1. [Start of transcript. Skip to the end.](https://courses.edx.org/xblock/block-v1:ColumbiaX+CSMM.101x+3T2020+type@vertical+block@25a29b15927142e28ea7423b903c78fd?show_title=0&show_bookmark_button=0#transcript-end-9159e17488194d36a76e10f65b2d7cac)
2. So as an alternative to propositional logic,
3. we have first order logic, which is another kind of logic,
4. that's a more powerful language that develops information
5. about objects in a more compact way,
6. and also relationships between these objects.
7. So in this lecture I will just give you a flavor
8. of what this looks like.
9. If you want to dive into this topic more,
10. I invite you to check chapter eight and nine in the book.
11. So what is the syntax of first order logic?
12. So now we have terms that can be either constant symbols,
13. such as A, 10, or Columbia, variables that are x,y,x,
14. et cetera.
15. And also you could use functions,
16. in terms of for example square root of x, sum of one and two,
17. et cetera.
18. So we are going to make the language
19. richer with constants, with variables, and with functions.
20. So you could see already that instead
21. of saying square one is clean, you could just use a variable
22. to express any square.
23. We're going to talk about atomic formulas and our predicates
24. that apply to terms.
25. For example brother xy means that x is brother of y.
26. Or the element a is on both the element b.
27. We're going to keep the same connectives, the conjunction,
28. disjunction, implication double implication and negation.
29. We're going to be able to use equality,
30. especially that we did with functions as well.
31. We're going to use what we call quantifiers,
32. and these are very important to express information
33. about all the objects or some of the objects.
34. So the connectives, the equality, and the quantifiers
35. can be applied to atomic formulas
36. to create sentences in first order logic that you call FOL.
37. So for instance to express in first order logic
38. that all squares are clean, we can write for all x,
39. if square of x, then clean of x.
40. This means that whenever there is an x that's a square
41. it is clean.
42. To express the fact that there exists some dirty squares,
43. we're going to use the quantifier exists.
44. There exists x such as square of x and not clean
45. of x, which means that there exists some squares that
46. are not clean.
47. Question for you as a homework: Can we
48. now express that some squares have chairs on top?
49. So to give you a hint, we are going
50. to create two variables one for squares and one for chairs.
51. And you need to put in a relationship
52. these two elements squares and chairs.
53. Note here that for all x P of x is like writing P of A,
54. and P of B, and P of C, so it's like you
55. are enumerating all possible elements that can be x, right?
56. But we keep it general by for all x, P of x.
57. So this is a compact way of representing
58. this big conjunction elements.
59. Likewise, exist x, P of x is like writing P of A, or P of B,
60. or P of C, et cetera without writing extensively
61. of the elements.
62. When you see not for all x, P of x,
63. is like you are doing exists x not P of x.
64. So you're going to introduce inward this negation.
65. So you transform the for all into exists,
66. and you transform the P of x into a not P of x.
67. So when you say for all x there exists a y like xy, ,
68. so for all elements there exists a y, such as x likes y,
69. is not like you're writing there exists y for all x likes xy.
70. So be careful with the order of the quantifiers.
71. If they are different you can't really, simply swap them.
72. So here are a few examples using first order logic
73. to express that, for example, all birds fly, you
74. could write for all x bird of x, then fly of x.
75. To express that all birds fly, actually except penguins,
76. you could write for all x, bird of x, and not
77. penguin of x, then fly of x.
78. If you would expect that every kid likes candy,
79. we're going to write this for all x, kid of x, then
80. likes x candy.
81. So candy in this case is a constant
82. and we have the likes which is a pretty good with two arguments.
83. The first one is the person, or the kid,
84. and the second one is the element that is liked.
85. Some kids like candy, we have to write this as exists
86. x, kid of x, and likes x candy.
87. To express that bothers are siblings,
88. we write that for all x and y, brothers x and y
89. means, or implies, that siblings x and y.
90. So a more complicated one, one's mother is one's female parent.
91. For all xy, mother of xy is, if and only if,
92. female of x, and parent x and y.
93. With first order logic, we can also do inference.
94. While it is a little bit more complicated
95. than propositional logic, there are
96. procedures to do inference with a knowledge base of first order
97. logic formulas.
98. For further reading, I recommend the book,
99. chapter eight and nine, that describes very well first order
100. logic, and its inference using different techniques.
101. So the aim is to try to reach natural language.
102. So we have expressed different formulas
103. in terms of propositional logic or first order logic.
104. The expressiveness of first order logic
105. is powerful and suggests that it is
106. possible to automate the conversion
107. between natural language and logical expression.
108. This is very valuable for different applications
109. including personal assistants, question-answering systems,
110. and communicating with computers in general.
111. That will put actually logical agents
112. in the smart side of the intelligence
113. level in our original intelligence axis.
114. To summarize, logical agents apply
115. inference to a knowledge base to derive new information
116. and make decisions.
117. The basic concepts of logic include
118. syntax, formal structure of sentences,
119. semantics, the truth of the sentences,
120. entailment, the necessary truth of one sentence given
121. another one.
122. Inference is deriving sentences from other sentences.
123. Soundness is the derivations that
124. produce only entailed sentences, and completeness,
125. which derivations that can produce all entailed sentences.
126. The Wompus world, as we have seen,
127. requires the ability to represent
128. partial and negated information, reasoned by cases, et cetera.
129. Forward-backward chaining are linear in time,
130. complete for horn clauses.
131. Resolution is complete for propositional logic as well.
132. First order logic is a powerful way also
133. to represent information and has proven actually
134. to be sound and complete when we use the methods that were
135. derived for first order logic.
136. It is worth mentioning here that's building
137. logical agents was a main research area in AI
138. before the mid '90s.
139. Logic is used in AI to represent the world,
140. but also to reason about the world.
141. Logical agent has pros and cons.
142. They are still used in some applications today.
143. But the problem with logical agents
144. is that they don't handle uncertainty, hence
145. the use of probability more and more in AI.
146. It is completely rule based, which
147. means it doesn't use any kind of data to model the world,
148. while machine learning addresses this point
149. and uses data to make invention, or to make models.
150. It is also how to model every aspect of the world,
151. so it can become very quickly very overwhelming
152. and tedious to write everything you know about the world.
153. And there is no guarantee that you modeled everything.
154. However, logical agent has the big advantage
155. of being intelligible.
156. The models produced are intelligible
157. and it's possible to follow any proof using
158. inference to know what's going on,
159. how this inference was made by using these models that
160. are encoded explicitly.
161. So logical agents tend to disappear today machine
162. learning and probability-based methods being more used today.
163. However, I think that there is still beauty in them,
164. in terms of framework, the propositional logic,
165. and first order logic frameworks are beautiful.
166. And they actually have this intelligible feature
167. that can be combined with other black-box models that do not
168. provide explanations of the reason for prediction
169. or Inference.
170. Today's lecture is dedicated to John McCarthy, who
171. is. remember the researcher who coined the term Artificial
172. Intelligence in the '50s.
173. He also invented Lisp, which is the one of the main languages
174. that started AI.
175. He also invented timesharing in computer science.
176. John McCarthy won the ACM award, along with the Kyoto prize,
177. and also founded, literally, the logical intelligence system
178. field with declarative knowledge.
179. In his seminal paper, "Programs with Common Sense,"
180. published in 1959.
181. In fact, you will see his biography in this link.
182. I hope you enjoyed this lecture.
183. Thank you for your attention and see you next time.
184. [End of transcript. Skip to the start](https://courses.edx.org/xblock/block-v1:ColumbiaX+CSMM.101x+3T2020+type@vertical+block@25a29b15927142e28ea7423b903c78fd?show_title=0&show_bookmark_button=0#transcript-start-9159e17488194d36a76e10f65b2d7cac)