CS 536 Announcements for Wednesday, March 20, 2024

Midterm 2

- Thursday, March 21, 7:30 – 9 pm
- S429 Chemistry
- bring your student ID

Last Time

- name analysis
    - handling `tuple`s
    - handling classes
- review for Midterm 2

Today

- type checking
- type-system concepts
- type-system vocabulary
- base
    - type rules
    - how to apply type rules

After Spring Break

- runtime environments

What is a type?

Short for **data type**

- classification identifying kinds of data
- a set of possible values that a variable can possess
- operations that can be done on member values
- a representation (perhaps in memory)

Type intuition – is the following allowed?

```
int a = 0;
int *pointer = &a;
float fraction = 1.2;
a = pointer + fraction;
```

Components of a type system

base types (built-in/primitive) integer logical void

rules for constructing types tuple struct class enum

means of determining if types are compatible or equivalent

Can values with different types be combined? If so, how?
e.g. 7+1.2

Can we consider two types the same? If so, how?

```
tuple Point {          tuple Pair {
  integer x.             integer a.
  integer y.             integer b.
}.                     }.
```

rules for inferring the type of an expession

Type rules of a language specify

What types the operands of an operator must be (+, >, ==, =)

```
double a;
int b;
a = b;  ← allowed in Java, C++
b = a;  ← not legal in Java, legal in C++
```

What type the result of an operator is

Type coercion

- implicit cast from one data type to another

  int j = 3.0; ← may result in information loss

- type promotion – destination type can represent source type

  double f = 123;

Places where certain types are expected

```
if (x = 4) {
  ...
}
```

need to have assignment return a value (eg x=y=z=7.)

In base, condition of if must evaluate to logical

Type checking: <u>when</u> do we check?

static typing – type checking done at compile time

dynamic typing – type checking done at runtime

combination of the two ← Java does this

Fruit

Apple Orange

```
Apple a = new Apple(x);
Fruit f = a;
```

upcasting

```
Apple a = new Apple();
Orange o = (Orange)a;
```

cross-casting – not allowed – static check

```
Fruit f = new Apple();
if (...) {
    f = new Orange();
}
Apple two = (Apple)f;
```

down-casting – compiles

– runtime error if f is an Orange

Static vs dynamic trade-offs

- static
  + compile-time error checking
  + compile-time optimizations may be more available
- dynamic
  + avoid dealing with errors that don't matter
  + some added flexibility
  – failures can happen at runtime

Duck typing - type is defined by methods and properties – often done dynamically

```
class bird:
    def quack() : print("quack")
class robobird
    def quack() : print("0100101101")
```

Type checking: <u>what</u> do we check?

strong vs weak typing – continuum with no precise defs

- degree to which type checks are performed
- degree to which type errors are allowed to happened at runtime

General principles

- statically typed → stronger (fewer type errors possible at run time)
- more implicit casting allowed → weaker
- fewer checks performed at runtime → weaker

Example

C (weaker)

```
union either {
    int i;
    float f;
} u;
u.i = 12;
float val = u.f;
```

Standard ML (stronger)

```
real(2) + 2.0
```

Type safety

- All successful operations must be allowed by the type system
- Java is explicitly designed to be type safe – if you have a variable declared to be of some type, then it is guaranteed (at runtime) to be of that type (or a subtype of that type)
- C is not

it allows → (type-safety violations)

```
printf("%s", 1);
struct big {
    int a[100000];
};
struct big *b = malloc(1);
```

← memory safety issue

- C++ is a little better

```
class T1 { char a; }
class T2 { int b; }
int main() {
    T1 *myT1 = new T1();
    T2 *myT2 = new T2();
    myT1 = (T1 *)myT2;
}
```

← allows unchecked casts

Type checking in base

base's type system

- primitive types integer, logical, void, string ← literals only
- type constructors tuple
- coercion logical cannot be used as an integer & vice versa

Type errors in base

Operators applied to operands of wrong type

- arithmetic operators must have integer operands
- logical operators must have logical operands
- equality operators == ~=
  - must have operands of the same type
  - can't be applied to
    - function names
    - tuple names
    - tuple variables

    tuple Point p1.
    tuple Point p2.
    p1 == p2 ← not allowed
    p1:x == p2:y ← ok (comparing integers)
    p1 = p2. ← not allowed
- other relational operators – must have integer operands
- assignment operator =
  - must have operands of the same type
  - can't be applied to
    - function names
    - tuple names
    - tuple variables

Expressions that, because of context, must be a particular type but are not

- expressions that must be logical (in base)
  condition of if, condition of while
- reading read >> x.
  x can't be function name, tuple name, tuple variable
- writing write << x.
  x can't be function name, tuple name, tuple variable
  – but can be string, expression eg (7+3)

Related to function calls

- invoking (i.e., calling) something that is not a function
- invoking a function with
  - wrong number of arguments
  - wrong types of arguments
- returning a value from a `void` function ie, can't have return x.
- not returning a value from a non-`void` function ie, can't have return.
- returning wrong type of value in a non-`void` function

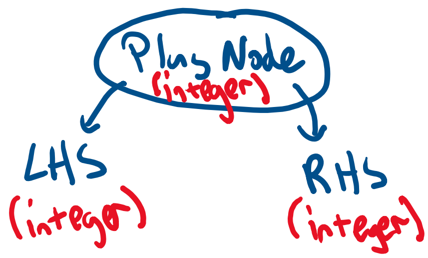
Type checking

Recursively walks the AST to

- determine the type of each expression and sub-expression using the type rules of the language
- find type errors (& report them)

Add a `typeCheck` method to AST nodes

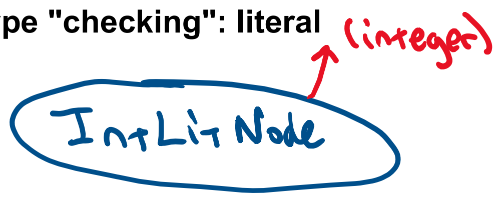
Type checking: binary operator



Get type of LHS
Get type of RHS
Check that types are compatible for operator

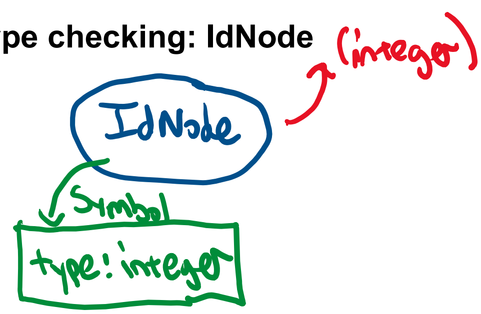
Set kind of node to be a value
Set type of node to be type of operator's result

Type "checking": literal



Cannot be wrong
- just pass type of literal up the tree

Type checking: IdNode



Look up type of declaration
- should be a symbol linked to node (from name analysis)

Pass symbol type up the tree

Type checking: others

- call to function *f*
    - get type of each actual parameter of *f*
    - match against type of corresponding formal parameter of *f*
    - pass *f*'s return type up the tree

  use symbol table entry for f to get info

- statement *s*
    - type check constituents of *s*

      - nothing to pass up the tree - statements don't produce a value → s has no "return type"

Type checking (cont.)

Type checking: errors

<u>Goals</u>:

- report as many *distinct* errors as possible
- don't report *same* error multiple times – avoid error cascading

Introduce internal `error` type

- when type incompatibility is discovered
  - report the error
  - pass `error` up the tree
- when a type check gets `error` as an operand
  - don't (re)report an error
  - pass `error` up the tree

Example:

```
integer a.
logical b.
a = True + 1 + 2 + b.
b = 2.
```