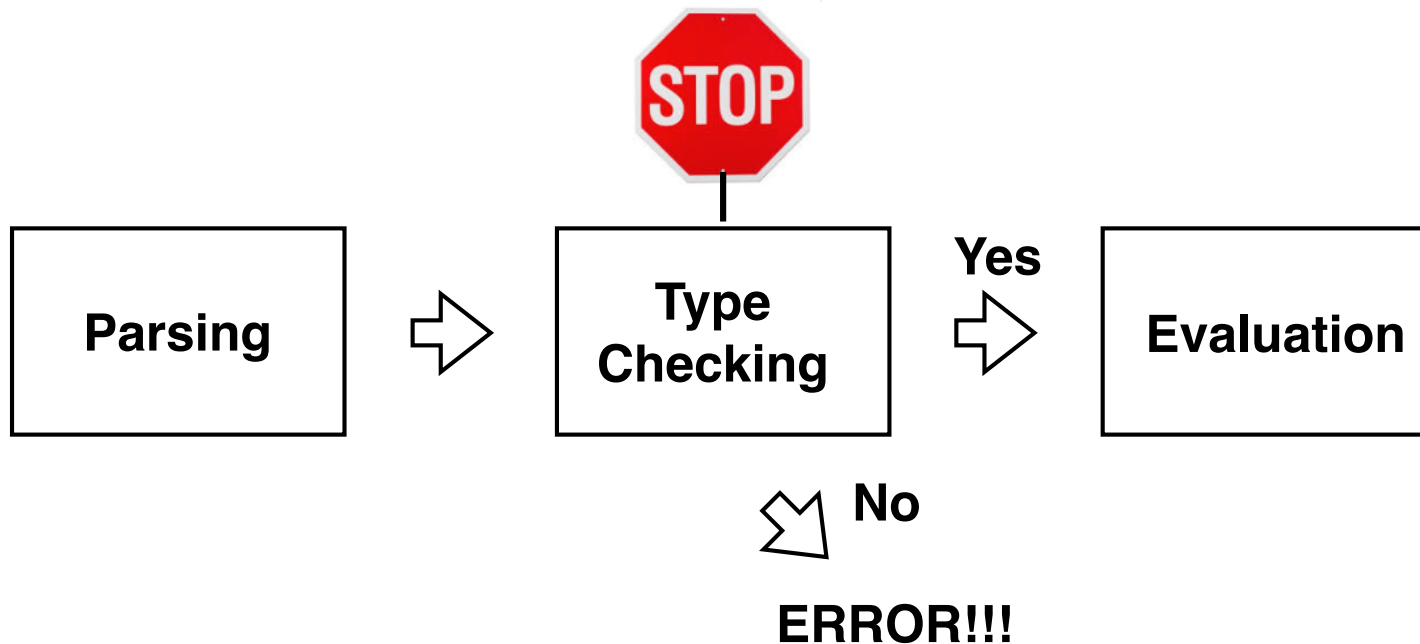
- Type "Child" is compatible with "Parent"

```
c = Child()  
isinstance(c, Parent)    # --> True
```

- Note: Type ontologies are a complex subject (we're not doing this in the compiler project).

Type Checking

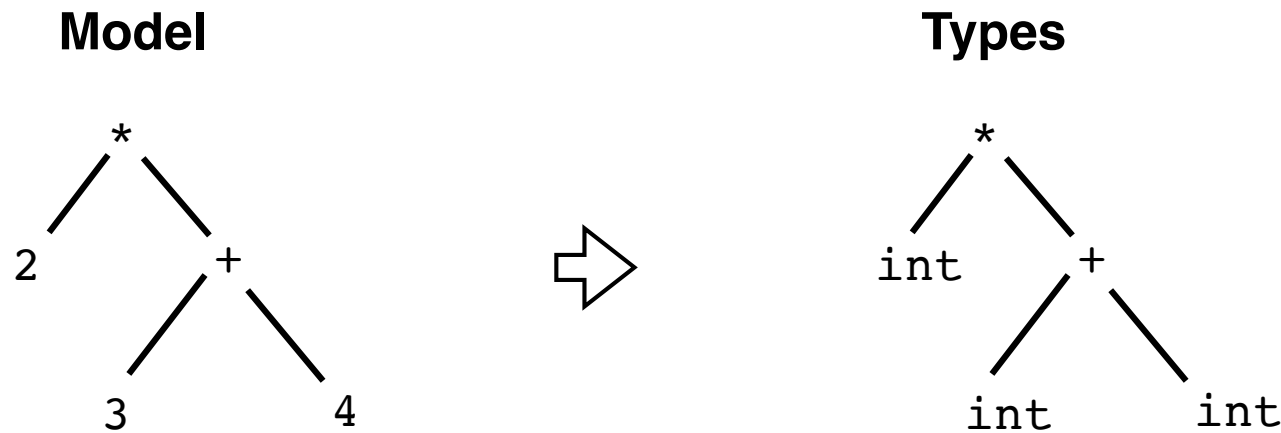
- It's a check in the middle of compilation



- Think of it as a filter: "all systems go."

How To Implement

- Run a type-level program simulation



- Watch how the types would evolve in evaluation
- Look for mismatches. Report errors.

Example:

```
def check_integer(node, env):
    return "int"

_binops = {
    ('+', 'int', 'int') : 'int',
    ('-', 'int', 'int') : 'int',
    ('<', 'int', 'int') : 'bool',
    ...
}

def check_binop(node, env):
    left_type = check_expression(node, env)
    right_type = check_expression(node, env)

    result_type = _binops.get((node.op, left_type, right_type))
    if result_type is None:
        error("Type Error!")

    return result_type
```

Confusion

- Type checking is NOT the same thing as running a program (that's an interpreter)
- No actual calculations are carried out
- It's at a higher level of abstraction

```
var x int;  
var y int;
```

```
z = x + y;           // We know that z must be an "int"  
                     // We know nothing about x, y values
```

- It's "meta". It fills in details about the program.

Checking of Names

- Type checking also involves name checking
- Consider this expression:

`42 + x`

- What type is "x"? What is "x"?
- Languages usually require declarations

`var x int;`

- No declaration -> Name Error

Symbol Tables

- Declarations are managed in a symbol table
- It represents the "environment"

```
env = {  
    'x': Variable(type="int", ...)  
}
```

- Declarations insert definitions in the table
- Later name references consult the table

Symbol Tables and Scopes

- You need nested symbol tables

```
var x int;           // Global

func spam() int {
    var y int;       // Locals
    var z int;
    ...
}
```

{ 'x': Variable('int') }



{
 'y': Variable('int')
 'z': Variable('int')
}

- Keep in mind: You're not running the program.
- You're tracking metadata (definitions).

Project

- Find the file
 - `wabbit/typecheck.py`
- Follow instructions inside.