# Homework #2: Operational Semantics for the WHILE Language

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## 1 Introduction to the WHILE Language

The "WHILE" language is a basic language that was defined in class. Figure 1 defines the expressions, values, and operators in this language. This notation for expressions ($e$), values ($v$), variables/addresses ($x$), and store ($\sigma$) applies to all sections of this document.

| | | |
|---|---|---|
| $e$ ::= | | *Expressions* |
| | $x$ | variables/addresses |
| | $v$ | values |
| | $x := e$ | assignment |
| | $e; e$ | sequential expressions |
| | $e$ *op* $e$ | binary operations |
| | `if` $e$ `then` $e$ `else` $e$ | conditional expressions |
| | `while` $(e)$ $e$ | while expressions |
| | `not` $e$ | not expressions |
| | `and` $(e)$ $(e)$ | and expressions |
| | `or` $(e)$ $(e)$ | or expressions |
| $v$ ::= | | *Values* |
| | $i$ | integer values |
| | $b$ | boolean values |
| *op* ::= | $+ \mid - \mid * \mid / \mid > \mid >= \mid < \mid <=$ | *Binary operators* |
| $\sigma$ | | *Store* |

**Figure 1:** The WHILE language

## 2 Base WHILE Language Small-Step Semantics Rules

The following figures enumerate the execution order, small-step semantics rules for the WHILE language expressions that were defined in class.

**Variable Evaluation Rule:**

$$[\text{SS-VAR}] \qquad \frac{x \in \mathit{domain}(\sigma) \qquad \sigma(x) = v}{x, \sigma \to v, \sigma}$$

**Figure 2:** Variable Small-Step Semantics Evaluation Order Rule

**Set/Assignment Evaluation Rules:**

$$[\text{SS-ASSIGNCONTEXT}] \qquad \frac{e, \sigma \to e', \sigma'}{x := e, \sigma \to x := e', \sigma'}$$

$$[\text{SS-ASSIGNREDUCTION}] \qquad \frac{}{x := v, \sigma \to v, \sigma[x := v]}$$

**Figure 3:** Set/Assignment Small-Step Semantics Evaluation Order Rules

**Binary Operator (`op`) Evaluation Rules:**

$$[\text{SS-OPCONTEXT1}] \qquad \frac{e_1, \sigma \to e_1', \sigma'}{e_1 \ op \ e_2, \sigma \to e_1' \ op \ e_2, \sigma'}$$

$$[\text{SS-OPCONTEXT2}] \qquad \frac{e, \sigma \to e', \sigma'}{v \ op \ e, \sigma \to v \ op \ e', \sigma'}$$

$$[\text{SS-OPREDUCTION}] \qquad \frac{v_3 = v_1 \ op \ v_2}{v_1 \ op \ v_2, \sigma \to v_3, \sigma}$$

**Figure 4:** Binary Operator (`op`) Evaluation Order Rules

**Sequence (`;`) Evaluation Rules:**

$$[\text{SS-SEQCONTEXT}] \qquad \frac{e_1, \sigma \to e_1', \sigma'}{e_1; e_2, \sigma \to e_1'; e_2, \sigma'}$$

$$[\text{SS-SEQREDUCTION}] \qquad \frac{}{v; e, \sigma \to e, \sigma}$$

**Figure 5:** Sequence (`;`) Evaluation Order Rules

**Conditional Statement (`if`) Evaluation Rules:**

[SS-IFCONTEXT]
$$\frac{e_1, \sigma \to e_1', \sigma'}{\texttt{if } e_1 \texttt{ then } e_2 \texttt{ else } e_3, \sigma \to \texttt{if } e_1' \texttt{ then } e_2 \texttt{ else } e_3, \sigma'}$$

[SS-IFTRUEREDUCTION]
$$\frac{}{\texttt{if true then } e_1 \texttt{ else } e_2, \sigma \to e_1, \sigma}$$

[SS-IFFALSEREDUCTION]
$$\frac{}{\texttt{if false then } e_1 \texttt{ else } e_2, \sigma \to e_2, \sigma}$$

**Figure 6:** Conditional (`if`) Small-Step Semantics Evaluation Order Rules

`while` **Evaluation Rule:**

[SS-WHILEREDUCTION]
$$\frac{}{\texttt{while } (e_1)\ e_2, \sigma \to \texttt{if } e_1 \texttt{ then } (e_2; \texttt{while } (e_1)\ e_2) \texttt{ else false}, \sigma}$$

**Figure 7:** `while` Small-Step Semantics Evaluation Order Rule

# 3 Boolean Expressions Small-Step Semantics Rules

In following subsections, I describe three additional expression types in the updated the WHILE language namely: `not`, `and`, and `or`.

## 3.1 `not` Expression

`not` in my modified version of the WHILE language behaves as a standard Boolean `not`. It takes a single Boolean value and returns its complement. If an expression is passed, the language simplifies that expression until it is in normal form at which point it applies the Boolean `not`.

`not` **Evaluation Rule:**

[SS-NOTREDUCTION]
$$\frac{}{\texttt{not } e, \sigma \to \texttt{if } e \texttt{ then false else true}, \sigma}$$

**Figure 8:** `not` Small-Step Semantics Evaluation Order Rule

### 3.2 `and` Expression

`and` is designed to mimic the Boolean `and` with the exception that it supports short circuit compare. Hence, if the first expression in the "`and`" evaluates to `false`, the second parameter is not evaluated at all.

`and` **Evaluation Rules:**

[SS-ANDCONTEXT]
$$\frac{e_1, \sigma \to e_1', \sigma'}{\texttt{and}\ (e_1)\ (e_2), \sigma \to \texttt{and}\ (e_1')\ (e_2), \sigma'}$$

[SS-ANDREDUCTION]
$$\frac{e' = \texttt{if}\ e\ \texttt{then true else false}}{\texttt{and}\ (v)\ (e), \sigma \to \texttt{if}\ v\ \texttt{then}\ e'\ \texttt{else false}, \sigma}$$

**Figure 9:** `and` Small-Step Semantics Evaluation Order Rules

### 3.3 `or` Expression

`or` is a composite of the expressions "`not`" and "`and`" described in sections 3.1 and 3.2 respectively.

`or` **Evaluation Rule:**

[SS-ORREDUCTION]
$$\frac{e_1' = \texttt{not}\ e_1 \qquad e_2' = \texttt{not}\ e_2 \qquad e_3 = \texttt{and}\ (e_1')\ (e_2')}{\texttt{or}\ (e_1)\ (e_2), \sigma \to \texttt{not}\ e_3, \sigma}$$

**Figure 10:** `or` Small-Step Semantics Evaluation Order Rule