Universidad Rey Juan Carlos
Escuela Técnica Superior Ingeniería Informática

Teach the importance of logic (programming) in Computer Science and why it is important.

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Objetive

Support the importance of teaching logic (and logic programming) in computer science degrees:

- Logic allows us to model (almost) everything and to reason about it.
- Some historical milestones:

$0, 1, \ldots$ Human reasoning: 4th century BC, 13th and 17th century, etc.
[...]
n Quantum mechanics: 21st century.
$n+1$ (A lot of) other things.

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$\ldots, m, \ldots$ Mathematics: mainly from 1910 to 1930.
$m + h$ In 1920, Hilbert proposed to axiomatize mathematics...
$m + g$ ... but in 1931, Gödel shows that it is not possible.
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Second incompleteness Theorem (Gödel, 1931)

Particular case of the first Theorem: One of the undeciable statements of a theory is the one that affirms the consistency of the theory.

… and also the computation inherits these these limitations

Answer to *Entscheidungsproblem* (Church, 1936)

First-order logic does not have a decision procedure (algorithm) that allows us to prove that any formula is a theorem of this logic. This logic is therefore considered undecidable.

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Halting problem (Turing, 1936)

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- Logic and Computation are equivalent: Determining the halting problem is reduced to proving in FOL the formula that expresses the existence of an output from the application of a series of instructions. PLAY[1]

Ver "Las Matemáticas tienen una Terrible Falla" (https://bit.ly/3sFyaxq)

Who I am

Joaquín Arias
Professor at Universidad Rey Juan Carlos (URJC).

- 2020 - today: Researcher at Group of IA at CETINIA, URJC.
- 2013 - 2020: Researcher at IMDEA Sotware Institute.
- Academic background:
  - Ph.D. in Computer Science (2020).
  - M.Sc. in Software and Systems (2015).
  - B.Sc. in Mathematics and informatic (2014).
  - M.Arch. in Architecture (2002).
- PhD Thesis: "Advanced Evaluation Techniques for (Non)-Monotonic Reasoning using Rules with Constraints".

Motivation and some teaching experience at URJC

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  - ...and there are deficiencies writing technical reports (including analysis or synthesis) and in preparing and giving presentations.

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- Second year: Functional + Logic programming...
- Third and fourth year: The acquired knowledge of logic is not valued.
  - ...and there are deficiencies writing technical reports (including analysis or synthesis) and in preparing and giving presentations.
- Final Degree Project: Last opportunity to incorporate issues related to logic, so important in the professional development of an engineer:
  - Motivation of the importance of the problem to be solved,
  - Modeling of problems; definition of objectives; analysis of existing solutions, justification of the proposal; synthesis of the results; etc.

Motivation and some teaching experience at URJC (cont.)

- Linking Logic With Programming

Motivation and some teaching experience at URJC (cont.)

- Linking Logic With Programming
  - Natural Deduction + DeduccionNatural.pl
  - How teach development techniques used in the industry.

    E.g., in groups choose, study and present one of them in depth.
  - Present historical context of Logic and its limitations:

    E.g., there are activities that cannot be automated.

    ... computer scientists' work is one of these activities.
  - Actual objective of these activities:
    - Awake critical thinking.

      E.g., searching for information (also in research articles).

      ... writing a short report with writing standards (and LaTeX).

      ... and/or preparing and giving a presentation.

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    - Awake critical thinking **(and interest in research)**.

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One Example: Natural deduction + DeduccionNatural.pl

- Propositional logic is simple and its semantics is sound and complete.
- First order logic represents knowledge more clearly and concisely.
- We infer new knowledge from premises: [Aristotle IV BC]

  All men are mortal. Socrates is a man. Therefore Socrates is mortal.

First order logic:

$$\frac{\forall x\ (Man(x) \rightarrow Mortal(x)) \quad Man(socrates)}{Mortal(socrates)}$$

Horn clauses:

$Mortal(x) \vee \neg Man(x)$

$Man(socrates)$

$\neg Mortal(socrates)$

Prolog:

```
mortal(X) :- man(X).
man(socrates).

?- mortal(socrates).
```

- A subset of the first order logic is decidable [Horn 1951, Robinson 1965].

One Example: Natural deduction + DeduccionNatural.pl

Demonstrations in natural deduction as programs

- Using DeduccionNatural.pl [Arias et al. 2023].
  - Implemented using Prolog, a logic programming language.
  - Can be executed online.
- Based on the Natural Deduction method by Gentzen (see [Arias 2022; Gallinari 2009; Gentzen 1935] for details):
  - The inference rules are predefined functions.
  - The proofs are programs.
  - The derived rules are subroutines.
- The student can read DeduccionNatural.pl (and manipulate it).

Natural Deduction by Gentzen I

Introducción de $\wedge$ ($I_\wedge$)

$$\frac{A \quad B}{A \wedge B}$$

$T[p, q] \vdash p \wedge q$	
1. p	premisa
2. q	premisa
3. $p \wedge q$	**$I_\wedge$ (1,2)**

Eliminación de $\wedge$ ($E_\wedge$)

$$\frac{A \wedge B}{A} \qquad \frac{A \wedge B}{B}$$

$T[p \wedge q] \vdash p$	
1. $p \wedge q$	premisa
2. p	**$E_\wedge$ (1)**

$T[p \wedge q] \vdash q$	
1. $p \wedge q$	premisa
2. q	**$E_\wedge$ (1)**

Natural Deduction by Gentzen II

Eliminación de ∨ ($E_\vee$)

$$\frac{A \vee B \quad A \rightarrow C \quad B \rightarrow C}{C}$$

T[p ∨ q, p → ¬r, q → ¬r] ⊢ ¬r

1.	p ∨ q	premisa
2.	p → ¬r	premisa
3.	q → ¬r	premisa
4.	¬r	**$E_\vee$ (1,2,3)**

Introducción de ∨ ($I_\vee$)

$$\frac{A}{A \vee B} \qquad \frac{B}{A \vee B}$$

T[p] ⊢ p ∨ r

1.	p	premisa
2.	p ∨ r	**$I_\vee$ (1)**

T[p] ⊢ r ∨ p

1.	p	premisa
2.	r ∨ p	**$I_\vee$ (1)**

Natural Deduction: Implement a simple example

$$T[\ s \wedge (p \vee q),\ \ p \rightarrow \neg r,\ \ q \rightarrow \neg r\ ] \vdash\ \ s \wedge \neg r$$

Natural Deduction: Implement a simple example

$$T[\ s \wedge (p \vee q),\quad p \rightarrow \neg r,\quad q \rightarrow \neg r\ ] \vdash \quad s \wedge \neg r$$

1.	$s \wedge (p \vee q)$	*premisa*
2.	$p \vee q$	$E_{\wedge}(1)$
3.	$p \rightarrow \neg r$	*premisa*
4.	$q \rightarrow \neg r$	*premisa*
5.	$\neg r$	$E_{\vee}(2,3,4)$
6.	s	$E_{\wedge}(1)$
7.	$s \wedge \neg r$	$I_{\wedge}(5,6)$

Natural Deduction: Implement a simple example

$$T[\, s \wedge (p \vee q),\quad p \rightarrow \neg r,\quad q \rightarrow \neg r \,] \vdash \quad s \wedge \neg r$$

1.	$s \wedge (p \vee q)$	*premisa*
2.	$p \vee q$	$E_{\wedge}(1)$
3.	$p \rightarrow \neg r$	*premisa*
4.	$q \rightarrow \neg r$	*premisa*
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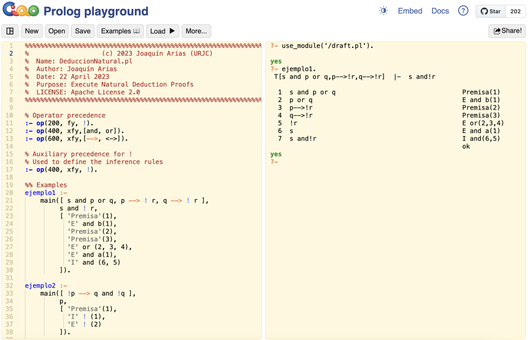

Demo

Natural Deduction by Gentzen III

Introducción ¬ ($I_\neg$)

$$\frac{A \rightarrow B \land \neg B}{\neg A}$$

Eliminación ¬ ($E_\neg$)

$$\frac{\neg\neg A}{A}$$

$T[\neg p \rightarrow q \land \neg q] \vdash p$	
1. $\neg p \rightarrow q \land \neg q$	premisa
2. $\neg\neg p$	$I_\neg$ (1)
3. p	$E_\neg$ (2)

Natural Deduction by Gentzen IV

Eliminación → ($E_{\rightarrow}$)

$$\frac{A \rightarrow B \quad A}{B}$$

$T[p \rightarrow \neg r, \neg r \rightarrow q, p] \vdash q$

1.	$p \rightarrow \neg r$	premisa
2.	p	premisa
3.	$\neg r$	**$E_{\rightarrow}$ (1,2)**
4.	$\neg r \rightarrow q$	premisa
5.	q	**$E_{\rightarrow}$ (3,4)**

Introducción → ($I_{\rightarrow}$)

$$\frac{A \text{ (supuesto)} \quad B}{A \rightarrow B}$$

$T[p \rightarrow q, q \rightarrow r] \vdash p \rightarrow r$

1.	$p \rightarrow q$	premisa
2.	$q \rightarrow r$	premisa
3.	p	supuesto
4.	q	$E_{\rightarrow}$ (1,3)
5.	r	$E_{\rightarrow}$ (2,4)
6.	$p \rightarrow r$	**$I_{\rightarrow}$ (3,5)**

Natural Deduction by Gentzen V

Introducción ↔ ($I_{\leftrightarrow}$)

$$\frac{A \rightarrow B \quad B \rightarrow A}{A \leftrightarrow B}$$

$T[p \rightarrow \neg r, \neg r \rightarrow p] \vdash p \leftrightarrow \neg r$	
1. $p \rightarrow \neg r$	premisa
2. $\neg r \rightarrow p$	premisa
3. $p \leftrightarrow \neg r$	**$I_{\leftrightarrow}$ (1,2)**

Eliminación ↔ ($E_{\leftrightarrow}$)

$$\frac{A \leftrightarrow B}{A \rightarrow B} \qquad \frac{A \leftrightarrow B}{B \rightarrow A}$$

$T[p \leftrightarrow q \wedge r, p] \vdash r$	
1. $p \leftrightarrow q \wedge r$	premisa
2. $p \rightarrow q \wedge r$	**$E_{\leftrightarrow}$ (1)**
3. p	premisa
4. $q \wedge r$	$E_{\rightarrow}$ (2,3)
5. r	$E_{\wedge}$ (4)

Natural Deduction: Implement derived rules

$$\frac{A \rightarrow B \qquad \neg B}{\neg A} \quad \textit{Modus Tollens (MT)}$$

Natural Deduction: Implement derived rules

$$\frac{\begin{array}{c} A \to B \\ \neg B \end{array}}{\neg A} \quad \textit{Modus Tollens (MT)}$$

- Implementation:

```
rule('MT',                      % Name
      [ FA --> FB,              % Hypotheses
        !FB ],
      !FA,                      % Deduction
      [ 'Premisa'(1),           % Proof
        'Premisa'(2),
        'Supuesto'(FA),
        'E' --> (1,3),
        'I' and (4,2),
        'I' --> (3,5),
        'I' ! (6) ]).
```

Natural Deduction: Implement derived rules

$$\frac{A \rightarrow B \qquad \neg B}{\neg A} \quad \textit{Modus Tollens (MT)}$$

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- Generated proof:

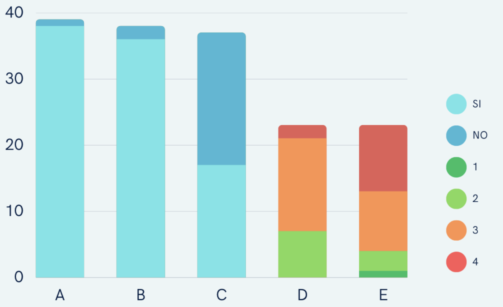
```
MT: T[A --> B, !B]  |-  !A

1  A --> B            Premisa(1)
2  !B                 Premisa(2)
3       A             Supuesto(A)
4       B             E-->(1,3)
5       B and!B       I and(4,2)
6  A --> B and!B      I-->(3,5)
7  !A                 I!6
                      ok
```

Natural Deduction: Home work (solve with/without derived rules)

$$T[\ r \rightarrow q \wedge s, \quad \neg(q \wedge s)\ ] \vdash \quad \neg r$$

Natural Deduction: Pilot experience during the 22/23 academic year.

- Small sample population but promising results.



Please answer Yes or No:
A: Have you used the program?
B: Have you used the program to check manifestations?
C: Have you used the program as a study tool?

Rate from 1 (bad) to 4 (very good):
D: Ease of use.
E: Usefulness for learning Natural Deduction.

Figure: Results of the DeduccionNatural.pl satisfaction survey on the Artificial Intelligence degree.

Conclusions

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    http://platon.etsii.urjc.es/~jarias/mmm/MDS/
  - Final Degree Projects:
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[2] Arias, Joaquín, Ramírez, Iván, and Gallinari, Alessandra (2023). **DeduccionNatural.pl: herramienta escrita en Prolog para el aprendizaje de la asignatura de Lógica**. In: *JENUI 2023*, pp. 129–136.

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