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First-order Logic (FOL)

INTRODUCTION TO ARTIFICIAL INTELLIGENCE

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1 Self-assessment

Criteria	Completion
Working with Prolog tools	100%
Build a Knowledge Base with Prolog	100%
Implement logic deductive system in the programming language (Python)	100%

2 Working with the Prolog tool

2.1 Main features of Prolog language

Prolog (or PROgramming in LOGics) is a programming language that uses logic to express programs. Prolog is a declarative language, which means that a program consists of KBs on the facts and rules (Logical relationship) rather than computing how to find a solution. The program consists of facts and rules that define relations between entities. A computation is performed by asking a query about these relations.

Prolog has several distinctive features, such as its declarative meaning, its built-in mechanism for logical inference, and its natural handling of lists and recursion. It can also try different options (backtracking) until it finds the solution.

Examples:

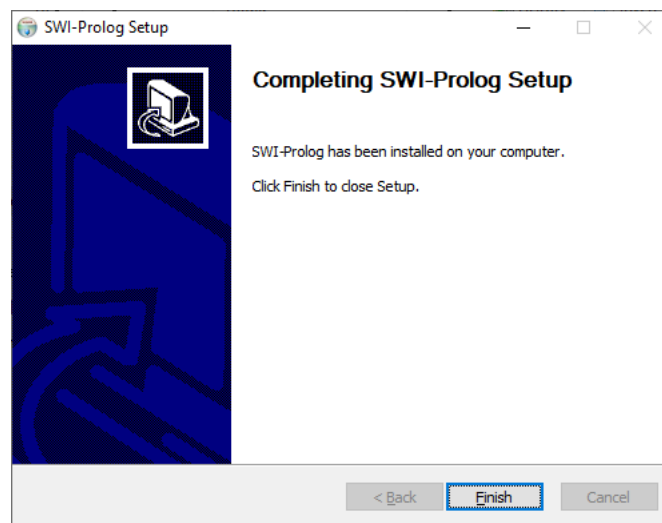
English sentence	FOL knowledge base	Prolog implementation
Everyone loves Santa.	$\forall x (\text{LOVE}(x, \text{Santa}))$	<code>love(X, "Santa").</code>
Rudolph is a reindeer and Rudolph has a red nose.	$\text{REINDEER}(\text{Rudolph}) \wedge \text{REDNOSE}(\text{Rudolph})$	<code>reindeer("Rudolph"), rednose("Rudolph").</code>
John owns a dog.	$\exists x (\text{DOG}(x) \wedge \text{OWN}(\text{John}, x))$	<code>dog(_), own("John", _).</code>
Anyone who does not play is not a football star.	$\forall x (\neg \text{PLAY}(x) \rightarrow \neg \text{STAR}(x))$	<code>not(star(X)) :- not(play(X)).</code>
Everyone who know Prolog or know Python is smart.	$\forall x (\text{KNOW}(x, \text{Prolog}) \vee \text{KNOW}(x, \text{Python}) \rightarrow \text{SMART}(x))$	<code>smart(X) :- (know(X, "Prolog") ; know(X, "Python")).</code>

where the given predicates are:

- $\text{LOVE}(x, y)$: x loves y.
- $\text{REINDEER}(x)$: x is a reindeer.
- $\text{REDNOSE}(x)$: x has a red nose.
- $\text{DOG}(x)$: x is a dog.
- $\text{OWNS}(x, y)$: x owns y.
- $\text{PLAY}(x)$: x plays.
- $\text{STAR}(x)$: x is a football star.
- $\text{KNOW}(x, y)$: x knows y.
- $\text{SMART}(x)$: x is smart.

2.2 How to implement Prolog language

- Our possible way to implement Prolog language on a programming environment is to use SWI-Prolog. To use SWI-Prolog, one needs to install it and then write Prolog programs using any text editors or IDEs. The programs can be compiled and executed (consulted) by using the swipl command or the graphical user interface (GUI) of SWI-Prolog.
- Steps to install SWI-Prolog (Windows):
 1. Go to SWI-Prolog download page and click **Stable release**.
 2. Choose the suitable version.
 3. Choose **I understand** and download the installation.
 4. Install until this popup appears on the screen, which means you installed successfully.



- Prolog syntax:

Operator	Prolog syntax
and	,
or	;
!=	\=
if	:-
not	not

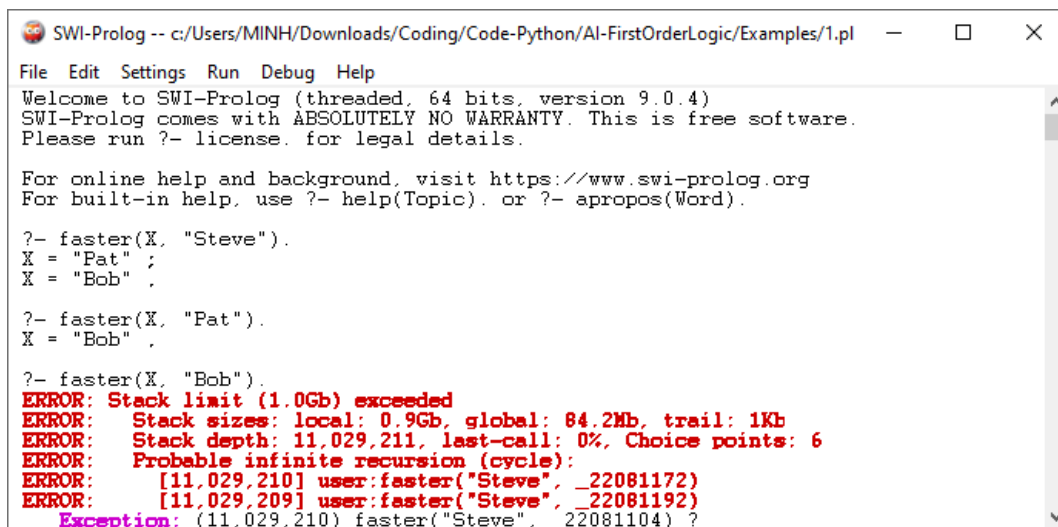
- Variable name starts with a capital letter. Predicate and function name starts with a letter.

- All sentences must end with a period (.).
- When defining a fact, if you do not declare a specific variable, by default, the program understands that variable has the value "for all".
For example: `loves(X, john).` Which means, everyone loves john.
- Syntax for Prolog rules: `left_side :- right_side. /* left_side ← right_side.*/.` Notice that `left_side` expression is required to contain only 1 positive literal.
- Syntax for Query: `?- query. .` If the program finds the answer to the query or proves the user's query is correct, SWI-Prolog will display **true** or the answers. Otherwise, SWI-Prolog returns **false**.

- Examples

The following examples below are located in `Examples/x.pl` where *x* is its order.

1. Given three animals: Buffalo (named Bob), pig (named Pat), and slug (named Steve), and a knowledge base: if A is faster than B (`faster(A, B)`) and B is faster than C (`faster(B, C)`) then A is faster than C (`faster(A, C)`). The fact is Bob is faster than Pat, Pat is faster than Steve. Find the animals that are faster than Steve, Pat, and Bob.



```

SWI-Prolog -- c:/Users/MINH/Downloads/Coding/Code-Python/AI-FirstOrderLogic/Examples/1.pl
File Edit Settings Run Debug Help
Welcome to SWI-Prolog (threaded, 64 bits, version 9.0.4)
SWI-Prolog comes with ABSOLUTELY NO WARRANTY. This is free software.
Please run ?- license. for legal details.

For online help and background, visit https://www.swi-prolog.org
For built-in help, use ?- help(Topic). or ?- apropos(Word).

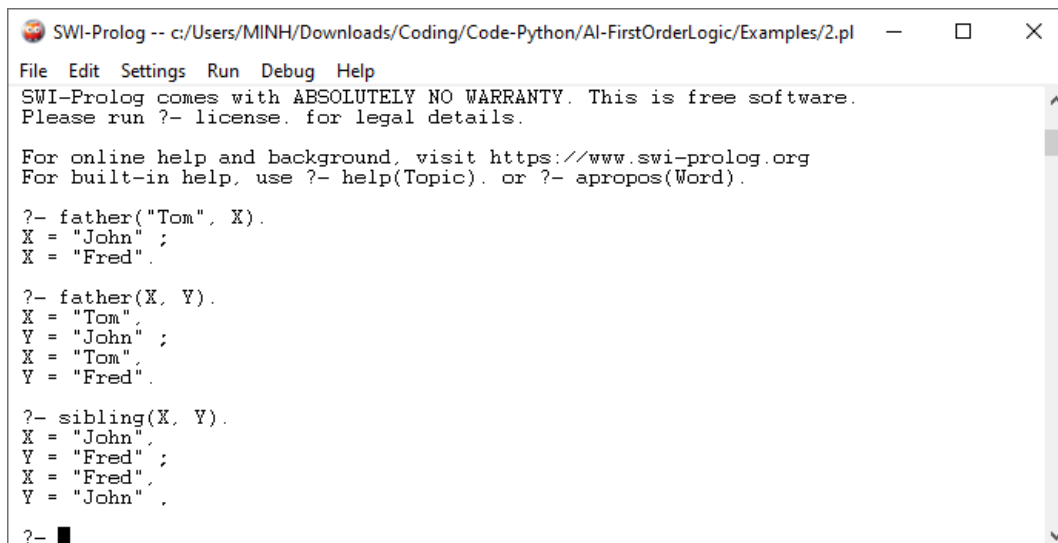
?- faster(X, "Steve").
X = "Pat" ;
X = "Bob" ;

?- faster(X, "Pat").
X = "Bob" ;

?- faster(X, "Bob").
ERROR: Stack limit (1.0Gb) exceeded
ERROR: Stack sizes: local: 0.9Gb, global: 84.2Mb, trail: 1Kb
ERROR: Stack depth: 11,029,211, last-call: 0%, Choice points: 6
ERROR: Probable infinite recursion (cycle):
ERROR: [11,029,210] user:faster("Steve", _22081172)
ERROR: [11,029,209] user:faster("Steve", _22081192)
Exception: (11,029,210) faster("Steve", _22081104) ?
  
```

The last query `faster(X, "Bob")` returns error message because Bob is the faster of the three, so there is no animal faster than Bob and the program reach the stack memory limitation.

2. Given the knowledge bases: P is father of C if P is parent of C and P is male. P1 and P2 are siblings if they have same parent. The program checks who is Tom's child, list paternities and the sibling relationships.



```

SWI-Prolog -- c:/Users/MINH/Downloads/Coding/Code-Python/AI-FirstOrderLogic/Examples/2.pl
File Edit Settings Run Debug Help
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Please run ?- license. for legal details.

For online help and background, visit https://www.swi-prolog.org
For built-in help, use ?- help(Topic). or ?- apropos(Word).

?- father("Tom", X).
X = "John" ;
X = "Fred" .

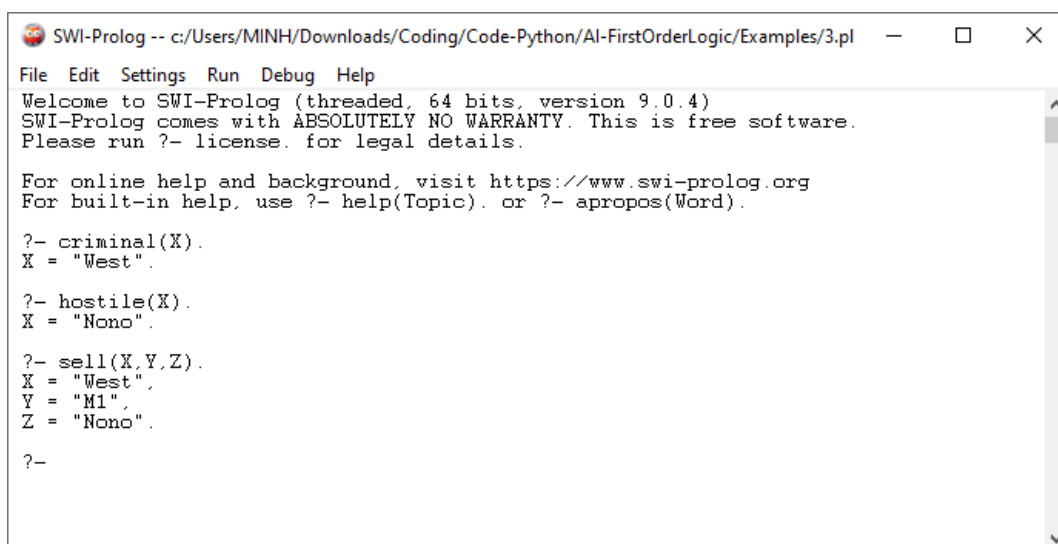
?- father(X, Y).
X = "Tom" ;
Y = "John" ;
X = "Tom" ;
Y = "Fred" .

?- sibling(X, Y).
X = "John" ;
Y = "Fred" ;
X = "Fred" ;
Y = "John" .

?-

```

3. The law says that it is a crime for an American to sell weapons to hostile nations. The country Nono, an enemy of America, has some missiles, and all of its missiles were sold to it by Colonel West. Who is the criminal.



```

SWI-Prolog -- c:/Users/MINH/Downloads/Coding/Code-Python/AI-FirstOrderLogic/Examples/3.pl
File Edit Settings Run Debug Help
Welcome to SWI-Prolog (threaded, 64 bits, version 9.0.4)
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Please run ?- license. for legal details.

For online help and background, visit https://www.swi-prolog.org
For built-in help, use ?- help(Topic). or ?- apropos(Word).

?- criminal(X).
X = "West" .

?- hostile(X).
X = "Nono" .

?- sell(X,Y,Z).
X = "West" ,
Y = "M1" ,
Z = "Nono" .

?-

```

4. Given four students, three teachers and three courses. Find the professor and the student of each course.



```

SWI-Prolog -- c:/Users/MINH/Downloads/Coding/Code-Python/AI-FirstOrderLogic/Examples/4.pl
File Edit Settings Run Debug Help
Welcome to SWI-Prolog (threaded, 64 bits, version 9.0.4)
SWI-Prolog comes with ABSOLUTELY NO WARRANTY. This is free software.
Please run ?- license. for legal details.

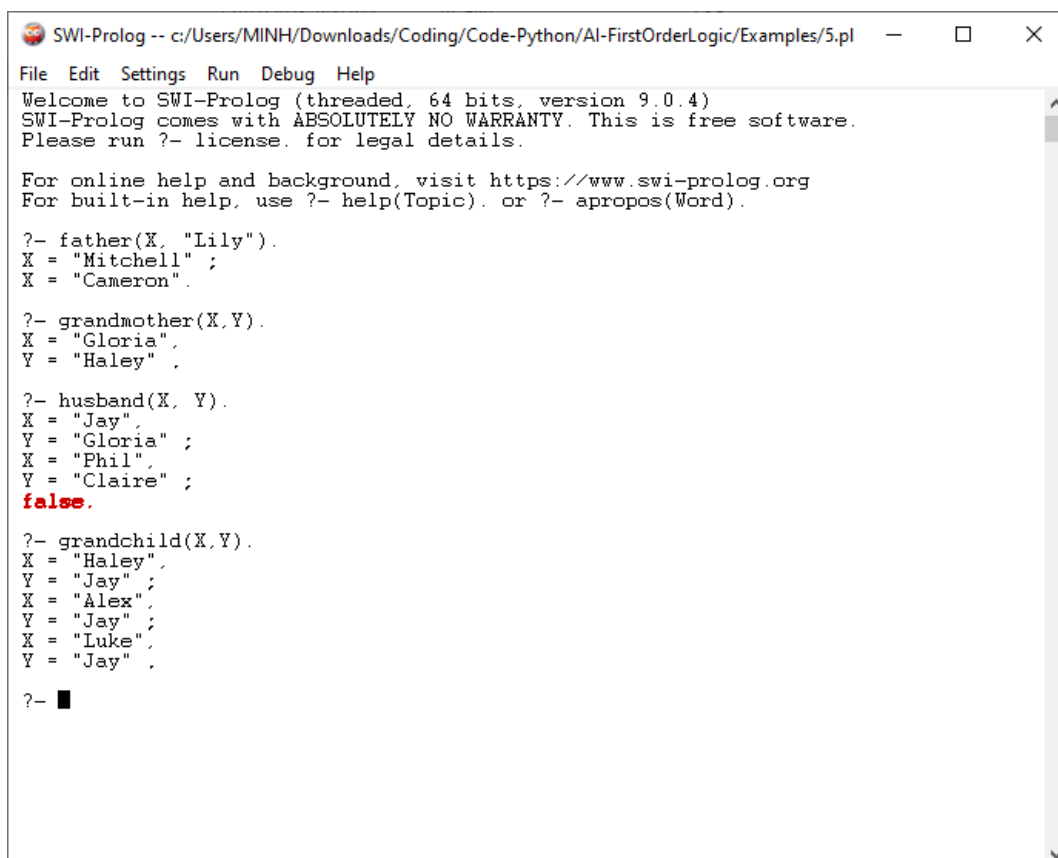
For online help and background, visit https://www.swi-prolog.org
For built-in help, use ?- help(Topic). or ?- apropos(Word).

?- professor(X, Y).
X = "Kirke",
Y = "Charlie" ;
X = "Kirke",
Y = "Olivia" ;
X = "Collins",
Y = "Jack" ;
X = "Jeniffer",
Y = "Arthur".

?-

```

5. Given a family, inspired by the "Modern Family" sitcom. Find out the relationship between some members.



```

SWI-Prolog -- c:/Users/MINH/Downloads/Coding/Code-Python/AI-FirstOrderLogic/Examples/5.pl
File Edit Settings Run Debug Help
Welcome to SWI-Prolog (threaded, 64 bits, version 9.0.4)
SWI-Prolog comes with ABSOLUTELY NO WARRANTY. This is free software.
Please run ?- license. for legal details.

For online help and background, visit https://www.swi-prolog.org
For built-in help, use ?- help(Topic). or ?- apropos(Word).

?- father(X, "Lily").
X = "Mitchell" ;
X = "Cameron".

?- grandmother(X, Y).
X = "Gloria",
Y = "Haley".

?- husband(X, Y).
X = "Jay",
Y = "Gloria" ;
X = "Phil",
Y = "Claire" ;
false.

?- grandchild(X, Y).
X = "Haley",
Y = "Jay" ;
X = "Alex",
Y = "Jay" ;
X = "Luke",
Y = "Jay".

?-

```

The *husband*(*X*, *Y*). query returns a false result because there are no more couples in the data but the user tries to explore more.

2.3 Build a Knowledge Base with Prolog

- **Set of 20 questions to ask the given family tree of the British Royal family:**

- | | |
|---|--|
| 1. Who is Prince Andrew's mother? | 11. Who is Prince Charles's sibling? |
| 2. Was Queen Elizabeth the wife of Mia Grace Tindall? | 12. Who is the uncle of Princess Beatrice? |
| 3. List all married couples. | 13. Who is son of Prince Phillip? |
| 4. List all divorced couples. | 14. Who is the nephew of Prince Andrew? |
| 5. List grandchildren of Prince Philip. | 15. Who is the niece of Princess Anne? |
| 6. Who is the grandparent of Princess Charlotte? | 16. Who is the wife of Prince Edward? |
| 7. Who is the sister of Prince Harry? | 17. Who is the grandson of Prince Phillip? |
| 8. Who is the sister of Princess Beatrice? | 18. Who is the child of Prince Phillip? |
| 9. Who is the brother of Princess Edward? | 19. Who is the daughter of Prince Phillip? |
| 10. Who is the uncle of Prince George? | 20. Who is the grandmother of grandmother Mia Grace Tindall? |

The questions and Prolog queries are written in *BritishRoyalFamily-Q.txt* file.

- **Set of 20 questions to ask the newly constructed knowledge system:**

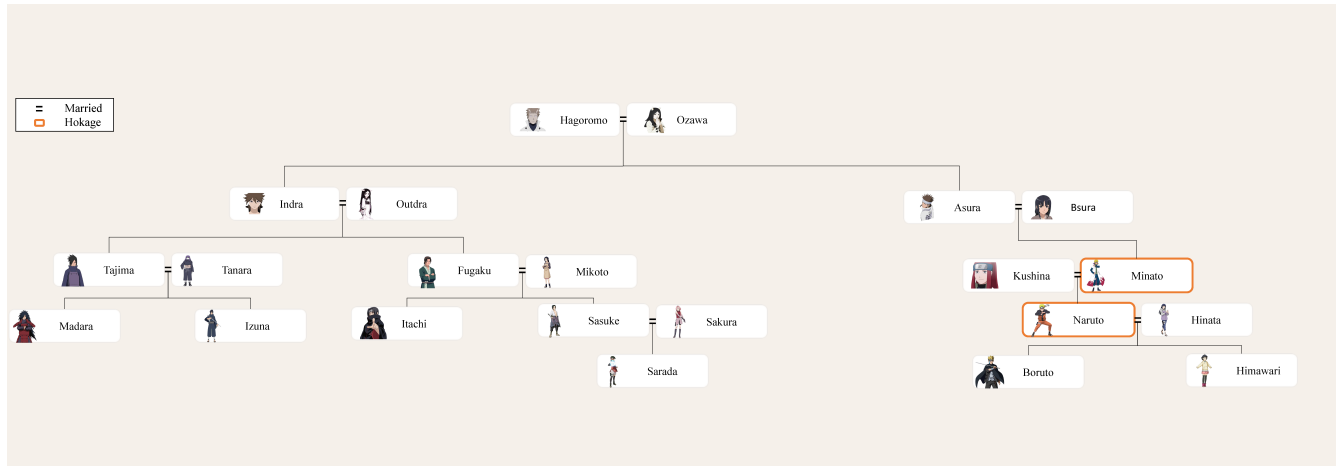
- | | |
|------------------------------------|--------------------------------------|
| 1. Who is parent of Boruto? | 10. Who is son of Naruto? |
| 2. Who is father of Sarada? | 11. Who is daughter of Sakura? |
| 3. Is Hinata male? | 12. Who is child of Tajima? |
| 4. Who is grandparent of Himawari? | 13. Is Sarada a daughter of Naruto? |
| 5. Who is grandchild of Indra? | 14. Who is nephew of Tajima? |
| 6. Who is sibling of Sasuke? | 15. Who is grandmother of Kushina? |
| 7. List all married couples. | 16. Who is granddaughter of Bsura? |
| 8. List all grandchild of Hagoromo | 17. Who is the grandchild of Outdra? |
| 9. Who is uncle of Sarada? | 18. Is Naruto sibling of Itachi? |

19. Who is the aunt of Mikoto?

20. List all hokage of Konoha.

The questions and Prolog queries are written in *MyBase-Q.txt* file.

The figure below shows the diagram of the relationship between the objects in the selected topic.



3 References

- Prolog main features
- Prolog fundamentals
- First-order logic examples
- First-order logic lecture slide