Language Paradigms

Different ways of expressing computation;

- imperative
- functional
- logic
- ...*object-oriented*

Others:

dataflow, coordination, algebraic, graph-based, etc

Note: distinction is sometimes fuzzy!

Imperative Paradigm

Example: compute m^n $(n \geq 0)$

```
result := 1;
while n > 0 do
    result := result * m;
    n := n - 1
end while;
```

Assessment:

- computation is expressed by repeated modification of an *implicit* store (i.e., components *command* a store modification),
- intermediate results are held in store
- iteration (loop)-based control

Functional Paradigm

Example: compute m^n $(n \geq 0)$

```
fun power (m,n) =
    if (n = 0)
       then 1
       else m * power(m,n-1);
```

Assessment:

- computation is expressed by function application and composition
- no implicit store
- intermediate results (function outputs) are passed directly into other functions
- recursion-based control

Logic Paradigm

Example: compute m^n $(n \geq 0)$

```
/* define predicate power(m,n,result) */

power(m,0,1).
power(m,n,result)
  <- minus(n,1,n_sub1),
     power(m,n_sub1,temp_result),
     times(m,temp_result,result).
```

Assessment:

- computation is expressed by proof search, or alternatively, by recursively defining *relations*
- no implicit store
- all intermediate results (i.e., function outputs) are stored in variables
- recursion-based control

Introduction to SML

SML is an *expression-based* (*functional*) language.

1. why SML in CIS505?
2. statements *vs.* expressions
3. basic SML expressions
   - literals, variable references, function calls, conditionals, ...
4. typing issues
5. variables and bindings
6. tuples and lists

Why SML?

- **Well-understood foundations:** This is a course about the foundations of programming languages, and the theory/foundations of SML have been studied more in recent years than almost any other language.
- **Well-designed:** Robin Milner, the principal designer of SML received the Turing Award, in part, because of his work on SML.
- **Advanced features:** Many of the features of SML, such as parametric polymorhism, pattern matching, and advanced modules are very elegant and do not appear in other languages like Java, C++, etc.

Why SML? (continued)

- **Very high-level:** Using SML lets us describe language processors very succinctly (much more concisely than any imperative language).
- **Clean:** SML is useful for various critical applications where programs need to be proven correct
- **It's different than Java:** At some point in your career, you will have to learn a new language. This course prepares you for that by forcing you to learn a new language (SML) quickly. In addition, compared to Java, C, etc., SML uses a totally different style to describe computation. This forces you to think more deeply (mental pushups!).
- **There's more!** There are also several different concurrent versions of SML, object-oriented extensions, libraries for various applications, etc.

Statement

- construct evaluated only for its effect

Examples:

```
m := 5;
n := 2;
result := 1;
while n > 0 do
    result := result * m;
    n := n - 1
end while;
write result;
```

Statement-oriented/imperative languages:

- Pascal, C, C++, Ada, FORTRAN, COBOL, etc

Expression

- construct evaluated to yield value

Examples:

```
A := 2 + 3;                /* rhs is expression */

power 5 2                  /* SML function call */

a = (b = c++) + 1;  /* C, C++, Java */
```

Pure expressions: no side-effects

Expression-oriented/functional languages:

- Scheme, ML, Lisp, Haskell, Miranda, FP, etc

Basic SML Expressions

- constants (i.e., literals)
- variable references
- function application
- conditional expressions

Constants

- **Integers:** 0, 22, 353,...
- **Reals:** 12.0, 3E-2, 3.14e12
- **Booleans:** true, false
- **Strings:** "KSU", "foo\n"
- **Characters:** #"x", #"A", #"\n"

Example Session


```
- 2;
val it = 2 : int
- it + 1;
val it = 3 : int
- it;
val it = 3 : int
- ~234 + 2;
val it = ~232 : int
- 12.0;
val it = 12.0 : real
- 12. + 3.1;
stdIn:16.1 Error: syntax error found at DOT
- "KSU";
val it = "KSU" : string
- "foo\n";
val it = "foo\n" : string
- #"x";
val it = #"x" : char
- #"gh";
... Error: character constant not length 1
```

Arithmetic Operators

Precedence: lowest to highest

- $+$, $-$
- $*$, $/$, div, mod
- ~

Also:

- ML is case sensitive (cf. `mod`)
- associativity and precedence as in other languages
- operators associate to the left
- parentheses are
  - needed only to enforce evaluation order, as in `x * (y + z)`
  - but may be freely added to improve clarity, as in `x + (y * z)`

String Operators

Concatenation:

```
- "abra" ^ "cadabra";
val it = "abracadabra" : string

- "abra" ^ "" ^ "cadabra" ^ "";
val it = "abracadabra" : string

- "abra" ^ ("" ^ "cadabra") ^ "";
val it = "abracadabra" : string
```

- "" (empty string) is identity element
- ^ is associative

Comparison Operators

$$=,\ <,\ >,\ <=,\ >=,\ <>$$

Note:

- cannot use $=$ or $<>$ on reals
  - to avoid problems with rounding
  - use e.g., $<=$ and $>=$ for $=$
- $<$ means "lexicographically procedes" for characters and strings

```
- "a" < "b";
val it = true : bool
- "c" < "b";
val it = false : bool
- "abc" < "acb";
val it = true : bool
- "stuv" < "stu";
val it = false : bool
```

Boolean Operators

`not, andalso, orelse`

- behave like C's `!`, `&&`, `||` — not like Pascal
- not commutative, as "short-circuit" operation

```
- (1 < 4) orelse ((5 div 0) < 2);
val it = true : bool
- ((5 div 0) < 2) orelse (1 < 4);
** error **
```

If-then-else Expressions

Examples:

```
- if 4 < 3 then "a" else "bcd";
val it = "bcd" : string

- val t = true;
val t = true : bool
- val f = false;
val f = false : bool

- if t = f then (5 div 0) else 6;
val it = 6 : int

- if t = true then 7 else "foo";
... Error: types of rules don't agree...
  earlier rule(s): bool -> int
  this rule: bool -> string
  in rule:
    false => "foo"
```

Typing Issues

ML has strong typing:

(strong/weak = how much)

- each value has exactly one type
- for example, 12 is `int` but not `real`
- explicit coercions therefore necessary

ML has static typing:

(static/dynamic = when)

- type-checking occurs *before* programs are run
  - thus `if x = y then 7 else "foo"` is an error
  - but it wouldn't be in a dynamically typed language

These concepts are too often mixed up, even in the Ullman textbook (pages 3 and 143)

Coercions

From integers to reals:

```
- real(11);
val it = 11.0 : real
- 5.0 + 11;
... Error: operator and operand mismatch
  operator domain: real * real
  operand:         real * int
  in expression:
    5.0 + 11
- 5.0 + real(11);
val it = 16.0 : real
```

From reals to integers:

```
- floor(5.4);
val it = 5 : int
- ceil(5.4);
val it = 6 : int
- round(5.5);
val it = 6 : int
- trunc(~5.4);
val it = ~5 : int
```

Coercions

Between characters and integers:

```
- ord(#"0");
val it = 48 : int

- chr(48);
val it = #"0" : char
```

Between strings and characters:

```
- str(#"a");
val it = "a" : string
```

What about from string to character?

Identifiers

SML has two classes of identifiers:

- alphanumeric (e.g., `abc`, `abc'`, `A_1`)
- symbolic (e.g., `+`, `$$$`, `%-%`)

Alphanumeric Identifiers: strings formed by

- An upper or lower case letter or the character ' (called apostrophe or "prime"), followed by
- Zero or more additional characters from the set given in (1) plus the digits and the character _ (underscore).

Symbolic Identifiers: strings composed of

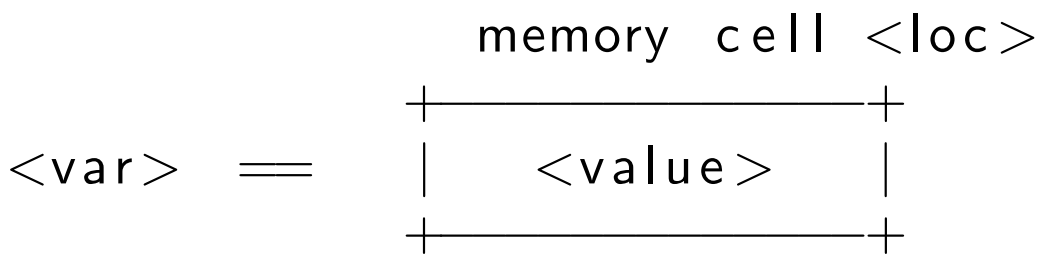
```
+ - / * < > = ! @ # $ % ^ & ` ~ \ | ? :
```

Variables

Consider from Pascal: `A := B + 2;`

- `B` is a *variable reference* (contrast with `A`)
- a memory location is associated with `A`
- a stored value (e.g., 5) is associated with `B`

Pascal, C, Java, Fortran, etc:



- variables bind to locations
- there is a level of indirection
- two mappings
  - environment: maps variables to locations
  - store: maps locations to values

Variables

SML: variables bound to values

<var> == <value>

- variables bind directly to values
- there is no indirection
- a binding cannot be modified (!!)
- no assignment (!!)
- one mapping
  - environment: maps variables to values

Top-level Environment


```
- val a = 2;
val a = 2 : int
- val b = 3;
val b = 3 : int
- val c = a + b;
val c = 5 : int
- val a = c + 2;
val a = 7 : int
- val c = c + 2;
val c = 7 : int
```

var	value
a	2
b	3
c	5
a	7
c	7

Tuples

Tuple: fixed-size ordered collection of two or more values.

```
- val t = (1, "a", true);
val t = (1,"a",true) : int * string * bool
- #3(t);
val it = true : bool
 - val s = (4, t);
val s = (4,(1,"a",true)) :
          int * (int * string * bool)
- #2(#2(s));
val it = "a" : string
- (4);
val it = 4 : int
- ();
val it = () : unit
- #2 t;
val it = "a" : string
- #4(t);
stdIn:16.1-16.6 Error: ...
```

Lists

ML lists are lists of values of the same type.

Example session:

```
- [1,2,3];
val it = [1,2,3] : int list
- [(1,2),(2,3),(3,4)];
val it = [(1,2),(2,3),(3,4)] :
    (int * int) list
- ["a"];
val it = ["a"] : string list
- ["a",2];
... Error: operator and operand don't agree...
- [[1],[2],[3]];
val it = [[1],[2],[3]] : int list list
- [];
val it = [] : 'a list
```

Polymorphic List Operations

empty list	`[]`	:	`'a list`
head	`hd`	:	`'a list → 'a`
tail	`tl`	:	`'a list → 'a list`
append	`@`	:	`'a list * 'a list → 'a list`
cons	`::`	:	`'a * 'a list → 'a list`

Example session:

```
- val ls = [1,2,3];
val ls = [1,2,3] : int list
- hd(ls);
val it = 1 : int
- hd(["a","b","c"]);
val it = "a" : string
- tl(tl(ls));
val it = [3] : int list
- tl(tl(ls)) @ ls;
val it = [3,1,2,3] : int list
- 3 @ ls;
... Error: operator and operand don't agree
- 3 :: ls;
val it = [3,1,2,3] : int list
```

Strings ↔ Lists

Example session:

```
- explode("abcd");
val it = [#"a",#"b",#"c",#"d"] : char list
- implode([#"f",#"o",#"o"]);
val it = "foo" : string
- implode(explode("abcd"));
val it = "abcd" : string
- explode(implode([#"f",#"o",#"o"]));
val it = [#"f",#"o",#"o"] : char list
```

Examples


```
- "abc" ^ implode([#"f",#"o",#"o"]) ^ "bar";
val it = "abcfoobar" : string
- ([4,5],[2],[ord(#"c")]);
val it = ([4,5],[2],[99]) :
         int list * int list * int list
- "abc" > "foo";
val it = false : bool
- 7 :: 5;
stdIn:37.1-37.7 Error:
    operator and operand don't agree [literal]
- ["a","b",#"c","d"];
stdIn:1.1-30.2 Error: operator and operand
    don't agree [tycon mismatch]
- 20 + (if #"c" < #"C" then 5 else 10);
val it = 30 : int
- ((),(),[()],([]));
... : unit * unit * unit list * 'a list
```

Summary

ML is an expression-based *(*functional*) language with* strong static *typing.*

Next lecture: user-defined functions