Prolog cumple 50, larga vida a Prolog!

Reflexiones sobre su evolución, situación actual, y desarrollo futuro

Manuel Hermenegildo[1,2]
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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.

The Year of Prolog

- Summer of 1972:
  Alain Colmerauer and team in Marseille develop the first version of Prolog.

- This event + earlier and later collaborations w/Bob Kowalski and colleagues in Edinburgh, lay the foundations for the Prolog and LP of today.

- The "Year of Prolog" celebrates the 50th anniversary of these events.

  Organizers: Association for Logic Programming and Prolog Heritage Association.

The Year of Prolog

- Initiatives:
  - **ALP Alain Colmerauer Prolog Heritage Prize**. *For recent practical accomplishments that highlight the benefits of Prolog-inspired computing.*
  - **Prolog Day Symposium** (November 10, 2022) in which the Alain Colmerauer Prize will be awarded (subsequent editions at ICLP). Registration open!
  - **Prolog Education initiative** (long-term initiative):
    - map and provide Prolog education resources for educators,
    - introduce schoolchildren/young adults to logic, programming, and AI w/Prolog.
  - **Survey paper** on "Fifty Years of Prolog and Beyond" published in the 20th anniversary special issue of TPLP.
  - **Special sessions and invited talks** (e.g., at CILC, ICLP/FLoC, ... SISTEDES!).
  - **Special volume** (Springer LNAI).

and others... do join in!

prologyear.logicprogramming.org

Activities are overseen by a Scientific Committee, chaired by Bob Kowalski.

- So, Prolog is 50!
  - What, 50 years?!? Half a century?!?!
  - Is Prolog therefore now 'old'? Is Prolog now irrelevant?

- 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'.
  - A truly impressive body of research and scientific firsts.

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Early steps, major milestones

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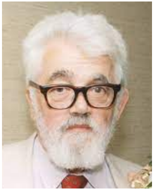

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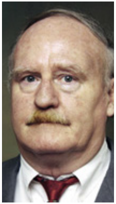

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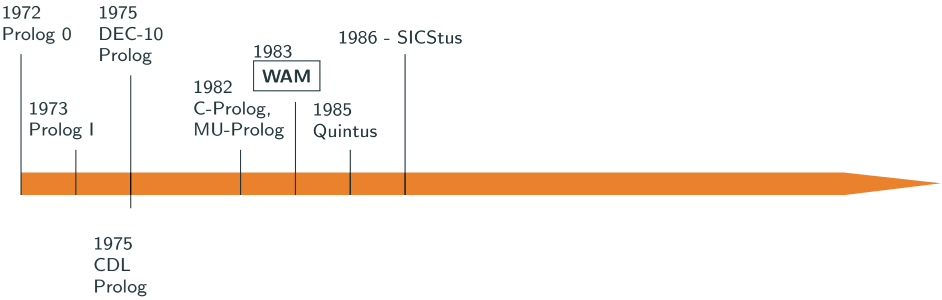

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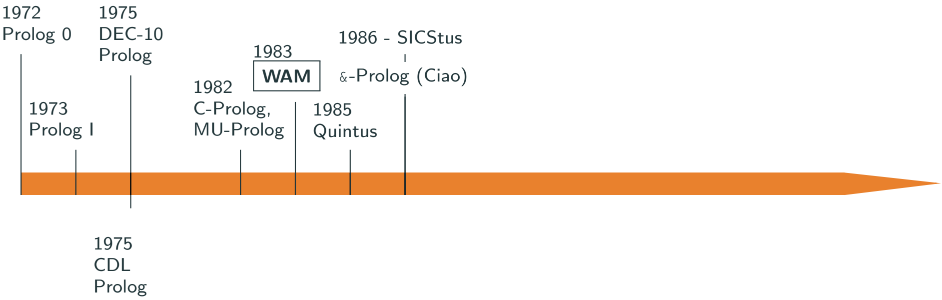

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- Or- and and-parallelism.
- *Global analysis* (abstract interpretation), P.Eval.; Aquarius, &-Prolog/Ciao.
  (Independence/aliasing, modes, types, determinacy, sharing, non-failure, cost, ...)
  First practical compiler(s) using abstract interpretation?

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

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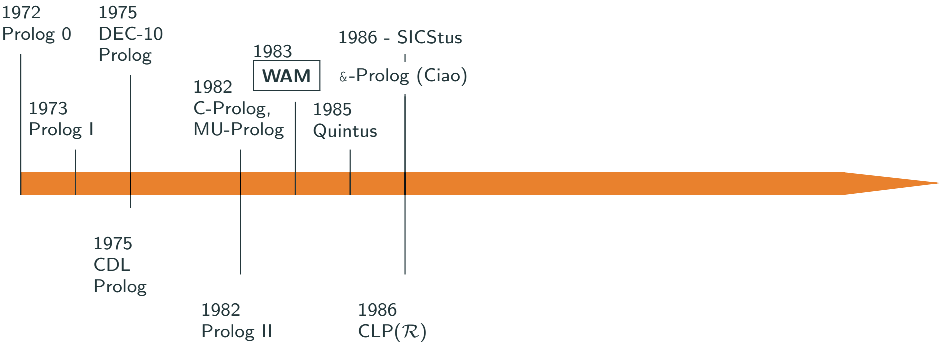

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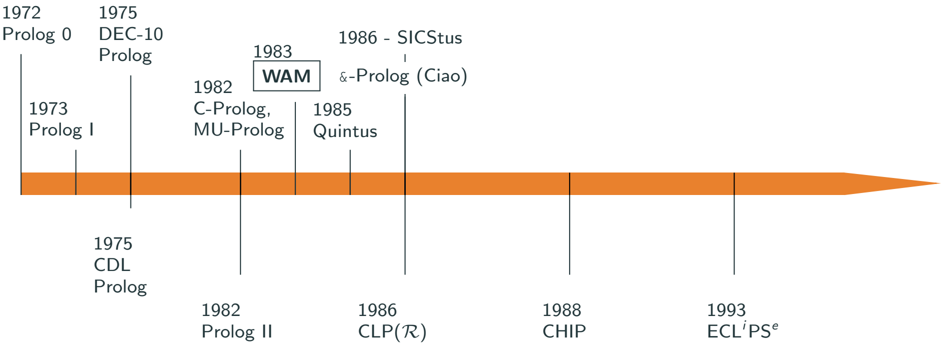

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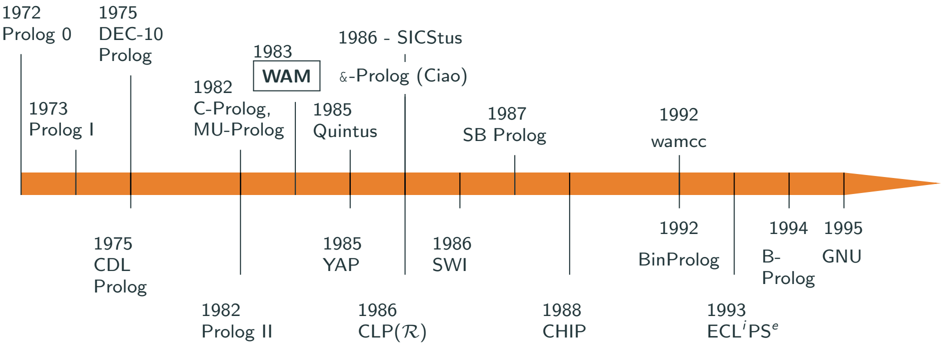

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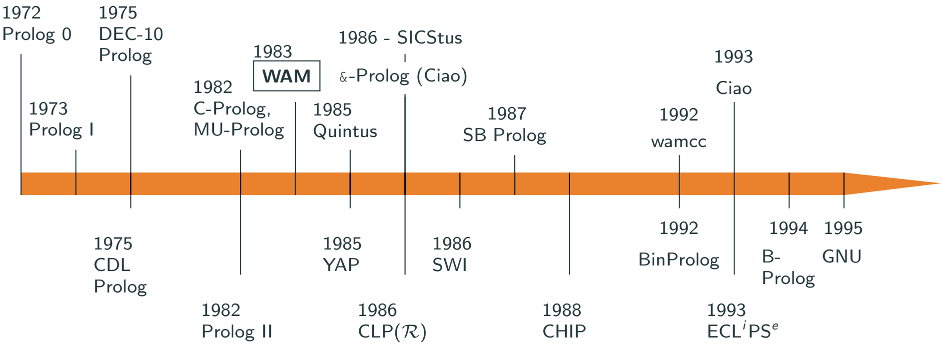

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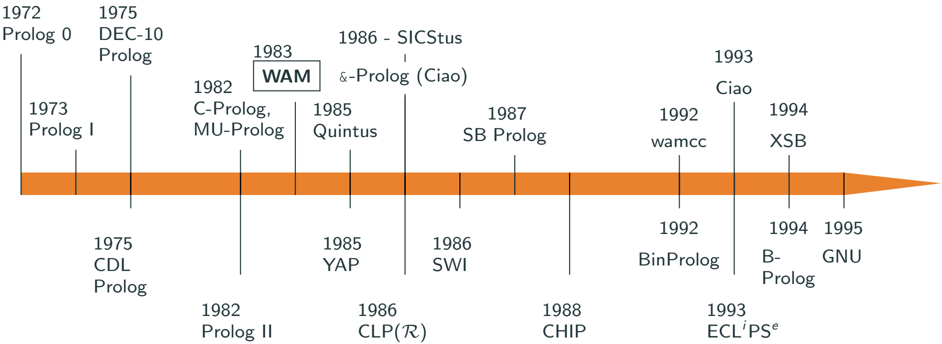

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- Early ded., *Tabling*, SLG-resolution, minimal-model / well-founded semantics.

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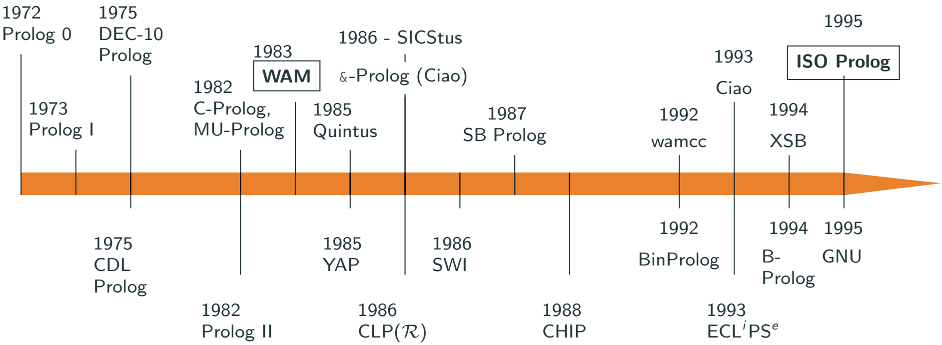

- *Constraints* (Prolog II; CLP scheme and CLP($\mathcal{R}$))
  - Finite domains.
- A good number of other WAM(and non-WAM)-based Prologs (see later).
- Higher-order / functional syntax support (λ-Prolog, HiLog, Hiord, ...).
- *Types/modes*, verification, testing, assertions.
- Early ded., *Tabling*, SLG-resolution, minimal-model / well-founded semantics.

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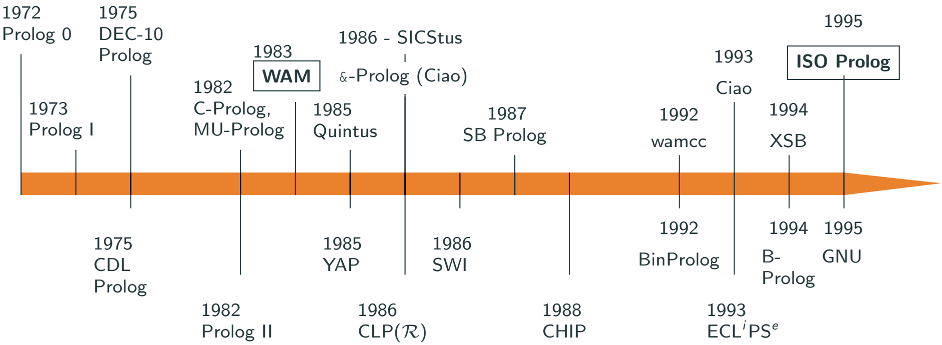

All this progressed in parallel with further advances in the theoretical underpinnings:

- Kowalski/van Emden (1976): linear res. for Horn clauses, no factoring rule, ...
- Clark (1978): correctness of NaF w.r.t. program completion.
- Reiter (1978): formalization of “Closed world assumption.”
- Minker, Gallaire, Cohen, Lassez/Jaffar/Maher, DHD Warren, Tamaki/Sato, DS Warren, ...

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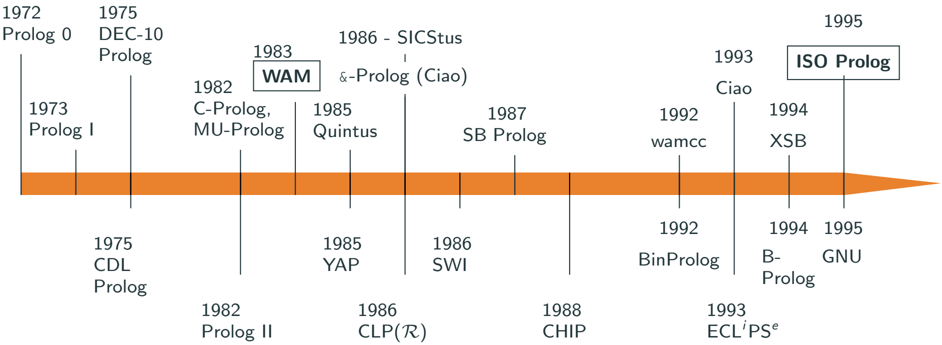

After ISO – much additional evolution:

- Constraints in standard Prologs: "Opening the box" (attvars/CHR).
- Learning (ILP), probabilistic.
- *ASP* ⇝ Prolog-ASP combinations ⇝ *s(CASP)*.
- Web embedding, playgrounds, notebooks.

\+ applications of techniques to other languages,
combination with deep learning / explainable AI, ...

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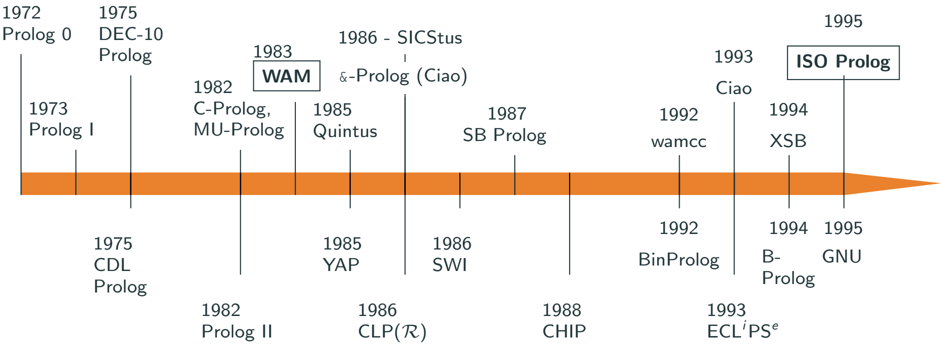

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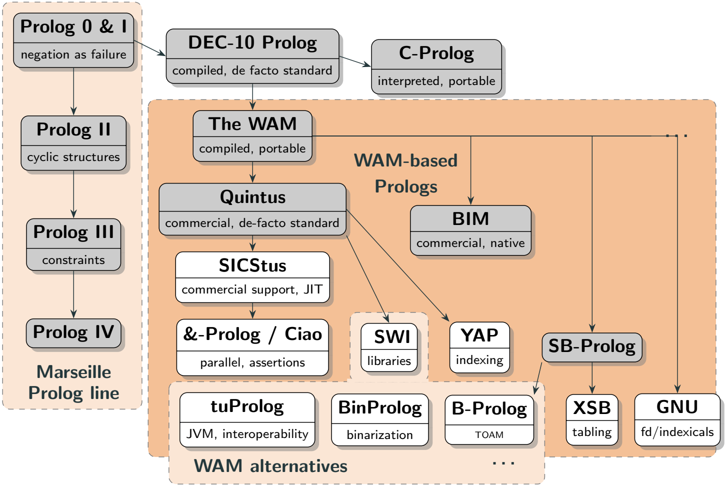
Let's jump forward and take a look at the current state of things!

An overview of current systems

Prolog system heritage



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

Again, more missing!: ECL^{i}PS^e, IBM, LIFE, Andorra-I, Scryer, Tau, ...

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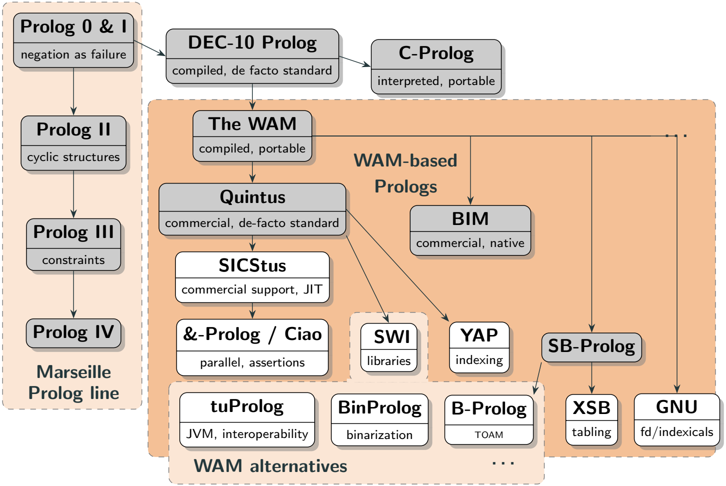

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Support status for selected features - I

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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Support status for selected features - II

System	CLP	CHR	Tabling	Parallelism	Indexing	Coroutines
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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	
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SICStus	$\mathcal{FD}$, $\mathcal{B}$, $\mathcal{Q}$, $\mathcal{R}$	✓			FA	✓
SWI	$\mathcal{FD}$, $\mathcal{B}$, $\mathcal{Q}$, $\mathcal{R}$	✓	✓	✓	MA, deep, JIT	✓
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Support status for selected features - 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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XSB	trace		✓			
YAP	trace	✓				

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Many other features!

- Auto-documentation, attributed variables, objects, enhanced expansions, playgrounds, ...

Summary (so far)

- Prolog systems have come a long way!
- ISO standard generally supported (with minor differences).
- *Basic* module system pretty compatible.
- A good number of commonly available features:
  - Constraints.
  - Multi-threading.
  - Tabling.
  - Coroutining.
  - ...

  However,

  - Interfaces and details often differ.
    Can mostly be bridged (c.f., Paolo Moura's work), but a real nuisance.
  - Some features (e.g., Types/modes/verification, s(CASP), ...)
    still in few systems.

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Influences on others

Influence in other languages within LP and its extensions

- Goedel, Mercury, Turbo-Prolog (static typing)
- λ-Prolog, Curry, Babel
- CP, GHC, Parlog, Erlang (committed choice)
- Datalog, ASP
- s(ASP) and s(CASP) (can also be seen as extensions)
- HyProlog, Flora-2/ErgoAI, Co-inductive LP, ...
- Probabilistic LP
- ProGol, ILP
- LogTalk
- Picat
- CHR, CHRG
- ...

Influence beyond LP

- Theorem proving technology.
- Java (abstract machine, specification, ...).
- Erlang.
- Many embeddings in other languages.
- Many others: C++, many compilers, ...
- Analyzers and verifiers for other languages.
- ...

Further analysis of current status and outlook

Prolog strengths

- Clean, simple syntax and semantics.
- Immutable persistent data structures, with "declarative" pointers (logic variables).
- Arbitrary precision arithmetic.
- Safety (garbage collection, no NullPointer exceptions, ...).
- Tail-recursion and last-call optimization.
- Efficient inference, pattern matching, and unification; DCGs.
- Meta-programming, programs as data.
- Constraint solving.
- Independence of the selection rule (coroutines).
- Indexing, efficient tabling.
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Some perspectives from the Ciao Prolog system:

A new-generation Prolog

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- Start from small, very *extensible* LP kernel – a language-building language.
- Build gradually extensions in layers on top of it.
- Syntactic and semantic extensions can be activated/deactivated per module.

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\+ many other extensions and libraries (e.g., s(CASP)).

Context (also early 90's):

- **A tendency to restrict languages** (generally for performance).
  - Elimination of unification: Mercury, GHC, CC, Erlang, ...
  - Elimination of non-determinism/search: GHC, CC, Erlang, ...
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Ciao principle II:
High performance via optimization, not language restriction.

- No need to eliminate unification or tabling or backtracking or constraints, etc.
- **Optimization** via analysis, partial evaluation, parallelization, profiling, . . .
- Separate/incr. compilation, small executables, **high-performance**, . . .
  Interfaces/Embeddability (C, many other languages, Web).

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Ciao principle III:
Combine the best of the dynamic and static language approaches.

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Enabler:

- **Abstract Interpretation-based checking of *optional* assertions** $\rightarrow$
  Provably safe approximations $\rightarrow$ The Ciao assertions model

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- Approach not particularly in line with the trends at the time!

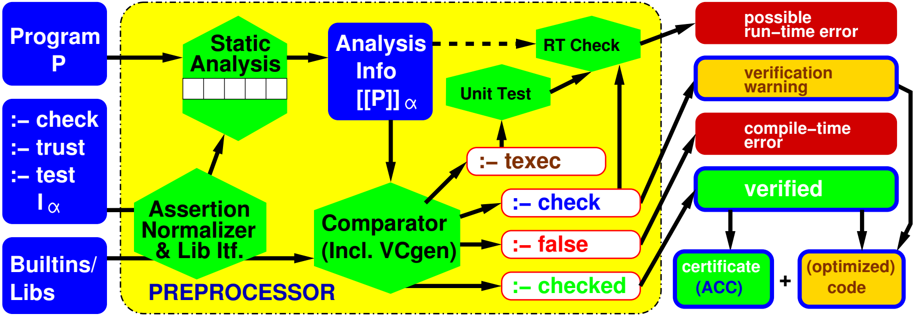
→ "Ciao: (first?) dynamic language with safety assurances,
trying to survive in a world dominated by strong typing."

- However, idea quite popular now: hybrid typing, Racket, liquid Haskell, etc.

Ciao Prolog demo (ciao-lang.org)

- Interactive CiaoPP (Verifly) (See also slides at the end.)
- The Ciao playground
  - A simple example
  - Web embedding / tutorial example
- s(CASP) playground

The Ciao Integrated Approach to Specification, Debugging, Verification, Testing, and Optimization



Discussion: Comparison with Classical Types

"Traditional" Types	Ciao Assertion-based Model
"Properties" limited by decidability	Much more general property language
May need to limit prog. lang.	No need to limit prog. lang.
"Untypable" programs rejected	Run-time checks introduced
(Almost) Decidable	Decidable + Undecidable (approximated)
Expressed in a different language	Expressed in the source language
Types must be defined	Types can be defined or inferred
Assertions are only of type "check"	"check", "trust", ...
Type signatures & assertions different	Type signatures *are* assertions

- But quite popular now: gradual typing, Racket, liquid Haskell, etc.
- Some key issues:
  Safe / Sound approximation — *Suitable assertion language*
  Abstract Interpretation — *Powerful abstract domains*
- Works best when properties and assertions can be expressed in the source language (i.e., source lang. supports *predicates*, *constraints*).

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- Prolog / LP / CLP *must* be taught in CS programs,
  - A CS graduate is simply not complete without knowledge of Prolog.

  (and maybe also in other majors and maybe in schools –cf. Prolog Year?)
- But it has to be done right!
  - The standard 'programming paradigms' approach can be counter-productive.
  - Simply cannot be done in a couple of weeks emulating Prolog in Scheme.
    - What to do if that is the only slot available?
- On the way *dispel unfounded myths* about the language, and show how many of the shortcomings of early Prologs have been *addressed over the years*.

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- "Prolog gets into infinite loops."

  This is true –in fact, of any programming language or proof system.
  However, it is likely to discourage beginners if not explained well:

  - Use a system that can *alternatively and selectively* run in breadth-first, iterative deepening, tabling, etc.
  - Start by running all predicates, e.g., breadth-first – everything works!
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  - Do relate it to the *halting problem*: no-one (Prolog, logic, nor other Turing-complete prog. language) can solve that (but tabling helps).
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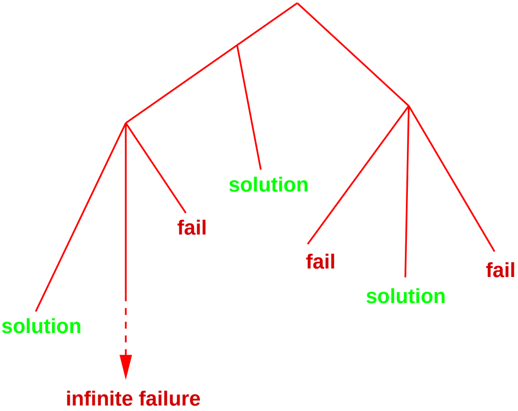
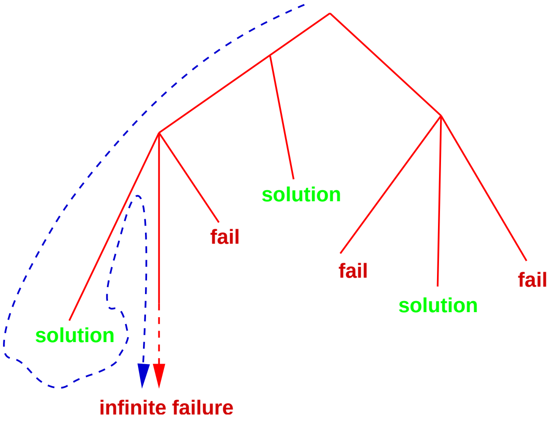


Depth-First Search



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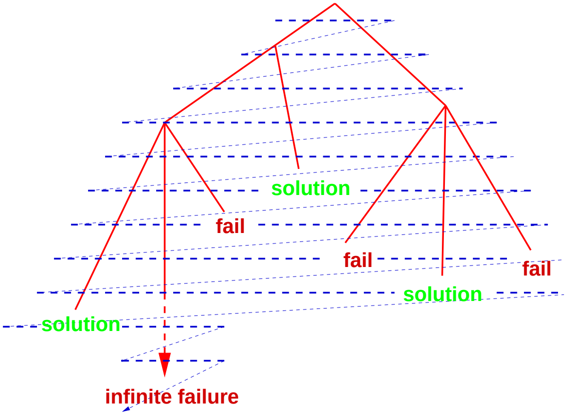

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On teaching (and preaching) Prolog

- "Arithmetic is not reversible."
  - Start with Peano arithmetic: beautiful but slow.
  - Then justify Prolog arithmetic for efficiency.
  - Then show (arithmetic) constraint domains: beautiful and efficient!
- "There is no occur check."
  - Explain why, and that there is a built-in for it.
  - Have a package (expansion) that calls it by default for all unifications.
  - Explain the existence of infinite tree unification (as a constraint domain).
- "Prolog is not pure (cut, assert, etc.)"
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Personal Sequential Inference –PSI– machine (Prolog machine) in FGCS ICOT's basement (the large refrigerator-size box on the right).

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- Do show the beauty:
  - Explain "Green's dream," discuss for what logics we have effective deduction procedures, justify the choice of FO and semi-decidability, SLD-resolution → classical LP (Kowalski/Colmerauer).
  - Show how logic programs are both logical theories (with declarative meaning) and procedural programs that can be debugged, followed step by step, etc.
    - An operational (in addition to declarative) semantics is a requirement in the language (vs., e.g., Goedel) and we do need to teach it.
    - Otherwise not a programming language, just specification/KR – Prolog is both.
    - How otherwise to reason about complexity, memory consumption, etc.? To say that these things don't matter does not make sense in PL.
  - Show with examples (and benchmarking them) how you can go from executable specifications to efficient algorithms gradually, and as needed.
  - Show how unification is also a device for *constructing and matching complex data structures with (declarative) pointers*. Show it in the top level, giving "the data structures class."
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  - Classical installation.
    Most appropriate for more advanced students / “real” use.
    Show serious, competitive language.
  - Playgrounds and notebooks
    (e.g., Ciao Playgrounds/Active Logic Documents, SWISH, τ-Prolog).
    - Server-based.
    - Browser-based.

    Can be attractive for beginners, young students.
    Very useful for executable examples in manuals and tutorials.
- Ideally the system should allow covering:
  - pure LP (with several search rules, tabling),
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    Most appropriate for more advanced students / "real" use.
    Show serious, competitive language.
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    - Server-based.
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    Can be attractive for beginners, young students.
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Demo slides for the part on:

Types, modes, and other properties

(Some perspectives from the Ciao Prolog system)

Example: qsort

Ciao warns that it cannot verify that the call to =</2 will not generate a run-time error (assertion is in library!):

```
:- module(_,[qsort/2],[assertions,nativeprops,.(nmodes)]).

qsort([], []).
qsort([First|Rest],Result) :-
    partition(Rest,First,Sm,Lg),
    qsort(Sm,SmS),
    qsort(Lg,LgS),
    append(SmS,[First|LgS],Result).

partition([],_,[],[]).
partition([X|Y],F,[X|Y1],Y2) :-
    X =< F,
    partition(Y,F,Y1,Y2).
partition([X|Y],F,Y1,[X|Y2]) :-
    X > F,
    partition(Y,F,Y1,Y2).

append([],Xs,Xs).
append([X|Xs],Ys,[X|Zs]) :-
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partition([],_,[],[]).
partition([X|Y],F,[X|Y1],Y2) :-
➤ At literal 1 could not verify assertion:
    partition(Y,F,Y1,Y2).
partition([X|Y],F,Y1,[X|Y2]) :-
    X > F,
    partition(Y,F,Y1,Y2).

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Example: qsort

Adding useful entry information Ciao can infer that $=</2$ is called correctly, and no warnings are flagged (this would normally be obtained from analysis of caller to this module):

```
:- module(_,[qsort/2],[assertions,nativeprops,.(nmodes)]).

:- pred qsort(+list(num),_).

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Example: qsort

We add some more assertions... :

```
:- pred qsort(+list(num),-list(num)) + is_det.

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:- pred partition(+list(num),+num,-list(num),-list(num)) + (is_det,not_fails).

partition([],_,[],[]).
partition([X|Y],F,[X|Y1],Y2) :-
    X =< F,
    partition(Y,F,Y1,Y2).
partition([X|Y],F,Y1,[X|Y2]) :-
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:- pred append(+list(num),+list(num),-list(num)) + is_det.

append([],Xs,Xs).
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Example: qsort

...and they get verified by Ciao:

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    append(SmS,[First|LgS],Result).

:- pred partition(+list(num),+num,-list(num),-list(num)) + (is_det,not_fails).
➤ Verified assertion:
:- check comp partition(A,B,C,D)
   : ( list(num,A), num(B) )
   + ( is_det, not_fails ).
➤ Verified assertion:
:- check success partition(A,B,C,D)
   : ( list(num,A), num(B) )
   => ( list(num,C), list(num,D) ).

:- pred append(+list(num),+list(num),-list(num)) + is_det.

append([],Xs,Xs).
append([X|Xs],Ys,[X|Zs]) :-
    append(Xs,Ys,Zs).
```

Example: qsort

If we replace =</2 with </2 Ciao warns that partition/3 can fail (cannot prove not_fails):

```
:- pred qsort(+list(num),-list(num)) + is_det.

qsort([], []).
qsort([First|Rest],Result) :-
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:- pred partition(+list(num),+num,-list(num),-list(num)) + (is_det,not_fails).

partition([],_,[],[]).
partition([X|Y],F,[X|Y1],Y2) :-
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:- pred append(+list(num),+list(num),-list(num)) + is_det.

append([],Xs,Xs).
append([X|Xs],Ys,[X|Zs]) :-
    append(Xs,Ys,Zs).
```

Example: qsort

If we replace `>=/2` with `>/2` Ciao warns that `partition/3` is not deterministic (cannot prove `is_det`):

```
:- pred qsort(+list(num),-list(num)) + is_det.

qsort([], []).
qsort([First|Rest],Result) :-
    partition(Rest,First,Sm,Lg),
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    append(SmS,[First|LgS],Result).

:- pred partition(+list(num),+num,-list(num),-list(num)) + (is_det,not_fails).

partition([],_,[],[]).
partition([X|Y],F,[X|Y1],Y2) :-
    X =< F,
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partition([X|Y],F,Y1,[X|Y2]) :-
    X >= F,
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:- pred append(+list(num),+list(num),-list(num)) + is_det.

append([],Xs,Xs).
append([X|Xs],Ys,[X|Zs]) :-
    append(Xs,Ys,Zs).
```

Example: nrev (using the functional syntax package)

An example with more complex properties, a cost error is flagged:

```
:- module(_, [nrev/2], [assertions,fsyntax,nativeprops]).

:- pred nrev(A,B) : {list, ground} * var => list(B)
   + ( not_fails, is_det, steps_o( length(A) ).

nrev( [] )     := [].
nrev( [H|L] ) := ~conc( ~nrev(L),[H] ).


:- pred conc(A,B,C) + ( terminates, is_det, steps_o(length(A)) ).

conc( [],     L ) := L.
conc( [H|L], K ) := [ H | ~conc(L,K) ].
```

Example: nrev

Ciao reminds us that `nrev/2` is of course quadratic, not linear:

```
:- module(_, [nrev/2], [assertions,fsyntax,nativeprops]).

:- pred nrev(A,B) : {list, ground} * var => list(B).
➤ False assertion:
:- check comp nrev(A,B)
   : ( list(A), ground(A), var(B) )
   + ( not_fails, is_det, steps_o(length(A)) ).
because the comp field is incompatible with inferred comp:
[generic_comp] covered,is_det,mut_exclusive,not_fails,steps_lb(0.5*exp(length(A)
,2)+1.5*length(A)+1),steps_ub(0.5*exp(length(A),2)+1.5*length(A)+1)
➤ Verified assertion:
:- check calls nrev(A,B)
   : ( list(A), ground(A), var(B) ).
➤ Verified assertion:
:- check success nrev(A,B)
   : ( list(A), ground(A), var(B) )
   => list(B).
```

Example: nrev

With the cost expression fixed all properties are now verified:

```
:- module(_, [nrev/2], [assertions,fsyntax,nativeprops]).

:- pred nrev(A,B) : {list, ground} * var => list(B)
   + ( not_fails, is_det, steps_o( exp(length(A),2)) ) ).

nrev( [] )     := [].
nrev( [H|L] ) := ~conc( ~nrev(L),[H] ).


:- pred conc(A,B,C) + ( terminates, is_det, steps_o(length(A)) ).

conc( [],     L ) := L.
conc( [H|L], K ) := [ H | ~conc(L,K) ].
```

Example: nrev

If we change the assertion for `conc/3` from complexity order (`_o`) to upper bound (`_ub`) then Ciao flags that `length(A)` is not a correct upper bound:

```
:- module(_, [nrev/2], [assertions,fsyntax,nativeprops]).

:- pred nrev(A,B) : {list, ground} * var => list(B)
   + ( not_fails, is_det, steps_o( exp(length(A),2) ) ).

nrev( [] )     := [].
nrev( [H|L] ) := ~conc( ~nrev(L),[H] ).


:- pred conc(A,B,C) + ( terminates, is_det, steps_ub(length(A)) ).

conc( [],    L ) := L.
conc( [H|L], K ) := [ H | ~conc(L,K) ].
```

Example: nrev

If we change the assertion for `conc/3` from complexity order (_o) to upper bound (_ub) then Ciao flags that `length(A)` is not a correct upper bound:

```
:- module(_, [nrev/2], [assertions,fsyntax,nativeprops]).

:- pred nrev(A,B) : {list, ground} * var => list(B)
   + ( not_fails, is_det, steps_o( exp(length(A),2) ) ).

nrev( [] )     := [].
nrev( [H|L] ) := ~conc( ~nrev(L),[H] ).


:- pred conc(A,B,C) + ( terminates, is_det, steps_ub(length(A)) ).
➤ False assertion:
:- check comp conc(A,B,C)
   + ( terminates, is_det, steps_ub(length(A)) ).
because the comp field is incompatible with inferred comp:
[generic_comp] covered,is_det,mut_exclusive,not_fails,steps_lb(length(A)+1),step
s_ub(length(A)+1)
➤ Verified assertion:
:- check calls conc(A,B,C).
```

Example: nrev

With the cost expression fixed all properties are now verified:

```
:- module(_, [nrev/2], [assertions,fsyntax,nativeprops]).

:- pred nrev(A,B) : {list, ground} * var => list(B)
   + ( not_fails, is_det, steps_o( exp(length(A),2) ) ).

nrev( [] )     := [].
nrev( [H|L] ) := ~conc( ~nrev(L),[H] ).


:- pred conc(A,B,C) + ( terminates, is_det, steps_ub(length(A)+1) ).

conc( [],    L ) := L.
conc( [H|L], K ) := [ H | ~conc(L,K) ].
```

Example: nrev

With the cost expression fixed all properties are now verified:

```
:- module(_, [nrev/2], [assertions,fsyntax,nativeprops]).

:- pred nrev(A,B) : {list, ground} * var => list(B)
   + ( not_fails, is_det, steps_o( exp(length(A),2) ) ).

nrev( [] )     := [].
nrev( [H|L] ) := ~conc( ~nrev(L),[H] ).


:- pred conc(A,B,C) + ( terminates, is_det, steps_ub(length(A)+1) ).
➤ Verified assertion:
:- check calls conc(A,B,C).
➤ Verified assertion:
:- check comp conc(A,B,C)
   + ( terminates, is_det, steps_ub(length(A)+1) ).
```