COSE212: Programming Languages

Lecture 10 — Type System
(1) Motivation

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Review: Our Programming Language System So Far

- Designed and implemented a programming language system:
  - Rigorously defined syntax and semantics of the language.
  - Faithfully implemented the interpreter based on the formal design.

$$\text{Program} \rightarrow \boxed{\text{Interpreter}} \rightarrow \text{Result}$$

- A well-designed language indeed, with clean syntax and semantics :-)
- However, the current system has a significant shortcoming.

The Language System is Unsafe

- It attempts to execute unsafe programs too, only to fail at runtime.

  Unsafe Program → [Interpreter] → Runtime Failure

  For example,

  - `if 3 then 88 else 99`
  - `(proc (x) (x 3)) 4`
  - `let x = iszero 0 in (3-x)`

- We want to avoid evaluating unsafe programs but the language system puts all the burden of writing safe programs on the programmers.
  - Also in C, C++, Python, JavaScript, etc.

- This manual approach of avoiding software errors has proven extremely unsuccessful.

Software Failures in History

- (1996) The Arian-5 rocket, whose development required 10 years and $8 billion, exploded just 37s after launch due to software error.

- (1998) NASA's Mars climate orbiter lost in space. Cost: $125 million
- (2000) Accidents in radiation therapy system. Cost: 8 patients died
- (2007) Air control system shutdown in LA airport. Cost: 6,000 passengers stranded
- (2012) Glitch in trading software of Knight Captal. Cost: $440 million
- (2014) Airbag malfunction of Nissan vehicles. Cost: $1 million vehicles recalled
- ... Countless software projects failed in history.

Dream: Safe Language System

- Automated technology for analyzing the safety and detecting all bugs of programs statically.

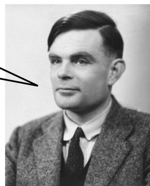
$$\text{Program} \rightarrow \boxed{\text{Analyzer}} \rightarrow \boxed{\text{Interpreter}} \rightarrow \text{Result}$$

- Static analyzer detects software bugs statically and automatically
  - static: by analyzing program text, before run/ship/embed
  - automatic: sw is analyzed by sw ("static analyzer")
- Next-generation software testing technology
  - finding bugs early / full automation / all bugs found

Static Analysis is Undecidable

- Unfortunately, “static analysis” is undecidable.

Halting problem is undecidable!



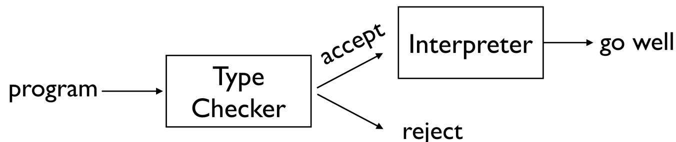
- More precisely, sound and complete static analysis is impossible.
- Approximate (yet useful) ones are possible.

Soundness and Completeness

- **Soundness**: Analyzer can prove the absence of errors. If analyzer accepts a program, then the program is safe. If a program has errors, analyzer rejects the program. All unsafe programs are rejected. No false negatives.
- **Completeness**: Analyzer can prove the presence of errors. If analyzer rejects a program, then the program has errors. If the program is safe, analyzer accepts the program. All safe programs are accepted. No false positives.

Plan: Building a Static Type System for Our Language

Static analyzer that detects type errors (runtime failures caused by type mismatches).



- `if true then 88 else 99`
- `if 3 then 88 else 99`
- `(proc (x) (x 3)) (proc (x) x)`
- `(proc (x) (3 x))` e
- `let x = iszero 0 in (3-x)`

cf) Detecting other types of errors is beyond the scope of our type system, e.g., `((proc (x) (4 / x)) 0`.

Sound but Incomplete Type System

- We settle for a sound but incomplete type system.
  - Sound: detecting all type errors.
  - Incomplete: some safe programs will not pass our type system.
- Type systems in modern programming languages such as ML, Haskell, and Scala are also sound but incomplete.
- cf) Type systems in languages like C and C++ are neither sound nor complete.

Next: Sound Type System for PROC

$$
\begin{array}{rcl}
E & \rightarrow & n \\
  & \mid & x \\
  & \mid & E + E \\
  & \mid & E - E \\
  & \mid & \texttt{iszero}\ E \\
  & \mid & \texttt{if}\ E\ \texttt{then}\ E\ \texttt{else}\ E \\
  & \mid & \texttt{let}\ x = E\ \texttt{in}\ E \\
  & \mid & \texttt{proc}\ x\ E \\
  & \mid & E\ E
\end{array}
$$