CSE 307: Principles of Programming Languages

Expressions

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Topics

Expressions

- Basic language constructs for generating values.
- Given by a *grammar*:

$$
\begin{array}{lcl}
E & \rightarrow & E + E \\
E & \rightarrow & E - E \\
E & \rightarrow & E * E \\
E & \rightarrow & - E \\
E & \rightarrow & (E) \\
E & \rightarrow & id \\
E & \rightarrow & int\_const
\end{array}
$$

Meaning of Expressions

- Meaning for expressions are given by "semantic functions" that associate a *value* with every expression.
  - What is the value of `x + 1`?
  - What is the value of `f(x)` where `f` is defined as `int f(int i) { return i+1;}`

  Depends on what the value of `x` is.
- An expression's value can be determined when the values of all variables in that expression are given.
- How to represent values of variables?
  - **Environment**: maps variable name to locations
  - **Store**: maps locations to values

Example: C flat (C $\flat$)

A small language to illustrate how semantic functions are written.

- Values
  - Integer constants
  - Boolean constants (`true`, `false`)
- Variables of type
  - `int`
  - Pointers

Expressions in C $\flat$

$$\begin{array}{rcl}
E & \rightarrow & E\ arith_op\ E \\
E & \rightarrow & -\ E \\
E & \rightarrow & (\ E\ ) \\
E & \rightarrow & id \\
E & \rightarrow & int_const \\
arith_op & \rightarrow & + \mid - \mid *
\end{array}
\qquad
\begin{array}{rcl}
C & \rightarrow & E\ comp_op\ E \\
C & \rightarrow & C\ logical_op\ C \\
C & \rightarrow & !\ C \\
C & \rightarrow & boolean_const \\
comp_op & \rightarrow & == \mid < \\
logical_op & \rightarrow & \&\& \mid ||
\end{array}$$

Abstract Syntax of C ♭ Expressions

```
type expr = Add of expr * expr
          | Sub of expr * expr
          | Mul of expr * expr
          | Neg of expr
          | Id of string
          | IntConst of int;;
```

```
type cond = Equal of expr * expr
          | Less of expr * expr
          | And of cond * cond
          | Or of cond * cond
          | Not of cond
          | True | False;;
```


Abstract syntax of C ♭ (Continued)

- Each expression in concrete syntax can be represented by an equivalent expression in abstract syntax.
- Examples:

Concrete	**Abstract**
`x+1`	`Add(Id("x"), IntConst(1))`
`x*(y+3)`	`Mul(Id("x"), Add(Id("y"), IntConst(3)))`
`x == y`	`Equal(Id("x"), Id("y"))`

- Abstract syntax ignores certain details (e.g., paranthesis in expressions), but makes certain features explicit (e.g. the “kind” of expression).

Environment and Store

- Only values we can store for now are integers.

  `type storable = Intval of integer;;`

  When we add pointers to the languages, we will add to the definition of `value`.
- Locations can be simply represented by integers.

  `type location = int;;`

Environment and Store

- Store maps locations to values.

  `type store = location * storable list;;`

  - Example: `[(1,Int(3)), (2,Int(7))]`: Location 1 has value 3 and 2 has value 7.
- Functions over store:
  - `value_at: store * location -> storable`
- Environment maps variables to locations.

  `type environment = string * location list;;`

  - Example: `[("x", 1), ("y", 2)]`: Variable `x` is at location 1 and `y` is at location 2.
- Functions over environment:
  - `binding_of: environment * string -> location`

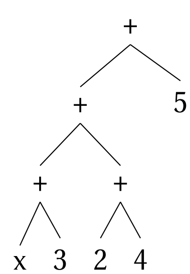
The meaning of expressions

- What is the value of `x + 1`?
  - It is the value of `x` added to the value of `1`.
  - The value of `x` is given by
    - **the environment** which specifies the location associated with `x`, and
    - **the store** which specifies the values stored in locations.
- "Value of" can be viewed as a function

  `eval_expr:expr * environment * store -> value`

Expression evaluation

- Order of evaluation
- For the abstract syntax tree



- the equivalent expression is (x + 3) + (2 + 4) + 5

Expression evaluation (Continued)

- One possible semantics:
  - evaluate AST bottom-up, left-to-right.
- This constrains optimization that uses mathematical properties of operators
- (e.g. commutativity and associativity)
  - e.g.,it may be preferable to evaluate of e1+(e2+e3)instead of (e1+e2)+e3
  - (x+0)+(y+3)+(z+4)=>x+y+z+0+3+4=>x+y+z+7
  - the compiler can evaluate 0+3+4 at compile time, so that at runtime, we have two fewer addition operations.

Expression evaluation (Continued)

- Some languages leave order of evaluation unspecified.
  - even the order of evaluation of procedure parameters are not specified.
- Problem:
  - Semantics of expressions with side-effects, e.g., `(x++) + x`
  - If initial value of x is 5
    - left-to-right evaluation yields 11 as answer, but
    - right-to-left evaluation yields 10
- So, languages with expressions with side-effects forced to specify evaluation order
- Still, a bad programming practice to use expressions where different orders of evaluation can lead to different results
  - Impacts readability (and maintainability) of programs

Left-to-right evaluation

- Left-to-right evaluation with short-circuit semantics is appropriate for boolean expressions.

  e1&&e2: e2 is evaluated only if e1 evaluates to true.

  e1||e2: e2 is evaluated only if e1 evaluates to false.
- This semantics is convenient in programming:
  - Consider the statement: `if((i<n) && a[i]!=0)`
  - With short-circuit evaluation, `a[i]` is never accessed if `i>= n`
  - Another example: `if ((p!=NULL) && p->value>0)`

Left-to-right evaluation (Continued)

- Disadvantage:
  - In an expression like "if((a==b)||(c=d))"
  - The second expression has a statement. The value of c may or may not be the value of d, depending on if a == b is true or not.
- Bottom-up:
  - No order specified among unrelated subexpressions.
  - Short-circuit evaluation of boolean expressions.
- Delayed evaluation
  - Delay evaluation of an expressions until its value is absolutely needed.
  - Generalization of short-circuit evaluation.

Evaluating expressions

Assume that we are interested only in int values:

*eval_expr: expr * environment * store -> int*

Recall:

```
type expr = Add of expr * expr          type location = int;;
          | Sub of expr * expr          type storable =
          | Mul of expr * expr              Intval of integer;;
          | Neg of expr                 type store =
          | Id of string                    location * storable list;;
          | IntConst of int ;;          type environment =
                                            string * location list;;
```

eval_expr(Id(x), env, store) $= i$
where binding_of(env, x) $= l$
and value_at(store, l) = Intval(i)

Evaluating expressions: The Program

```
eval_expr(expr, env, store) =
  match expr with
| IntConst(i) -> i

| Id(x) ->
    let l = binding_of(env, x)
    in let Intval(i) = value_at(store, l)
    in i

| Add(e1, e2) ->
    let v1 = eval_expr(e1, env, store)
    and v2 = eval_expr(e2, env, store)
    in  v1 + v2
...
```

Similarly we can define eval_cond: cond * environment * store -> bool

Evaluation order

- Consider evaluating conditions with the following fragment:

```
Or(c1, c2) ->
   let b1 = eval_cond(c1, env, store)
   and b2 = eval_cond(c2, env, store)
   in  b1 || b2
```

- What is the effect of `(i==0) || (x/i)`?
- **Short-circuit evaluation:** For $c_1 \,||\, c_2$, evaluate c_2 only if c_1 is false.

```
Or(c1, c2) ->
   if (eval_cond(c1, env, store))
      then true
      else eval_cond(c2, env, store)
```


Evaluation order (contd.)

- In the fragment of C ♭considered so far, expressions do not have any side effect (i.e. cannot change the store)
  and hence, order of evaluation does not change the final result.
- In C/C++/Java/. . ., expressions may have side effects (e.g. `x++`)
- Side effects modify the store
- Expression valuation function then becomes:
  `eval_expr: expr * environment * store -> (int * store)` i.e., meaning that the expression returns its value *and the updated store*