50 Years of Prolog and Beyond

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The Prolog Year
Prolog Day Symposium, November 10, 2022

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*Part of the contents of this talk appear in the recent TPLP paper "**50 years of Prolog and Beyond**," by Philipp Körner, Michael Leuschel, João Barbosa, Vítor Santos Costa, Verónica Dahl, Manuel V. Hermenegildo, Jose F. Morales, Jan Wielemaker, Daniel Diaz, Salvador Abreu, and Giovanni Ciatto written for Prolog's 50th anniversary and TPLP's 20th anniversary.*

Also big thanks to Bob Kowalski for historical input, feedback, and permanent inspiration.

Prolog is 50

- So, then, Prolog is 50!
  - What, 50 years?!? Half a century?!?!
  - Is Prolog therefore now 'old'?
- Actually... continued interest:
  - Many *active implementations*, and *more appearing* continuously.
  - TIOBE index of programming languages shows Prolog:
    - In upper 10% of all languages tracked (270).
    - Stable, even somewhat upward trend since 2012.
    - One of only 13 languages that are tracked 'long term'.

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What is Prolog? Why is it important?

Prolog is an acronym of two words:

Programming
and
Logic

- What is the best way to **program** computers?
  I.e., how do we get them to solve problems and/or do what we need?
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A New View of Computing

- If we have an *effective mechanical proof method*.

⇝ *a new view of problem solving and computing is possible*:

  - First: program once and for all this *deduction procedure* in the computer,
  - Then, for each problem we want to solve:
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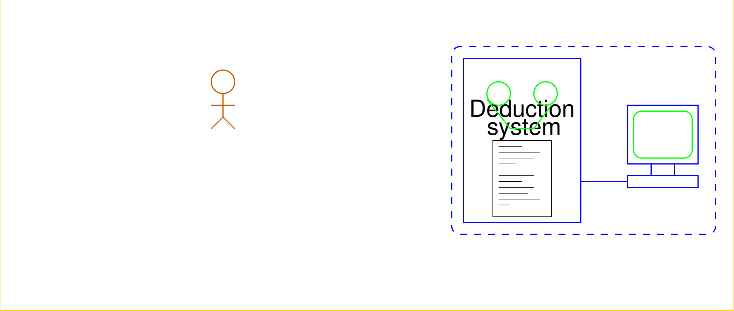

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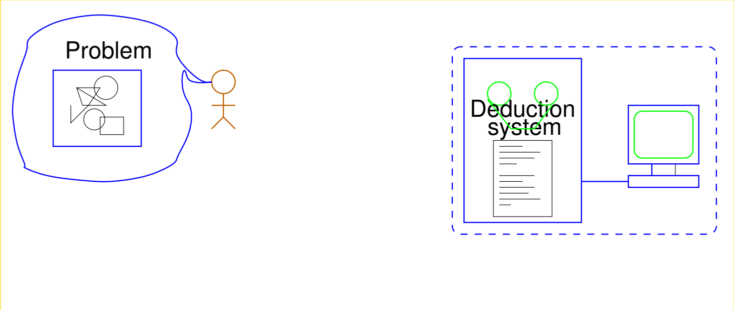

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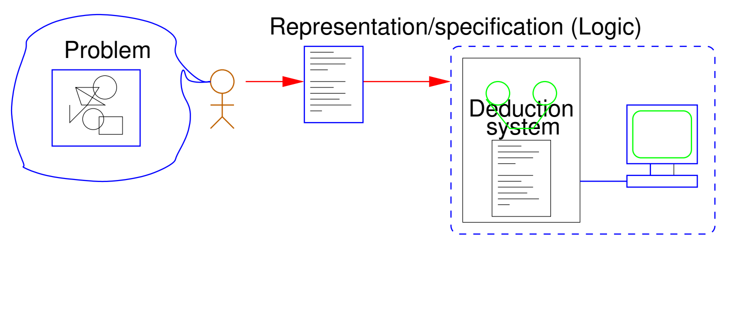

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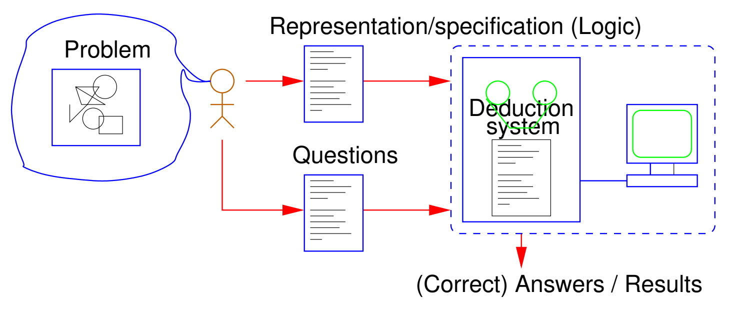

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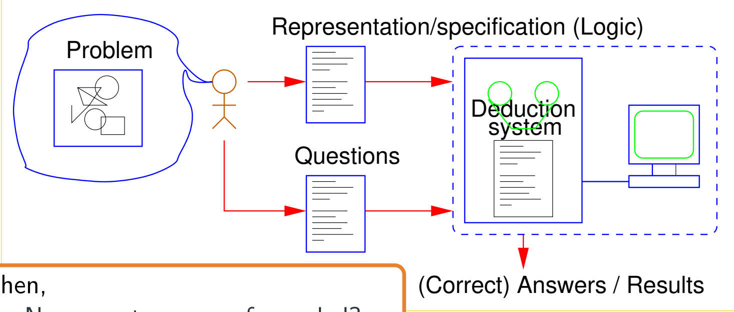

But then,

- No correctness proofs needed?
- Even no programming needed?
- Is this possible?

Prolog is the Materialization of this Dream!

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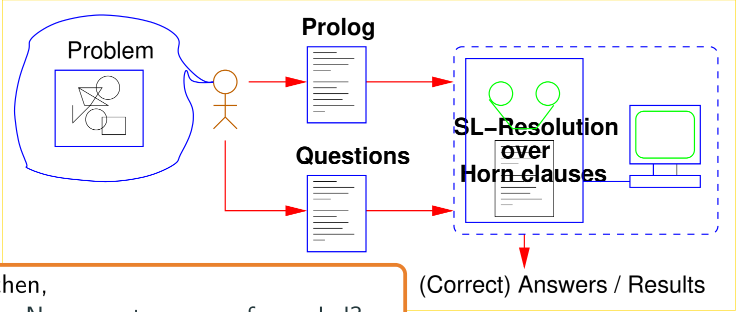

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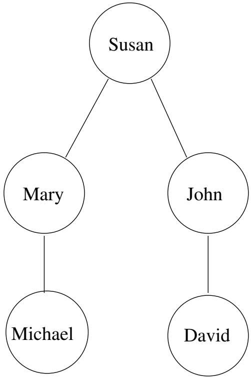
Family relations

Susan is the mother of Mary.
Susan is the mother of John.
Mary is the mother of Michael.



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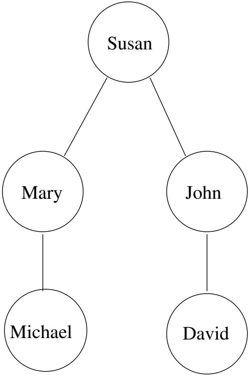

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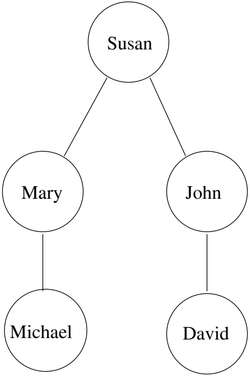

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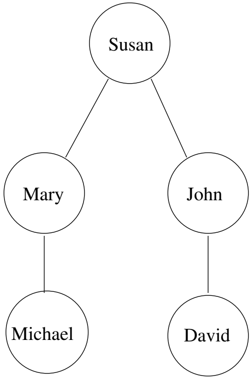

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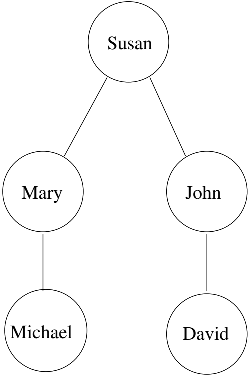
One is the grandmother of someone else if one is the mother of the mother (or father) of that other person.



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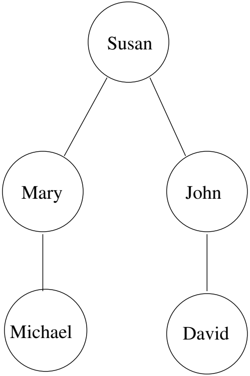

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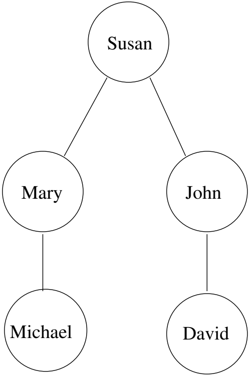

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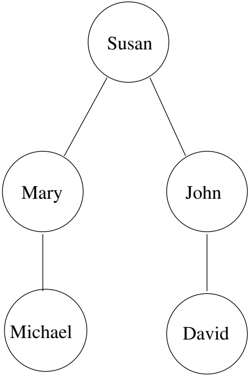

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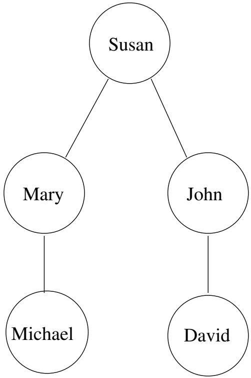

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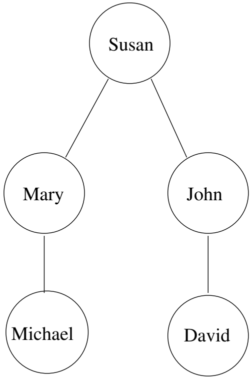

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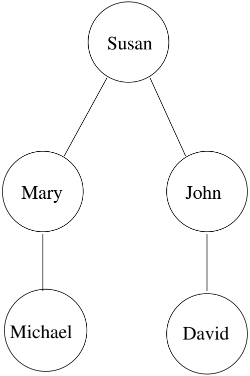

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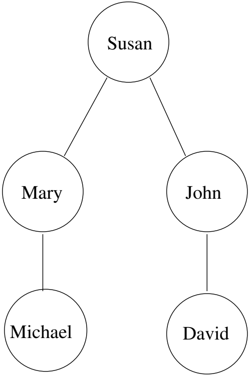

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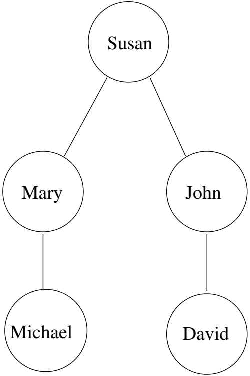

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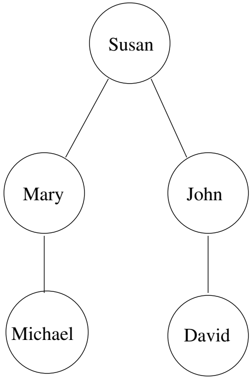

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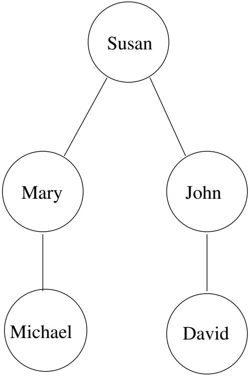
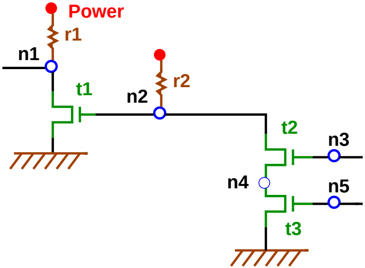


Circuit topology

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transistor(n2,ground,n1).
transistor(n3,n4,n2).
transistor(n5,ground,n4).
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inverter(Input,Output) :-
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nand_gate(Input1,Input2,Output) :-
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and_gate(Input1,Input2,Output) :-
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`?- and_gate(In1,In2,Out)` ⇝ `In1=n3, In2=n5, Out=n1`

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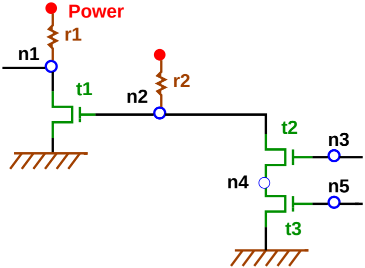


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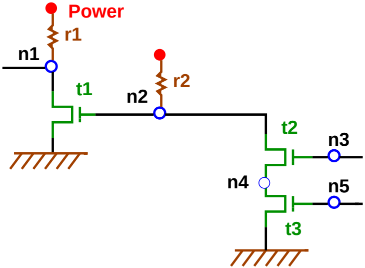


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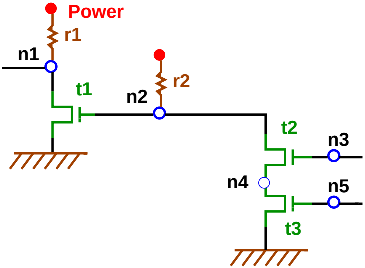


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From specifications to efficient programs

"Max is the maximum element of a set if there is no element in the set that is larger than it."

$$max(L, Max) \leftarrow Max \in L \ \wedge \ \nexists E \mid E \in L \ \wedge \ E > Max$$

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```
max2([H|T],Max) :-
    max_(T,H,Max).

max_([],Max,Max).
max_([H|T],TMax,Max) :-
        H > TMax,
        max_(T,H,Max).
max_([H|T],TMax,Max) :-
        H =< TMax,
        max_(T,TMax,Max).
```

```
?- max2([3,5,2,8,1],Max).
Max = 8
```

So, what is Prolog?

Procedure	=	Horn clause	+	Top-down reasoning (SL-resolution)
(Algorithm	=	Logic	+	Control)

So:

- Computational procedures can be given a logical form.
- Horn clause reasoning can be performed as efficiently as computation.

The birth of Prolog (Sources: Colmerauer, Kowalski)

Colmerauer
et al 1972.
Prolog!

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Robinson, 1965
The resolution principle

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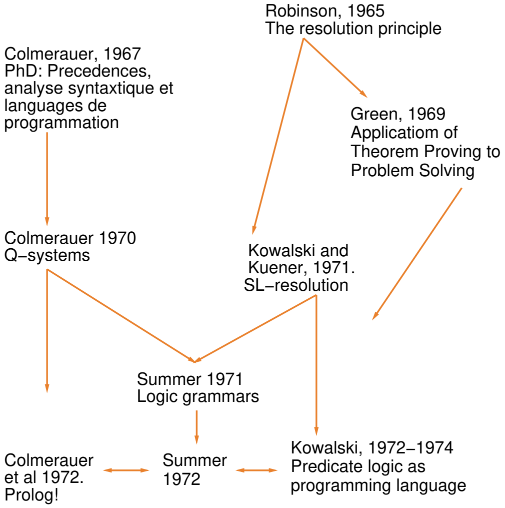

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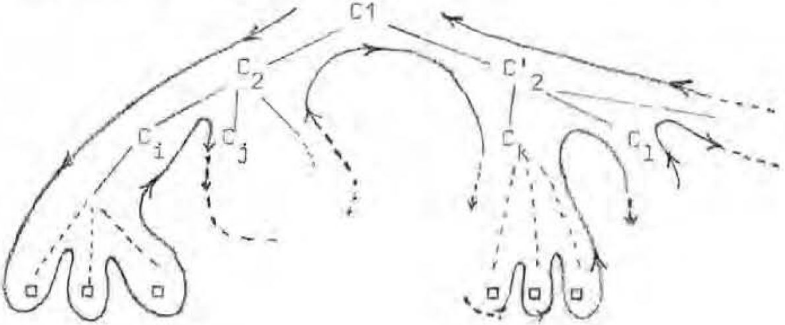
Warren et al 1975
DEC10 Prolog

The original Prolog

```
+Frere(*y,*z)-Pere(*x,*y)-Pere(*x,*z).

+Pere(Paul,Pierre)

+Mere(Marie,Jacques)

+Mari(Paul,Marie)

+Pere(*x* y)-Mari(*x,*z)-Mere(*z,*y)


** CONCATENATION DE LISTES ..

+CONC(*X.NIL,*X) ..
+CONC((*X.*Y).*Z,*X.*U) -CONC(*Y.*Z,*U) ..
+CONC(NIL.*X,*U) -CONC(*X,*U) ..
```

The original Prolog

On peut représenter les descendants d'une clause C_1 de <données> sous forme d'un arbre:



Some milestones (≈ up to ISO)

- First *Prolog*(s): all fundamental characteristics of the language already there!

Some milestones (≈ up to ISO)

- Dec-10 Prolog: *compilation* (+ improved syntax, etc.)

⇝ performance (≈ lisp),

⇝ much more widespread use –but portability an issue.

Some milestones (≈ up to ISO)

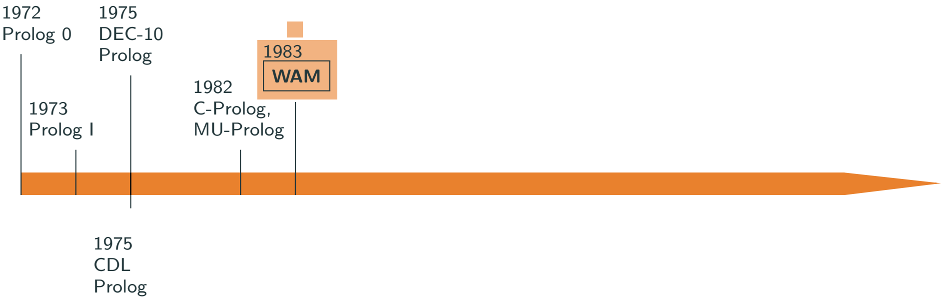
- In parallel, many further advances in the theoretical underpinnings:
  - Kowalski (1974): linear resolution for Horn clauses, no factoring rule.
  - Kowalski and vanEmden (1976): minimal model and fixed-point semantics.
  - Clark (1978): correctness of NaF w.r.t. program completion.
  - Reiter (1978): formalization of "closed world assumption."

  Others: Minker, Gallaire, Cohen, Lassez/Jaffar/Maher, DHD Warren, Sato/Tamaki, DS Warren, ...

Some milestones (≈ up to ISO)

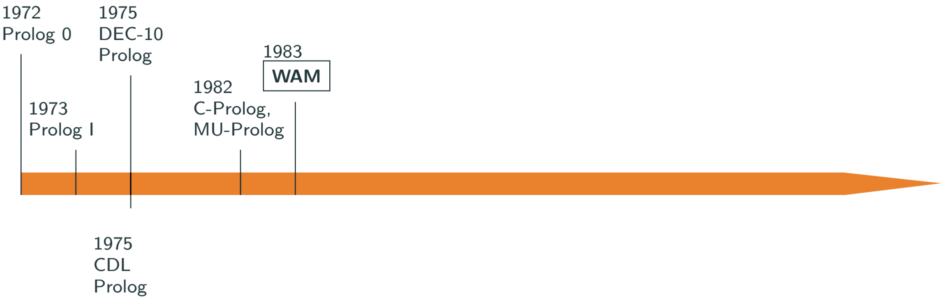
- CDL-Prolog, MU-Prolog, ...,
- C-Prolog: portability (but interpreter).

Some milestones (≈ up to ISO)



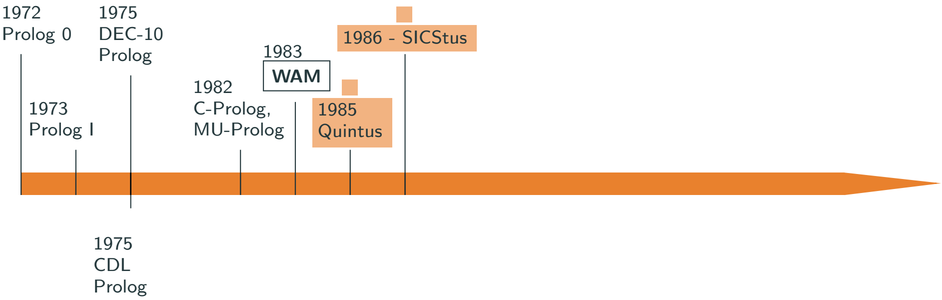
- The *WAM:* portability + speed... and implementation beauty.

Some milestones (≈ up to ISO)



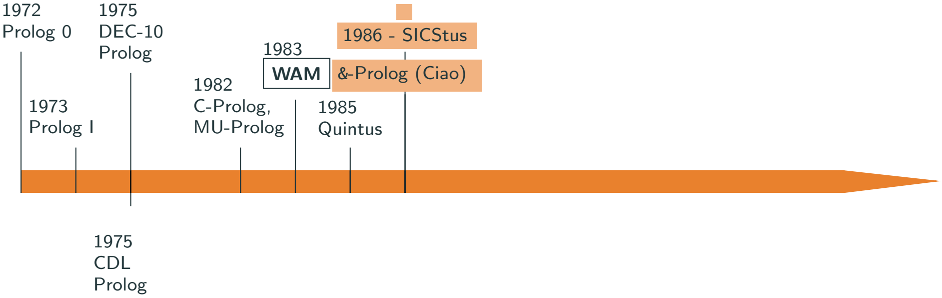
- FGCS ⇝ MCC ⇝ ECRC ⇝ ESPRIT ⇝ EU research programs, and others.

Some milestones (≈ up to ISO)



- First WAM-based systems: Quintus, SICStus, BIM, ...
  - Both commercial and public domain ⇝ more dissemination.
  - Many optimizations, GC, ... ⇝ more performance.

Some milestones (≈ up to ISO)



- Or- and and-parallelism: Aurora, &-Prolog/Ciao, MUSE, DASWAM, IDIOM, Andorra, EAM, ...

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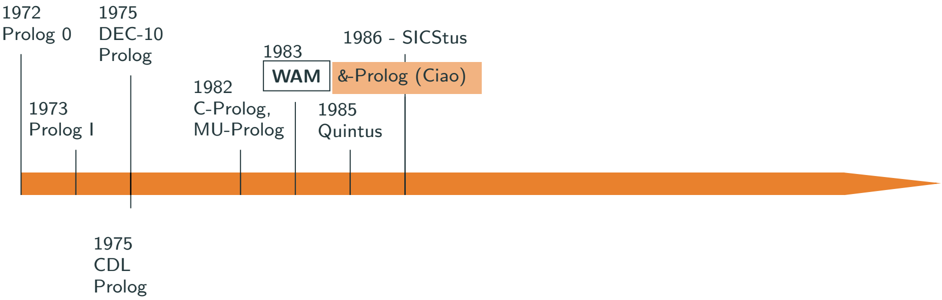

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- *Global analysis* (abstract interpretation): Aquarius, &-Prolog/Ciao.
  (Independence,modes, types, determinacy, non-failure, cost, ...)
  First practical compiler(s) using abstract interpretation?

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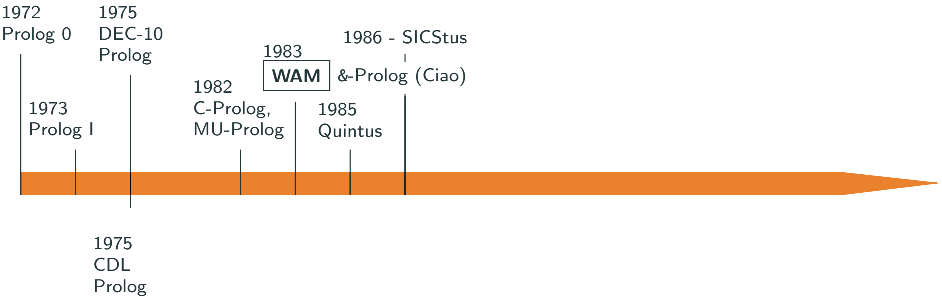

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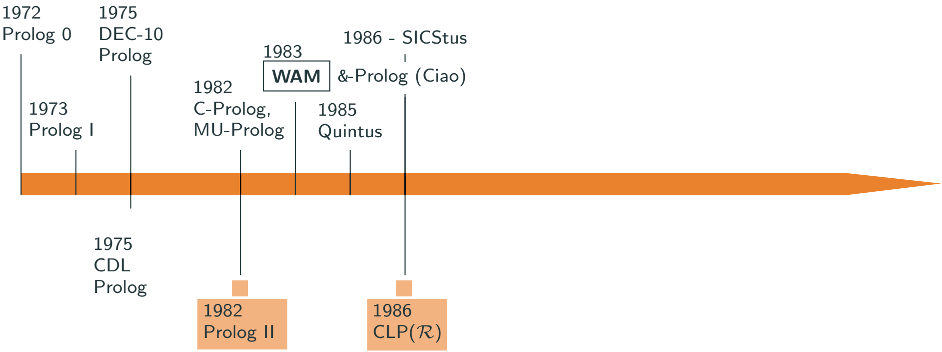
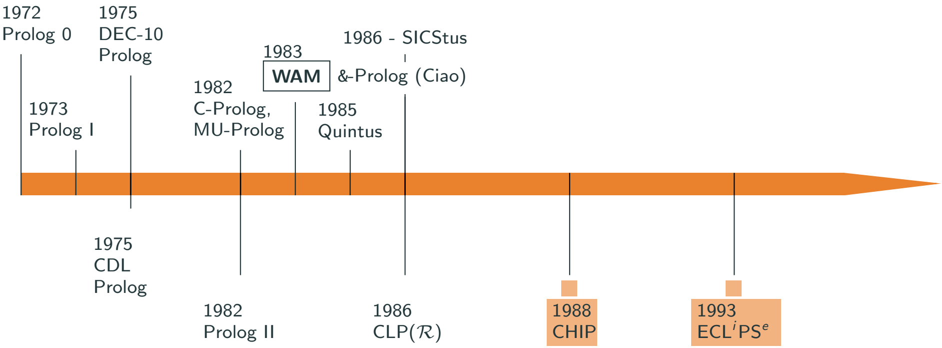
⇝ Performance (≈ imperative), auto-parallelization - real parallel speedups.

Some milestones (≈ up to ISO)



- *Constraints* (Prolog II; CLP scheme and CLP($\mathcal{R}$))
  - Allow many extensions to unification ("domains"), e.g., infinite terms.
  - Recover declarativity for Prolog arithmetic (now also reversible!).

Some milestones (≈ up to ISO)



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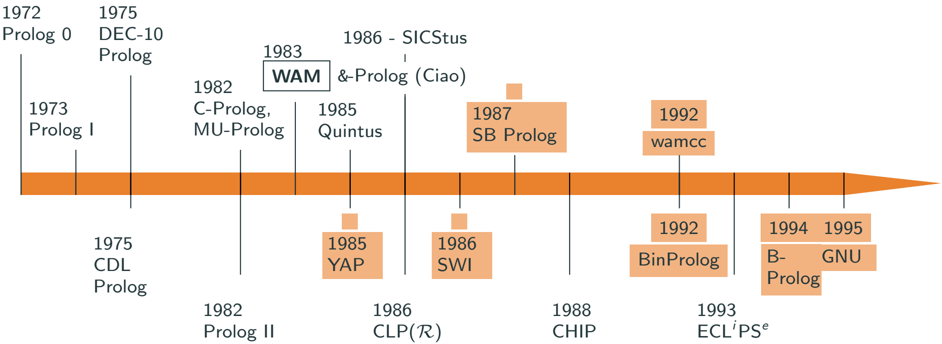

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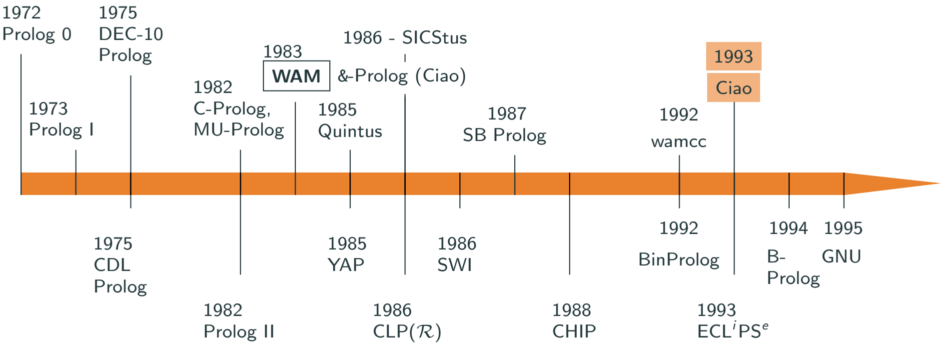
  - Allow many extensions to unification ("domains"), e.g., infinite terms.
  - Recover declarativity for Prolog arithmetic (now also reversible!).
  - Finite domains.
- A good number of other WAM and non-WAM-based Prologs (see later).
- Constraints in standard Prologs: "Opening the box" (attvars,CHR).

Some milestones (≈ up to ISO)



- A different form of building the language:
  - Pure kernel, all built-ins are in libraries.
  - ⇝ pure subsets of Prolog supported.
  - ⇝ Many extensions: e.g., full higher-order and functional syntax support.

(also λ-Prolog, HiLog, Hiord, ...).

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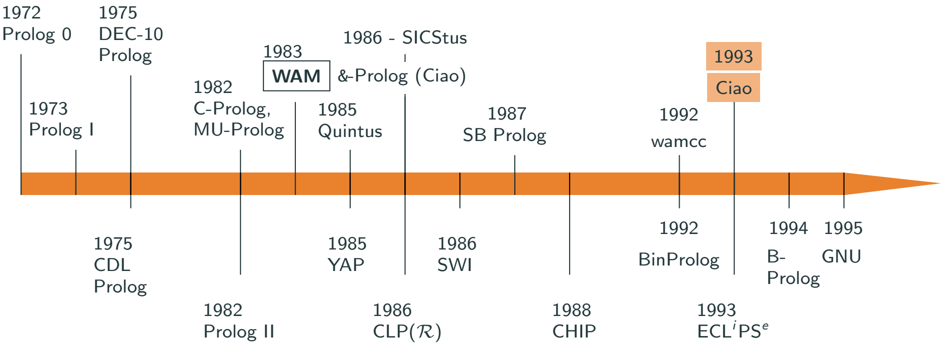

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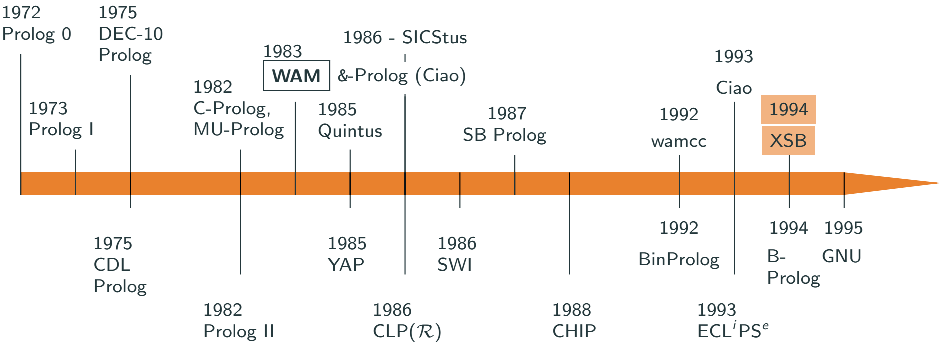
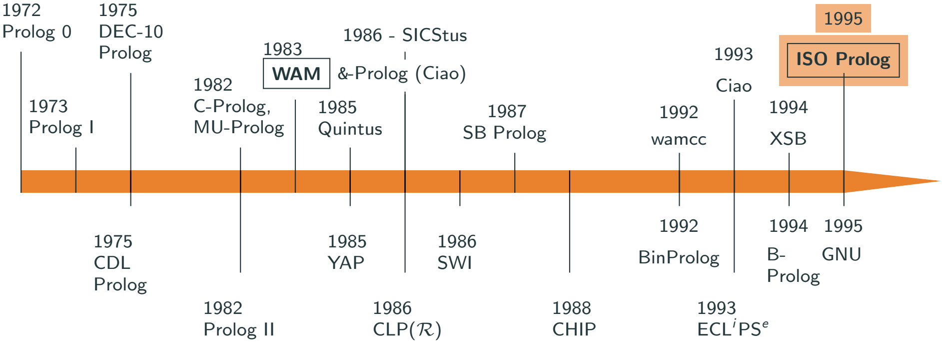
  (also λ-Prolog, HiLog, Hiord, ...).
- Assertions: Types/modes, det, cost ⇝ verification, automatic. testing.

Some milestones (≈ up to ISO)



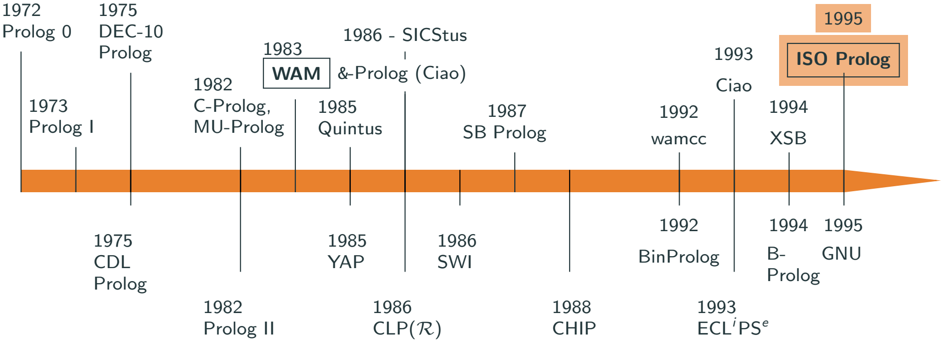
- Tabling (Early deduction, SLG-resolution, ...):
  - Much improved termination (bounded term size).
  - Some nice complexity guarantees.
  - Support for negation with well-founded semantics.

Some milestones (≈ up to ISO)



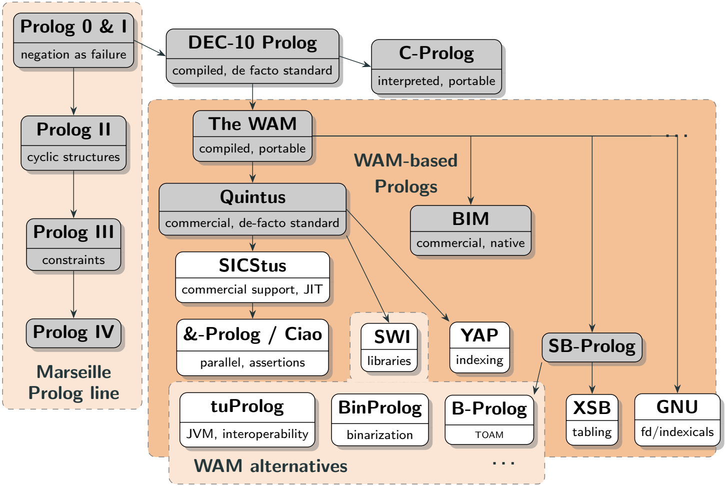
- The ISO standard brought much needed standardization; most systems followed (mostly).

Fast forward...



⇝ Let's jump forward and take a look at the current state of things!

Prolog system heritage



White background: currently active/supported systems.
Lower legends: just some highlight(s) (see later).
Arrows: influences and inspiration.

Again, more missing!: microProlog, LPA, ECL^iPS^e, IBM, LIFE, Andorra-I, Scryer, Tau, ...

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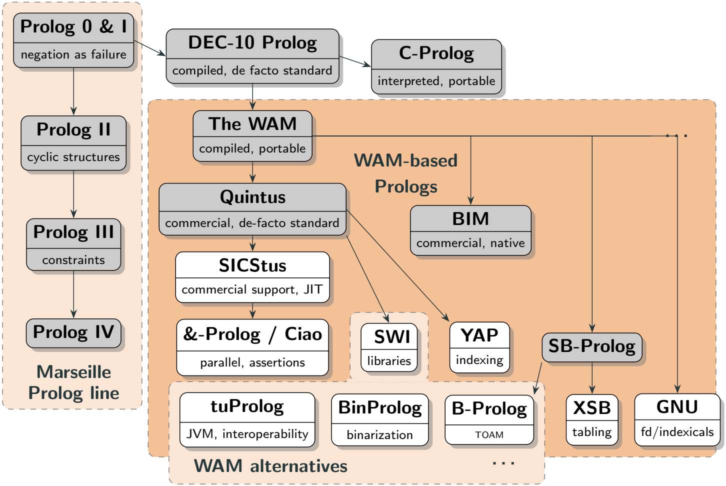

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Some features of current systems - I

System	Open Src.	Modules	Non-Std. Data Types	Foreign Language Interfaces
B-Prolog			arrays, sets, hashtables	C, Java
Ciao	✓	✓		C, Java, Python, JScrpt
ECLiPSe	✓	✓	arrays, strings	C, Java, Python, PHP
GNU Prolog	✓		arrays	C, Java, PHP
JIProlog	✓	✓		Java
SICStus		✓		C, Java, .NET, Tcl/Tk
SWI	✓	✓	dicts, strings	C, C++, Java
τProlog	✓	✓		JavaScript
tuProlog	✓		arrays	Java, .NET, Android, iOS
XSB	✓	✓		C, Java, PERL, Python
YAP	✓	✓		C, Python, R

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Some features of current systems - II

System	CLP	CHR	Tabling	Parallelism	Indexing	Coroutines
B-Prolog	$\mathcal{FD}$, $\mathcal{B}$, *Set*	✓	✓		N-FA	✓
Ciao	$\mathcal{FD}$, $\mathcal{Q}$, $\mathcal{R}$	✓	✓	✓	FA, MA	✓
ECLiPSe	$\mathcal{FD}$, $\mathcal{Q}$, $\mathcal{R}$, *Set*	✓		✓	most suitable	✓
GNU Prolog	$\mathcal{FD}$, $\mathcal{B}$				FA	
JIProlog					undocumented	
SICStus	$\mathcal{FD}$, $\mathcal{B}$, $\mathcal{Q}$, $\mathcal{R}$	✓			FA	✓
SWI	$\mathcal{FD}$, $\mathcal{B}$, $\mathcal{Q}$, $\mathcal{R}$	✓	✓	✓	MA, deep, JIT	✓
τProlog					undocumented	
tuProlog				✓	FA	
XSB	$\mathcal{R}$	✓	✓	✓	all, trie	✓
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Some features of current systems - III

System	Debugger	Global Vars.	Mutables	Testing	Types/Modes	s(CASP)
B-Prolog	trace	✓				
Ciao	trace / source	✓	✓	✓	✓	✓
ECLiPSe	trace	✓		✓		
GNU Prolog	trace	✓	✓			
JIProlog	trace					
SICStus	trace / source		✓	✓		
SWI	trace / graphical	✓	✓	✓		✓
τProlog						
tuProlog	spy					
XSB	trace		✓			
YAP	trace	✓				

Some features of current systems - III

System	Debugger	Global Vars.	Mutables	Testing	Types/Modes	s(CASP)
B-Prolog	trace	✓				
Ciao	trace / source	✓	✓	✓	✓	✓
ECLiPSe	trace	✓		✓		
GNU Prolog	trace	✓	✓			
JIProlog	trace					
SICStus	trace / source		✓	✓		
SWI	trace / graphical	✓	✓	✓		✓
τProlog						
tuProlog	spy					
XSB	trace		✓			
YAP	trace	✓				

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  - Applications of Prolog technology to other languages (analyzers, provers, ...).

Summary of current state

- Prolog systems have come a very long way!
  - As seen, a good number of features available on several systems:
    - Indexing, constraints/CHR, multi-threading, tabling, foreign interfaces, coroutining, global vars, mutables, testing, ...
- An issue is portability:
  - ISO standard generally supported (with only minor differences).
  - *Basic* module system pretty compatible.

  However,
  - Interfaces and details of extensions often differ.
    Can mostly be bridged (c.f., Paolo Moura's work), but a real nuisance.
  - Some useful features still present in only a few systems:
    e.g., types/modes/verification, functional syntax, s(CASP), ...

→ Work needed to improve portability.

- Also, better community infrastructure would be useful (see at the end).

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Prolog influences

- In other languages within LP and its extensions:
  - Goedel, Mercury, Turbo-Prolog (static typing)
  - λ-Prolog, Curry, Babel, HiLog (FP/HO)
  - CP, GHC, Parlog, Erlang (committed choice)
  - Datalog, ASP – Co-inductive LP, s(ASP) and s(CASP) (Prolog extensions)
  - HyProlog (assumptions and abduction), Flora-2/ErgoAI, ...
  - Probabilistic LP, ProbLog, ...
  - ProGol, ILP (learning)
  - LogTalk (objects), Picat (imperative syntax)
  - CHR, CHRG, ...
- Beyond LP:
  - Theorem proving technology
  - Erlang
  - Java (abstract machine, specification, ...)
  - Many embeddings in other languages
  - Many others: C++, many compilers, ...
  - Many analyzers and verifiers for other languages
  - ...

Some Prolog strong points

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- Powerful programming paradigm, includes most others (e.g. functions are relations).
- Allows going smoothly from executable specifications to efficient implementation.
- Clean, simple syntax and semantics. Easy meta-programming.
- Immutable persistent data structures, with "declarative" pointers (logic variables).
- Safety: garbage collection, no NullPointer exceptions, ...
- Efficiency: very efficient inference, pattern matching, and unification; tail-recursion and last-call optimization; indexing, efficient tabling.
- Many features (as we saw, but also DCGs, arbitrary precision arithmetic, ...).
- Fast development: interactive top-level, debugging, ...
- Sophisticated tools: analyzers, verifiers, partial evaluators, parallelizers, ...
- Community:
  - Both commercial and open-source systems (some very substantive and mature!).
  - Active developer community with constant new implementations, features, etc.
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- Successful applications, including:
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- Somewhat fragmented community.
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- New programming languages.
- The perception that it is an "old" language.
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- New features and developments:
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- Should Prolog/LP/CLP be taught in CS programs?
  Yes!: CS grads simply not complete without. But... has to be done right.
  - Typical 'programming paradigms' course can be counter-productive.
  - But what to do if, as frequently, that is the only slot available?

- Modern Prologs address well most of the shortcomings of early systems via tabling, constraints, multiple search rules, etc. — take advantage of this!
- Discuss the "dream" (Green), logics and deduction procedures ⇝ Horn clauses & SLD-resolution (effectiveness/semi-decidability) ⇝ classical LP (Kowalski/Colmerauer).
- Important to show the beauty and multiple facets of the language:
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- Students will find non-termination early on: help them understand it.
  - A fact of life in programming languages (halting problem) or proof systems.
  - Start running programs breadth-first (or iterative deepening, tabling, etc.): all solutions in finite time (explain with picture of tree); discus the trade-offs.
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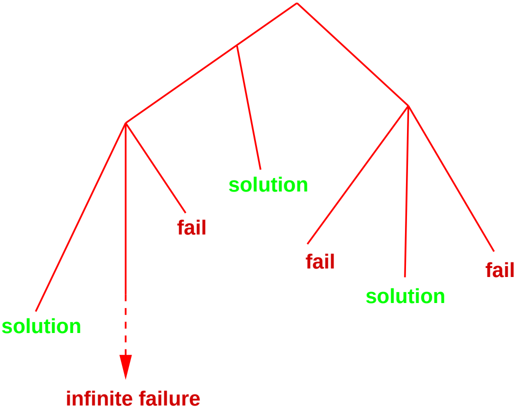
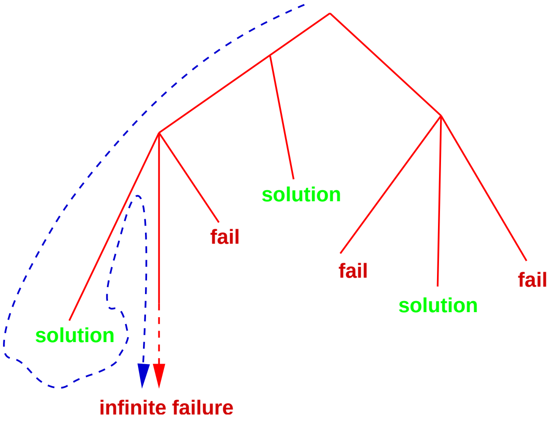
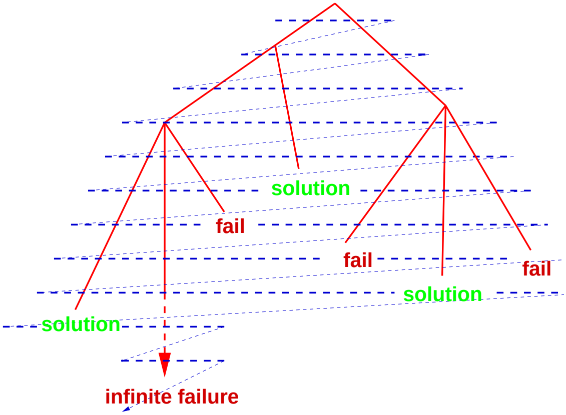


Depth-First Search



Breadth-First Search



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