Logic Programming
Prolog: Arithmetic, Equalities, Operators, I/O. (PLP 11)
Databases: assert, retract. (CTM 9.6)

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Arithmetic Goals

- \( N > M \)
- \( N < M \)
- \( N =< M \)
- \( N >= M \)

- \( N \) and \( M \) must be bound to numbers for these tests to succeed or fail.

- \( X \text{ is } 1+2 \) is used to assign numeric value of right-hand-side to variable in left-hand-side.
Loop Revisited

natural(1).
natural(N) :- natural(M), N is M+1.
my_loop(N) :- N>0,
natural(I), % generate
write(I), nl,
I=N, % test
!.

my_loop(_).

Also called generate-and-test.
= is not equal to  ==  or  =:=

\[ X = Y \quad X \not= Y \]

test whether \( X \) and \( Y \) can be or cannot be unified.

\[ X == Y \quad X \not== Y \]

test whether \( X \) and \( Y \) are currently co-bound, i.e., have been bound to, or share the same value.

\[ X :== Y \quad X \not== Y \]

test arithmetic equality and inequality.
Can take expressions and evaluates them to a numeric value before testing. Do not bind variables.
More equalities

\[ X \cong Y \quad \quad X \not\cong Y \]

test whether \( X \) and \( Y \) are \textit{structurally identical}.

- \( \cong \) is weaker than \( \cong \) but stronger than \( = \).

- \textbf{Examples:}

\[
\begin{align*}
\text{a} \cong &\cong A \quad \quad \quad \quad \text{false} \\
A &\cong B \quad \quad \quad \quad \quad \text{true} \\
x(A,A) &\cong x(B,C) \quad \quad \quad \text{false} \\
x(A,A) &\cong x(B,B) \quad \quad \quad \text{true} \\
x(A,B) &\cong x(C,D) \quad \quad \quad \text{true}
\end{align*}
\]
More on equalities

$X \equiv Y$

$\Rightarrow \quad X \equiv @ \equiv Y$

$\Rightarrow \quad X = Y$

but not the other way ($\Leftarrow$).

- If two terms are currently co-bound, they are structurally identical, and therefore they can unify.
- Examples:

  $a = @ = A$ \hspace{1cm} false
  $A = @ = B$ \hspace{1cm} true
  $x(A, A) = @ = x(B, C)$ \hspace{1cm} false
  $x(A, A) = @ = x(B, B)$ \hspace{1cm} true
  $x(A, B) = @ = x(C, D)$ \hspace{1cm} true
Prolog Operators

:- op(P,T,O)
    declares an operator symbol O with precedence P and type T.

- Example:
  :- op(500,xfx,'has_color')
  a has_color red.
  b has_color blue.

  then:
  ?- b has_color C.
  C = blue.
  ?- What has_color red.
  What = a.
Operator precedence/type

- Precendence $P$ is an integer: the larger the number, the less the precedence (*ability to group*).
- Type $T$ is one of:

<table>
<thead>
<tr>
<th>$T$</th>
<th>Position</th>
<th>Associativity</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>$xfx$</td>
<td>Infix</td>
<td>Non-associative</td>
<td>is</td>
</tr>
<tr>
<td>$xfy$</td>
<td>Infix</td>
<td>Right-associative</td>
<td>, ;</td>
</tr>
<tr>
<td>$yfx$</td>
<td>Infix</td>
<td>Left-associative</td>
<td>+ - * /</td>
</tr>
<tr>
<td>$fx$</td>
<td>Prefix</td>
<td>Non-associative</td>
<td>?-</td>
</tr>
<tr>
<td>$fy$</td>
<td>Prefix</td>
<td>Right-associative</td>
<td></td>
</tr>
<tr>
<td>$xf$</td>
<td>Postfix</td>
<td>Non-associative</td>
<td></td>
</tr>
<tr>
<td>$yf$</td>
<td>Postfix</td>
<td>Left-associative</td>
<td></td>
</tr>
</tbody>
</table>
Testing types

\texttt{atom}(X)

tests whether $X$ is an \textit{atom}, e.g., ‘foo’, bar.

\texttt{integer}(X)

tests whether $X$ is an \textit{integer}; it does not test for complex terms, e.g., \texttt{integer}(4/2) fails.

\texttt{float}(X)

tests whether $X$ is a \textit{float}; it matches exact type.

\texttt{string}(X)

tests whether $X$ is a \textit{string}, enclosed in ` ` ... ` `.
Prolog Input

seeing \(X\)

succeeds if \(X\) is (or can be) bound to *current read port*.

\(X = \text{user}\) is keyboard (standard input.)

see \(X\)

*opens* port for input file bound to \(X\), and makes it *current*.

seen

*closes* current port for input file, and makes \(\text{user}\) *current*.

read \(X\)

*reads* Prolog type expression from *current* port, storing value in \(X\).

end-of-file

is returned by *read* at <*end-of-file*>. 
**Prolog Output**

**telling**(Χ)
  succeeds if Χ is (or can be) bound to *current output port*.
  Χ = user is screen (standard output.)

**tell**(Χ)
  *opens* port for output file bound to Χ, and makes it *current*.

**told**
  *closes* current output port, and reverses to screen output
  (makes user *current.*)

**write**(Χ)
  *writes* Prolog expression bound to Χ into *current* output port.

**nl**
  new line (line feed).

**tab**(N)
  writes N spaces to current output port.
I/O Example

```prolog
browse(File) :-
    seeing(Old), /* save for later */
    see(File),  /* open this file */
    repeat,
    read(Data), /* read from File */
    process(Data),
    seen, /* close File */
    see(Old), /* prev read source */
    !. /* stop now */

process(end_of_file) :- !.
process(Data) :- write(Data), nl, fail.
```

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## First-Class Terms Revisited

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
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<tr>
<td><code>call(P)</code></td>
<td>Invoke predicate as a goal.</td>
</tr>
<tr>
<td><code>assert(P)</code></td>
<td>Adds predicate to database.</td>
</tr>
<tr>
<td><code>retract(P)</code></td>
<td>Removes predicate from database.</td>
</tr>
<tr>
<td><code>functor(T,F,A)</code></td>
<td>Succeeds if ( T ) is a term with functor ( F ) and arity ( A ).</td>
</tr>
<tr>
<td><code>findall(F,P,L)</code></td>
<td>Returns a list ( L ) with all elements ( F ) satisfying predicate ( P ).</td>
</tr>
<tr>
<td><code>clause(H,B)</code></td>
<td>Succeeds if the clause ( H : - B ) can be found in the database.</td>
</tr>
</tbody>
</table>
Databases: assert and retract

• Prolog enables direct modification of its knowledge base using assert and retract.
• Let us consider a tic-tac-toe game:

We can represent a board with facts $x(n)$ and $o(n)$, for $n$ in \{1..9\} corresponding to each player’s moves.
• As a player (or the computer) moves, a fact is dynamically added to Prolog’s knowledge base.
% main goal:
play :- clear, repeat, getmove, respond.

getmove :- repeat,
      write('Please enter a move: '),
      read(X), empty(X),
      assert(o(X)).

respond :- makemove, printboard, done.

makemove :- move(X), !, assert(x(X)).
makemove :- all_full.

clear :- retractall(x(_)), retractall(o(_)).
The strategy is to first try to win, then try to block a win, then try to create a split (forced win in the next move), then try to prevent opponent from building three in a row, and creating a split, finally choose center, corners, and other empty squares. The order of the rules is key to implementing the strategy.

\[
\text{move}(A) :\neg \text{good}(A), \text{empty}(A), \text{!}.
\]

\[
\text{good}(A) :\neg \text{win}(A).
\]

\[
\text{good}(A) :\neg \text{block\_win}(A).
\]

\[
\text{good}(A) :\neg \text{split}(A).
\]

\[
\text{good}(A) :\neg \text{strong\_build}(A).
\]

\[
\text{good}(A) :\neg \text{weak\_build}(A).
\]

\[
\text{good}(5).
\]

\[
\text{good}(1). \quad \text{good}(3). \quad \text{good}(7). \quad \text{good}(9).
\]

\[
\text{good}(2). \quad \text{good}(4). \quad \text{good}(6). \quad \text{good}(8).
\]
Tic-tac-toe: Strategy(2)

- Moving x(8) produces a split: x(2) or x(7) wins in next move.

```
win(A) :- x(B), x(C), line(A,B,C).
block_win(A):- o(B), o(C), line(A,B,C).
split(A) :- x(B), x(C), different(B,C),
           line(A,B,D), line(A,C,E), empty(D), empty(E).
strong_build(A) :- x(B), line(A,B,C), empty(C),
                 not(risky(C)).
weak_build(A)   :- x(B), line(A,B,C), empty(C),
                 not(double_risky(C)).

risky(C)       :- o(D), line(C,D,E), empty(E).
double_risky(C) :- o(D), o(E), different(D,E),
                  line(C,D,F), line(C,E,G), empty(F), empty(G).
```

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Oz supports dynamic database modifications using a RelationClass. The initial relation is defined as follows:

\[ \text{Rel} = \{\text{New RelationClass init}\} \]

Once we have a relation instance, the following operations are possible:

- \( \{\text{Rel assert}(T)\} \) adds tuple \( T \) to \( \text{Rel} \).
- \( \{\text{Rel assertall}(Ts)\} \) adds the list of tuples \( Ts \) to \( \text{Rel} \).
- \( \{\text{Rel query}(X)\} \) binds \( X \) to one of the tuples in \( \text{Rel} \). \( X \) can be any partial value. If more than one tuple is compatible with \( X \), then search can enumerate all of them.
GraphRel = \{\text{New RelationClass init}\}
\{GraphRel \text{ assertall} ([\text{edge(a b)} \text{ edge(b c)} \text{ edge(c d)}
\quad \text{ edge(d e)} \text{ edge(b e)} \text{ edge(d f)]})\}\}
\text{proc EdgeP A B} \{\text{GraphRel query(\text{edge(A B)})}\} \text{ end}
\{\text{Browse \{Search.base.all proc \{\$ X\} \{EdgeP b X\} end\}}\}
% displays all edges from node b: [c e]
proc \{Path X Y\}
  choice
    X = Y
  [] Z in
    \{EdgeP Z Y\}
    \{Path X Z\}
  end
end

\{Browse \{Search.base.all proc \$ X\} \{Path b X\} end\}

% displays all nodes with a path from node b: [b c e e f d]
87. The Prolog predicate `my_loop/1` can succeed or fail as a goal. Explain why you may want a predicate to succeed, or fail depending on its expected calling context.

88. CTM Exercise 9.8.1 (page 671). Do it both in Prolog and Oz.

89. PLP Exercise 11.7 (page 571), in Oz.

90. Develop a tic-tac-toe game in Oz.