CSC 501 – Semantics of Programming Languages

- Subtitle: An Introduction to Formal Methods.
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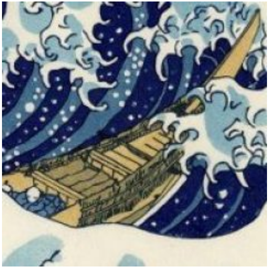

Books

There are no required books in this course; however, occasionally I will assign readings based on material available on the web.

Course Objectives

The aim of this course is to

- Familiarize you with the basic techniques of applying formal methods to programming languages.
- This includes constructing models for programming languages and using these models to prove properties such as correctness and equivalence of programs.
- Look at all major programming language constructs including assignments, loops, type systems, and procedure calls together with their models.
- Introduce mechanical theorem provers so that we can test and prove properties of non-trivial programs.

Some Definitions

Definition: In **programming language semantics** we are concerned with the *rigorous mathematical study* of the *meaning* of programming languages. The meaning of a language is given by a *formal system* that describes the possible computations expressible within that language.

Some Definitions

Definition: In computer science and software engineering, **formal methods** are techniques for the specification, development and verification of software and hardware systems based on *formal systems*.

Formal Systems

Definition: A **formal system** consists of a *formal language* and a set of *inference rules*. The formal language is composed of primitive symbols that make up well formed formulas and the inference rules are used to derive expressions from other expressions within the formal system. A formal system may be formulated and studied for its intrinsic properties, or it may be intended as a description (i.e. a model) of external phenomena.[1]

In order to be truly useful in computer science, we require our formal systems to be *machine executable*.

[1]Wikipedia

Uses of Formal Methods

Implementation Issues Formally specified models can be considered machine-independent specifications of program behavior. They can act as "yard sticks" for the correctness of program implementations, transformations, and optimizations.

Verification Basis of methods for reasoning about program properties (e.g. equivalence) and program specifications (program correctness).

Language Design Can bring to light ambiguities and unforeseen subtleties in programming language constructs.

Observations

When programming we can observe two mental activities:

- We construct *correct looking* programs - *syntactically* correct programs.
- We construct *models* of the intended computation in our minds. Consider,

```
x := 1
while (x <= 10) do
     writeln(x)
     x := x + 1
end whiledo
```

  Any person with some familiarity of programming immediately has a mental picture that this program will generate a list of integers from 1 through 10.

Programming Language Definitions

Mirroring our intuition, language definitions consist of two parts:

Syntax The formal description of the **structure** of well-formed expressions, phrases, programs, etc.

Semantics The formal description of the **meaning** of the syntactic features of a programming language usually understood in terms of the runtime **behavior** each syntactic construct evokes. The formal description of the behavior of all the syntactic features of a language is considered a **model** of the language.

Evaluation/Interpretation

Syntax and semantics of a programming language are usually related via an *evaluation relation* or *interpretation*, say h. Then we say that the interpretation h takes each syntactic element and maps it into the appropriate semantic construct.

We often represent this with the diagram

$$\begin{array}{c} \mathit{Semantics} \\ h \big\uparrow \\ \mathit{Syntax} \end{array}$$

Note: In order for the interpretation h to make any sense we will have to define the syntax and semantics in terms of sets.

Formal Systems and Programs

The formal systems we will be using in this course are:

- First-order logic extended with natural deduction – natural semantics.
- The *first order predicate calculus* (often also called first order logic) to construct semantics of programming languages.

Readings

- Read Chapter 0 in "Denotational Semantics" by David Schmidt (available from the course website).
- Read Sections 2.1 and 2.2 in "Denotational Semantics" by David Schmidt.