Semantics and Domain Theory – Notes on lecture 1

Herman Geuvers

1 Content of the course

- semantics: "assigning meaning to programs" (more generally: to phrases in a *formal* language)
- domain theory: the mathematical theory of the *sets-with-structure* necessary to achieve this

One contrasts

- operational semantics: "evaluation"
- axiomatic semantics: "logic" (assertions about programs)
- denotational semantics: "model theory"

1.1 Operational semantics

- inductive definitions
- grammars
- systems of inference rules defining derivations of judgments
- definition by structural recursion (on syntax, on rules)
- proof by induction
- specification of *behaviour* by execution/evaluation
- exp $\Rightarrow$ val, evaluation judgments, for apppropriate notions of "exp" (expressions) and "val" (values).
- config $\Rightarrow$ st, execution judgemnts, for an abstract machine with *configurations* "config" and *final states* "st"
- styles of operational semantics
  - **big-step**: evaluation/execution all in one go;
  - **small-step**: consider intermediate configurations of an abstract machine; take transitive closure to reach a final state
- operational semantics gives an **intensional** theory of behaviour: **how**, not what.

1.2 Denotational semantics

- abstract mathematical structures
- behaviour described in terms of mathematical functions operating on such abstract values
- **extensional** theory of behaviour: **what**, not how
- "equal values map to equal results": need notions of equality of abstract programs
- typically *recursive* (rather than inductive) definitions
- "a general theory of recursive definitions"

Another view on denotational semantics/domain theory is: "a general theory of partiality/partial recursive definitions"

1.3 Programming languages

- The simple imperative language (IMP) or (WHILE):
  - assignment to variables (called "locations" by Pitts), conditional execution, unbounded iteration sequential composition (need to put smaller program together to make larger ones)
  - origins: Turing/von Neumann model (1930s), ForTran (Backus, 1957)
  - meanings given by transformations on states: partial functions from locations (variables) to values, so: ... higher-order functions ...
- Functional languages, essentially varieties of lambda calculus (PCF):
  - function application and abstraction, possibly built on top of some primitives.
  - origins: Church (untyped 1930s, typed 1940s), LISP (McCarthy, 1957).
  - meanings given by... already in terms of ... higher-order functions (again!).
  - defined (usually) by (possibly many) syntactic categories (phrase types) T, E, C, ... specified by a (context-free) grammar.
  - each phrase type C gives rise to a set of the well-formed phrases of that type. We identify C with this set.

1.4 Domains

A domain is ...

- an appropriate target $[\![C]\!]$ for interpreting (giving meaning to) elements of C;
- it will turn out to be analysed in terms of suitable set-with-structure (an order relation reflecting *partial states of knowledge*).

1.5 Denotational Semantics

A denotational semantics for the phrase type C is simply a mapping

$$[\![-]\!] : C \to [\![C]\!].$$

So we overload $[\![-]\!]$ in the usual way; these double braces are usually called *Scott brackets* after Dana Scott, who basically founded the subject; he was originally a student of Tarski)

$[\![-]\!]$ should respect/reflect the appropriate structure on C and $[\![C]\!]$.

1.6 Summarising

The principal aim of the subject:

> to develop the interplay between these two points-of-view on the meaning/behaviour of programs, that is, to relate

- execution of programs,
  e.g. $\langle \text{prog}, \text{config} \rangle \Rightarrow \text{config}$
- mathematical description in terms of functions,
  e.g. $[\![\text{prog}]\!] : [\![\text{config}]\!] \to [\![\text{config}]\!]$

taking into account

- partiality
- recursion
- appropriate notions of equality, and simulation, between programs

For next time: DENS (Pitts), Ch. 1 For those who haven't followed the course *Semantics and Correctness* (or a similar course): read pages 7-26 of *Semantics with applications*, by Hanne Riis Nielson and Flemming Nielson (Wiley 1999), see the webpage of the course.