50th Anniversary of the Birth of Prolog:
Some reflections on Prolog’s Evolution, Status, and Future

Manuel Hermenegildo¹,²
ICLP’22 (FLoC’22), August 4, 2022

¹T. U. of Madrid (UPM)
²IMDEA Software Institute

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.

- Objectives:
  - Highlight the continuing significance of Prolog and LP for both symbolic, explainable AI, and computing more generally.
  - Inspire a new generation of students, by drawing their attention to the logic-based approach to computing.
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and others... do join in! prologyear.logicprogramming.org

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  ▶ What, 50 years?!? Half a century?!?!
  ▶ Is Prolog therefore now ’old’? Is Prolog now irrelevant?

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Early steps, major milestones
Ancestors and birth


- Anyway, some highlights:
  - McCarthy (1962): the AI language LISP → “very high-level languages.”
  - Green (1969): extend resolution to answer questions in FO-logic (QA3).
  - Boyer and Moore (1972): structure sharing.
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Early Prologs and main milestones (≈ up to ISO)

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(FGCS → MCC → ECRC → ESPRIT → EU research programs, and others.)
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  → commercial/PD, dissemination, more performance.
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- 1972 Prolog 0
- 1975 DEC-10 Prolog
- 1973 Prolog I
- 1975 CDL Prolog
- 1982 C-Prolog, MU-Prolog
- 1983 WAM
- 1985 Quintus
- 1986 - SICStus &-Prolog (Ciao)

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- Or- and and-parallelism.

  (Independence/aliasing, modes, types, determinacy, sharing, non-failure, cost, ...)
  First practical compiler(s) using abstract interpretation?

  $\rightarrow$ Performance ($\approx$ imperative), auto-parallelization, real parallel speedups.
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- **1975**
  - Prolog II

- **1982**
  - C-Prolog, MU-Prolog
  - WAM

- **1983**
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<tr>
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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, ...
Early Prologs and main milestones (∼ up to ISO)

1972
Prolog 0

1973
Prolog I

1975
DEC-10 Prolog

1975
CDL Prolog

1973
Prolog I

1982
WAM

1982
C-Prolog, MU-Prolog

1983
WAM

1983
&-Prolog (Ciao)

1985
Quintus

1985
YAP

1986
SICStus

1986
CLP(\mathcal{R})

1986
SWI Prolog

1986
SICStus

1987
SB Prolog

1987
SB Prolog

1988
CHIP

1988
CHIP

1993
ISO Prolog

1992
Ciao

1992
wamcc

1992
BinProlog

1992
B-Prolog

1994
XSB

1994
SWI Prolog

1995
GNU

1995
Ciao

After ISO – much additional evolution:

- Constraints in standard Prologs: “Opening the box” (attvars/CHR).
- Learning (ILP), probabilistic.
- \textit{ASP} \rightarrow \textit{Prolog-ASP combinations} \rightarrow \textit{s(CASP)}.
- Web embedding, playgrounds, notebooks.
- Applications of techniques to other languages, combination with deep learning / explainable AI, ...
Early Prologs and main milestones (≈ up to ISO)

- **1972**: Prolog 0
- **1973**: Prolog I
- **1975**: DEC-10 Prolog, CDL Prolog
- **1982**: C-Prolog, MU-Prolog, WAM
- **1983**: WAM, &-Prolog (Ciao)
- **1985**: Quintus
- **1986**: SICStus
- **1987**: SB Prolog
- **1988**: CHIP
- **1989**: CLP(\(\mathcal{R}\))
- **1992**: BinProlog, YAP, SWI Prolog, wamcc, Ciao
- **1993**: ECL, iPS, ISO Prolog
- **1994**: B-Prolog, GNU
- **1995**: XSB

After ISO – much additional evolution:
- Constraints in standard Prologs: “Opening the box” (attvars/CHR).
- Learning (ILP), probabilistic.
- ASP ⇝ Prolog-ASP combinations ⇝ s(CASP).
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Let’s jump forward and take a look at the current state of things!

Manuel Hermenegildo – Some Reflections on Prolog’s Evolution, Status, and Future on its 50th Anniversary (ICLP’22/FLoC’22, Aug. 4, 2022)
An overview of current systems
Prolog system heritage

Prolog 0 & I
negation as failure

Prolog II
cyclic structures

Prolog III
constraints

Prolog IV
Marseille Prolog line

DEC-10 Prolog
compiled, de facto standard

C-Prolog
interpreted, portable

The WAM
compiled, portable

Quintus
commercial, de-facto standard

BIM
commercial, native

SICStus
commercial support, JIT

&-Prolog / Ciao
parallel, assertions

SWI
libraries

YAP
indexing

SB-Prolog

B-Prolog

XSB
tabling

GNU
fd/indexicals

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

Again, more missing!: ECL\textsuperscript{i}PS\textsuperscript{e}, IBM, LIFE, Andorra-I, Scryer, Tau, ...
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- compiled, de facto standard

**C-Prolog**
- interpreted, portable

**The WAM**
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**Quintus**
- commercial, de-facto standard

**SICStus**
- commercial support, JIT

**&-Prolog / Ciao**
- parallel, assertions

**SWI**
- libraries

**YAP**
- indexing

**SB-Prolog**

- **SB-Prolog**
  - tabling
  - fd/indexicals

**B-Prolog**
- TOAM

**tuProlog**
- JVM, interoperability

**BinProlog**
- binarization

**GNU**
-.fd/indexicals

**B-Prolog**
- TOAM

**XSB**
- tabling

**Prolog system heritage**

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Again, more missing!: ECLiPS, IBM, LIFE, Andorra-I, Scryer, Tau, ...
## Support status for selected features - 1

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<th>Modules</th>
<th>Non-Std. Data Types</th>
<th>Foreign Language Interfaces</th>
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## Support status for selected features - II

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</thead>
<tbody>
<tr>
<td>B-Prolog</td>
<td>trace</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Ciao</td>
<td>trace / source</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>ECLiPSe</td>
<td>trace</td>
<td>✓</td>
<td></td>
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<tr>
<td>GNU Prolog</td>
<td>trace</td>
<td>✓</td>
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<tr>
<td>JIProlog</td>
<td>trace</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SICStus</td>
<td>trace / source</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SWI</td>
<td>trace / graphical</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>τ-Prolog</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>tuProlog</td>
<td>spy</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>XSB</td>
<td>trace</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>YAP</td>
<td>trace</td>
<td></td>
<td></td>
<td>✓</td>
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<td></td>
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<tr>
<td>System</td>
<td>Debugger</td>
<td>Global Vars.</td>
<td>Mutables</td>
<td>Testing</td>
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Many other features!
- Auto-documentation, attributed variables, objects, enhanced expansions, playgrounds, ...

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Influences on others
Influence in other languages within LP and its extensions

- Goedel, Mercury, Turbo-Prolog (static typing)
- $\lambda$-Prolog, Curry, Babel
- CP, GHC, Parlog, Erlang (committed choice)
- Datalog, ASP
- s(ASP) and s(CASP) (can also be seen as extensions)
- HyProlog, Co-inductive LP, ...
- Probabilistic LP
- LogTalk
- Picat
- CHR, CHRG
- ...

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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.
- ...

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Further analysis of current status and outlook
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  - Post-desktop world of JavaScript web-applications.
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  - Library infrastructure and conditional code,
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- Module system (some aspects), interfaces, objects.
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Types, modes, and other properties
(Some perspectives from the Ciao Prolog system)
Dynamic vs. Static languages – the classic dilemma

**Dynamic languages** (Prolog, Lisp/Scheme, Python, Javascript, ...)

- Dynamic checking of basic types, modes, and some other properties:
  - ..., A is B+C, ...
    - B and C checked by is/2 to be *instantiated to numexpr* at run time.
  - ..., arg(N,T,A), ...
    - N checked by arg/3 to be nat & ≤ arity(T) ("array bounds").

→ Flexibility, compactness, rapid prototyping, scripting, ..., but
  - Most errors only detected at run time.
  - Need to use tags (*boxing* of data) to identify type and mode, store arity, etc.

**Static languages** (ML, Haskell, Mercury, Gödel, ...)

- Compiler statically checks *types*.

→ Safety guarantees (types), performance, scalability, ..., but
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- Note that some languages (e.g., C) are neither (even if still very useful!):
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### Dynamic languages (Prolog, Lisp/Scheme, Python, Javascript, ...)

- Dynamic checking of basic types, modes, and some other properties:
  - ..., A is B+C, ...
    - B and C checked by `is/2` to be *instantiated* to `numexpr` at run time.
  - ..., arg(N,T,A), ...
    - N checked by `arg/3` to be `nat` & $\leq$ `arity(T)` ("array bounds").

→ Flexibility, compactness, rapid prototyping, scripting, ..., but
  - Most errors only detected at run time.
  - Need to use tags (*boxing* of data) to identify type and mode, store arity, etc.

### Static languages (ML, Haskell, Mercury, Gödel, ...)

- Compiler statically checks *types*.

→ Safety guarantees (types), performance, scalability, ..., but
  - more rigid, limitations on language and provable properties.

- Note that some languages (e.g., C) are neither (even if still very useful!):
  - no checking of, e.g., array bounds at compile time or run time...
Solving the Dynamic vs. Static Dilemma

The Ciao Approach (mid 90’s’s!):

1. **Assertions** can be used to express types, modes, and many other properties.
   - But voluntary: provided up front, gradually, or not at all.

2. Then, *advanced program analysis* (abstract interpretation) is used to:
   - Verify the assertions:
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   - Achieve high performance:
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     - Unboxing, specialization, slicing, automatic parallelization, ...

3. Also, easily generate tests from assertions (this is (C)LP!).

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The Ciao Integrated Approach to Specification, Debugging, Verification, Testing, and Optimization
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Demo! (See slides at the end.)
Teaching (and preaching) Prolog
On teaching (and preaching) Prolog

• 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 is has to be done right!
  ▶ The standard 'programming paradigms' approach is 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 *dispell 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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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!
▶ Then, explain the shape of the tree (solutions at finite depth, possible infinite failures, etc.), and thus why breadth-first works, and why depth-first sometimes may not.
▶ 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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Characterization of the search tree

- solution
- fail
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- infinite failure
Depth-First Search
On teaching (and preaching) Prolog

- “Arithmetic is not reversible.”
  - Start with Peano arithmetic: beautiful but slow.
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  - Then show (arithmetic) constraint domains: beautiful and efficient!

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- “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.
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• “Prolog has no applications / interest / nobody uses it.”
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  ► Show some good examples of applications (cf. Prolog Year).

• “The Fifth Generation failed!” Not true...
  and it did not use Prolog or “real LP” anyway!
  They used in fact “something like Erlang”
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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.”
  ► Do use types (and properties in general): define them as predicates, show them used to check if something is in the type (dynamic checking), or “run backwards” to generate the “inhabitants”; property-based testing for free!
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  - Classical installation.  
    Most appropriate for more advanced students / “real” use.  
    Show serious, competitive language.
  - Playgrounds and notebooks (e.g., SWISH, Ciao Playgrounds/active manuals, \(\tau\)-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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    - 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),
  - ISO-Prolog,
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- **System types:**
  - Classical installation.  
    Most appropriate for more advanced students / “real” use.  
    Show serious, competitive language.
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- The classical characteristics of Prolog are still unique and demanded.
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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!):

```prolog
:- 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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    append(SmS, [First|LgS], Result).

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).

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

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

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

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

Example: qsort

We add some more assertions... :

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

qsort([], []).
qsort([First|Rest], Result) :-
    partition(Rest, First, Sm, Lg),
    qsort(Sm, SmS),
    qsort(Lg, LgS),
    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,
    partition(Y, F, Y1, Y2).
partition([X|Y], F, Y1, [X|Y2]) :-
    X > F,
    partition(Y, F, Y1, Y2).

:- 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

...and they get verified by Ciao:

```prolog
% qsort is a predicate
:- pred qsort(+list(num), -list(num)) + is_det.

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

% partition is a predicate
:- 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]) :- 
    X > F, 
    partition(Y, F, Y1, Y2).

% append is a predicate
:- pred append(+list(num), +list(num), -list(num)) + is_det.

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

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Example: qsort

...and they get verified by Ciao:

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

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

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

查验断言:
:- check comp partition(A,B,C,D)  
    : ( list(num,A), num(B) )  
    + ( is_det, not_fails ).

查验断言:
:- 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 \(\text{partition}/3\) can fail (cannot prove not_fails):

```prolog
:- pred qsort(+list(num),-list(num)) + is_det.
qsort([], []). qsort([First|Rest],Result) :-
  partition(Rest,First,Sm,Lg),
  qsort(Sm,SmS),
  qsort(Lg,LgS),
  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,
  partition(Y,F,Y1,Y2).
partition([X|Y],F,Y1,[X|Y2]) :-
  X > F,
  partition(Y,F,Y1,Y2).

:- 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 \( \geq /2 \) with \( > /2 \) Ciao warns that partition/3 is not deterministic (cannot prove is_det):

```prolog
:- pred qsort(+list(num),-list(num)) + is_det.
qsort([], []).
qsort([First|Rest],Result) :-
    partition(Rest,First,Sm,Lg),
    qsort(Sm,SmS),
    qsort(Lg,LgS),
    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,
    partition(Y,F,Y1,Y2).
partition([X|Y],F,Y1,[X|Y2]) :-
    X =\( \geq \) F,
    partition(Y,F,Y1,Y2).

:- pred append(+list(num),+list(num),-list(num)) + is_det.
append([],Xs,Xs).
append([X|Xs],Ys,[X|Zs]) :-
    append(Xs,Ys,Zs).
```

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Example: nrev (using the functional syntax package)

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

```prolog
:- 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) ].
```
Ciao reminds us that \texttt{nrev/2} is of course quadratic, not linear:

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

:- pred nrev(A,B) : {list, ground} * var => list(B).

exual 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).  

exual assertion:
:- check calls nrev(A,B)
  : ( list(A), ground(A), var(B) ).

exual 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:

```prolog
:- 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) ].
```
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:

```prolog
:- 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: \texttt{nrev}

If we change the assertion for \texttt{conc/3} from complexity order (\texttt{o}) to upper bound (\texttt{ub}) then Ciao flags that \texttt{length(A)} is not a correct upper bound:

\begin{verbatim}
:- module(nrev,[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),steps_ub(length(A)+1)

> Verified assertion:
> :- check calls conc(A,B,C).
\end{verbatim}
Example: nrev

With the cost expression fixed all properties are now verified:

```prolog
:- 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:

```prolog
:- module(nrev,[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] ).
```

```prolog
:- 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) ).
```

Manuel Hermenegildo – Some Reflections on Prolog’s Evolution, Status, and Future on its 50th Anniversary (ICLP’22/FLoC’22, Aug. 4, 2022)