Languages

How are functional and imperative languages similar?
How are they different?

Mathematics is all about constants
\( x = x+1 \) is false for all values of \( x \)
Values of “variables” never change

Prolog is All About

Given a goal, find out if it’s true or not.
Prolog uses backward chaining (goal driven search)
In Prolog, anything that can not be derived is false
This is known as the “closed world” assumption

An Example

Say I want to confirm/deny that “I am a descendant of Thomas Jefferson”.
He was born around 250 years ago and we assume 25 yr.
per generation. We also assume that people general have more children than parents (say an average of 3 children)
The required path back would be around 10. If we assume 2 parents for each person, then there are \( 2^{10} = 1024 \) possible states to search.
The required path forward would be around \( 3^{10} = 59049 \)

Which one?

Goal-driven search suggested if:
Goal-hypothesis is given in the problem and is easily formulated.
Example: a theorem prover
There are a large number of rules that match the facts of the problem and thus produce an increasing number of conclusions or goals.
Problem data are not given but must be acquired by the problem solver.
Example: a medical diagnosis system where diagnostic tests are ordered to confirm/deny a particular hypothesis

The other?

Data-driven search is suggested if:
All or most of the data are given in the initial problem statement.
Systems that analyze data fall into this category
There are a large number of possible goals, but only a few ways to use the facts.
Example: DENDRAL, an expert system that finds the molecular structure of organic compounds based on their formula, mass spectrographic data, and knowledge of chemistry
It's difficult to form a goal or hypothesis

Logic and Prolog

Lecture based off of material available from:
http://computing.unn.ac.uk/staff/cgpb4/prologbook/node1.html

How might Logic Systems Work?

Rules: Describe a single chuck of problem solving knowledge
Facts: A description of the current state of the work in a reasoning process.
Questions: Also called goals, they start a recognize-act cycle

The Goal

Logical languages:
Allow the creation of rules and facts
Allow goals or questions to be asked
Have language support for finding solutions to the goals
Allow you to insert facts into your database
You don’t have to write the code to go through all actions and definitions to figure out what action occurs

Declarative vs. Procedural Programming

Declarative:
The programmer must know the relationships between different entities

Procedural:
The programmer must tell the computer how to do something

Prolog

PROgramming in LOGic
It’s pretty synonymous with the term “logical language”, although there are other languages such as Goedel and LPL and the CLP(D) set of languages

Note of Caution
Prolog is difficult to master, because it doesn’t have the same structures as most other programming languages

A Review of Logic

Taken from: Russell & Norvig’s AI book

Language
What exists?
What states of knowledge?

Propositional logic

Facts
True/False/Unknown

First-order logic

Facts, objects, relations
True/False/Unknown

Temporal logic

Facts, objects, relations, times
True/False/Unknown

Probability theory

Facts
Degree of belief 0..1

Fuzzy logic

Degree of truth
Degree of belief 0..1

Propositional Logic Semantics

Each model specifies true/false for each proposition symbol

Rules for evaluation truth with respect to a model \( m \):
\(~S\) is true iff \( S\) is false
\( S_1 \land S_2\) is true iff \( S_1\) is true AND \( S_2\) is true
\( S_1 \lor S_2\) is true iff \( S_1\) is true OR \( S_2\) is true
\( S_1 \implies S_2\) is true iff \( S_1\) is false OR \( S_2\) is true
\( S_1 \iff S_2\) is true iff \( S_1\) is true AND \( S_2\) is false
\( S_1 \iff S_2\) is true iff \( S_1\) implies \( S_2\) AND \( S_2\) implies \( S_1\)

What We Would Like to Do

If \( p\) stands for “all functional languages are icky” and \( p\) is true then we would like to be able to prove that “eLisp is icky”.
This is where first order predicate logic (FOPL) comes in handy.
Predicate Logic Syntax

Constants: eLisp, 2, RIT
Predicates: Sister, >, Icky, ...
Functions: Sqrt, Eat, ...
Variables: x, y, a, b
Connectives: ∧ ∧ ∧ ∧ ∨ ∨ ∨ ∨ ¬ ¬ ¬ ¬
Equality: =
Quantifiers: ∀ ∀ ∀ ∀ ∃ ∃ ∃ ∃

Atomic Sentences
Atomic sentences:
– predicate(term 1 ,…,term n )
– term 1 = term 2

Term:
– function(term 1 ,…,term n )
– or constant
– or variable

Examples
Daughter(Lisa, Homer)

Representing in Prolog
Thinks(Justin, Icky(eLisp))
thinks(justin, icky(elisp)).
∀ ∀ ∀ ∀ x smelly(x)
smelly(X).

Complex Sentences
Complex sentences are made from atomic sentences using connectives
¬ S
S1∧S2
S1∨S2
S1⇒S2
S1⇔S2

Examples:
Sibling(Pico, HAL) ⇒ Sibling(HAL, Pico)
>(42,3) ∨ ≤≤≤≤ (42,3)
>(42,3) ∧ ¬ >(42,3)

Universal Quantification
∀ <variables> <sentence
“Everyone in Computer Science is smart”
∀x In(x,ComputerScience) ⇒ Smart(x)
∀x P is equivalent to the conjunction of instantiations of P
In(Matt,ComputerScience) ⇒ Smart(Matt)
∧ In(Dan,ComputerScience) ⇒ Smart(Dan)
∧ In(Tim,ComputerScience) ⇒ Smart(Tim)
∧ ...

Universal Quantification - Common Mistake
Typically, ⇒ is the main connective with ∀.
Common mistake: using ∧ as the main connective
∀x In(x,ComputerScience) ∧ Smart(x)
Means “Everyone is in Computer Science and everyone is smart”

Existential Quantification
∃ <variables> <sentence
“Somebody in Computer Science is smart”
∃x In(x,ComputerScience) ∧ Smart(x)
∃x P is equivalent to the disjunction of instantiations of P
In(Matt,ComputerScience) ∨ Smart(Matt)
∨ In(Dan,ComputerScience) ∨ Smart(Dan)
∨ In(Tim,ComputerScience) ∨ Smart(Tim)
∨ ...

Existential Quantification - Common Mistake
Typically, ∧ is the main connective with ∃.
Common mistake: using ⇒ as the main connective
∃x In(x,ComputerScience) ⇒ Smart(x)
Is true if there’s anyone who’s not in Computer Science!
Also true if anyone is Smart!

More about Quantifiers
∀x∀y is the same as ∀y∀x
∃x∃y is the same as ∃y∃x
∃x∀y is not the same as ∀y∃x

There is a person who loves everyone in the world.
∃x∀y Loves(x, y)

Everyone in the world is loved by at least one person
∀y∃x Loves(x, y)

Quantifier Duality
Each can be expressed using the other
∀x Eats(x, Mushrooms)
⇒ ∃x ¬Eats(x, Mushrooms)
or
∃x Eats(x, Mushrooms)
⇒ ∀x ¬Eats(x, Mushrooms)
A Couple of Prolog Basics

Starting Prolog: pl
You probably want to type your facts/rules in a file and then load the file:

```
[filename].
```

Note: filename is really filename.pl

Stopping the Prolog interpreter: halt.

Help on a topic: help(topic).

Edit a file test.pl: edit(test).

List child to screen: listing(child).

Trace descendant: trace(descendant).

Switch tracing off: trace(descendant, -all).

English into First Order Logic

Can you do these?

- Every dog hates cats.
- All purple mushrooms are tasty.
- You can fool some of the people all of the time.
- You can fool all of the people some of the time.

[answers discussed in class]

How Do We Display Them in Prolog?

Based on First order predicate logic

Uses a restricted version of clausal form called Horn clause form

```
q1 ∧ q2 ∧ ... ∧ qn ⇒ q0
```

where each qi and q0 is an atomic sentence and all variables are universally quantified.

Multiple Clauses

A clause is basically a prolog sentence (and ends with a period)

Example: eats(snoopy, birdFood).

How do we represent?:

Snoopy eats bird food and wood.

Answer

- FOPL: 
  Eats(Snoopy, BirdFood) ∧ Eats(Snoopy, Wood)
- Prolog: 
  eats(snoopy, birdFood), eats(snoopy, wood).

What about?

The square root of 25 is 5 or it is going to rain.

Perl, Java, and eLisp are all languages.

Rules

If a dog is wet and dirty, then he is smelly

```
Ax Wet(x) ∧ Dirty(x) ∧ Dog(x) ⇒ Smelly(x)
```

Prolog:

```
smelly(X) :- wet(X),dirty(X),dog(X)
```

Only one goal is allowed at the head of the rule (before the :-)

Goals and Subgoals

```
smelly(X) :- wet(X),dirty(X),dog(X)
```

In prolog smelly(X) is a goal and wet(X)/dirty(X)/dog(X) are subgoals

Why?

Represent These Statements

In predicate logic and Prolog

- All animals eat jelly beans.
- Everyone loves Frodo.
- Snoopy likes to eat Jessica’s furniture.

Translate

- Two people live in the same house if they have the same address.
- Two people are siblings if they have the same parents.
- Someone is happy if they’re healthy, wealthy, or wise.
- A dog is happy if he’s healthy, wealthy, or wise.

Note that predicates are called “functors”

Proof Methods

Model checking

- Truth table enumerating
- Heuristic search in model space

Application of inference rules

- Legitimate generation of new sentences from old
- Proof: a sequence of inference rule applications. We can use inference rules as operators in a standard search algorithm.

Some Basic Prolog

Facts

- likes(joe, eLisp).
- likes(john, eLisp).
- likes(joe, mary).
- likes(mary, books).
- likes(mary, frankenstein).
- likes(john, frankenstein).

Questions

```
?- likes(joe, eLisp).
```

Yes

```
?- likes(mary, joe).
```

No

```
?- likes(mary, frankenstein).
```

Yes

```
?- dislikes(mary, joe).
```

No

Multiple Matches

Facts

- likes(joe, eLisp).
- likes(john, eLisp).
- likes(joe, mary).
- likes(mary, books).
- likes(mary, frankenstein).
- likes(john, frankenstein).

Questions

```
?- likes(joe, X).
```

If you type “;” prolog will search for more matches.

Prolog searches the facts from top to bottom.

How Do We Ask?

Is there anything that John and Mary both like?

```
likes(john,X),likes(mary,X).
```

In this case, Prolog will backtrack to find the right answer.
Unification
Prolog uses unification to match terms
The unification of two terms proceeds by matching functions and arguments
   If anything fails to match the unification fails
   If a variable is matched to a term then a temporary binding of the variable is made
   If a variable is matched to a variable then they are temporarily set to be equal
   If unification is successful it returns all of the temporary variable bindings

For sound logic it is wrong to unify something with a container of the same thing
Unification of X and S(X) would lead to an effective infinite object
This is called the "occurs check" and is generally disabled in Prolog for speed

Prolog Execution
First a database of clauses is read in or generated somehow
Then queries are run against this database
A query is executed by matching all terms of the query against the database and if all terms match then the resulting variable bindings are returned
To match a term it is unified with the head of each clause in the database
   If unification fails the next clause in the database is considered
   If there are no more clauses then the match fails
   If the unification succeeds then the terms on the RHS of the clause are (recursively) matched against the database
      If all terms match then the resulting bindings are returned
      If any clause fails the bindings for the term are undone and the system backtracks and tries the next possibility

Rules
How do we write?
Jack likes anyone who likes books.
  likes(jack,X), likes(X,books).
  likes(jack,likes(X,books)).
  likes(jack, X) :- likes(X, books).
Jack likes anyone who likes books and fish.
Happy people are people who like themselves.
  happy(Person) :- likes(Person,Person).

Recursion
  descendant(X,Y) :- child(X,Y).
  descendant(X,Y) :- child(X,Z), descendant(Z,Y).

Avoid circular definitions:
  child(X,Y) :- parent(Y,X).
  parent(X,Y) :- child(Y,X).

Logically Correct, But...
  descendant(X,Y) :- child(X,Y).
  descendant(X,Y) :- descendant(Z,Y), child(X,Z).
The above statement is logically correct, but may cause Prolog to go into an infinite loop, because of Prolog's left-to-right, depth-first order of evaluation.

Prolog Variables
Variables only refer to the same entity if they're inside the same clause.

Note: logical variables are a bit different from other variables
    X=1; X=2; will result in 2 in Java
    X=1,X=2 won't work since the value X can only be one value

List Notation
[ ] is the empty list
[X] is the list containing X
[X|Y] is the list with X the head of the list and Y the rest of the list
[X,Y,Z] is a three element list
[X,Y,Z|W] is a list beginning with X, Y, and Z followed by the elements in the list W

Append in Prolog
Here are the rules for appending to a list
app([],Z,Z).
app([Item|X],Y,[Item|Z]):-app(X,Y,Z).

Here are some uses of append
swm-kayrun[154]: pl
Welcome to SWI-Prolog (Version 3.1.0)
Copyright (c) 1993-1998 University of Amsterdam.
All rights reserved.

For help, use ?- help(Topic). or ?- apropos(Word).
1 ?- [append].
append compiled, 0.00 sec, 1,140 bytes.

Yes
2 ?- app([1,2],[3,4],Z).
   Z = [1, 2, 3, 4] ;

No
3 ?- app(X,Y,[1,2,3]).
   X = []
   Y = [1, 2, 3] ;
   X = [1]
   Y = [2, 3] ;
   X = [1, 2]
   Y = [3] ;
   X = [1, 2, 3]
   Y = [] ;

No
4 ?-