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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  **Deadline:** September 2

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

● Actually... continued interest:
  ► TIOBE index of programming languages shows Prolog:
    ● Stable, even somewhat upward trend since 2012.
    ● In upper 10% of all languages tracked (270).
    ● One of only 13 languages that are tracked 'long term'.
     Ahead of Lisp, Scala, Haskell, Scheme, ML, Erlang, OCaml, Typescript, Racket, ...
  ► Many active implementations, and more appearing continuously.
  ► A truly impressive body of research and scientific firsts.
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Early steps, major milestones
Ancestors and birth

• Not possible to do full justice in this talk!

• Anyway, some highlights:
  ► McCarthy (1962): the AI language LISP → “very high-level languages.”
  ► Robinson (1965): resolution inference rule.
  ► Green (1969): extend resolution to answer questions in FO-logic (QA3).
  ► Boyer and Moore (1972): structure sharing.
  → Marseilles - Edinburgh collaboration (Colmerauer/Kowalski and teams).
  → Prolog! (1972–1973)
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  → performance (≈ lisp),
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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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- 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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- 1975: CDL Prolog
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- 1982: Prolog II
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- 1983: Constraints (Prolog II, CLP scheme/CLP(\(\mathcal{R}\)))
- 1985: Quintus
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1986 CLP(\(\mathcal{R}\))
1986 SWI Prolog
1987 SB Prolog
1987
1988 CHIP
1988
1992 BinProlog
1992 wamcc
1992 Ciao
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1993 ISO Prolog
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1993 GNU
1994 B-Prolog
1994 XSB
1995

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- 1995: B-Prolog
- 1995: GNU
- 1997: ECL\textsuperscript{i}PS\textsuperscript{e}

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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DEC-10
Prolog
1973
Prolog I
1975
CDL
Prolog
1975
DEC-10
Prolog
1982
C-Prolog, MU-Prolog
1982
YAP
1983
WAM
1985
Quintus
1985
YAP
1986
- SICStus
1986
- Prolog (Ciao)
1986
CLP(R)
1986
SWI
Prolog
1987
SB Prolog
1987
SB Prolog
1988
CHIP
1988
CHIP
1989
Ciao
1990
wamcc
1992
BinProlog
1992
wamcc
1993
ISO Prolog
1993
Ciao
1994
XSB
1994
B-Prolog
1995
GNU
1995
ISO Prolog
1995
ISO Prolog

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, ...

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

WAM alternatives

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

Again, more missing!: ECLiPS, IBM, LIFE, Andorra-I, Scryer, Tau, ...
Prolog system heritage

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Again, more missing!: ECL\textsuperscript{i}, PS\textsuperscript{e}, IBM, LIFE, Andorra-I, Scryer, Tau, ...
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Manuel Hermenegildo – Some Reflections on Prolog’s Evolution, Status, and Future on its 50th Anniversary (ICLP’22/FLoC’22, Aug. 4, 2022) 11
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<td>trace</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GNU Prolog</td>
<td>trace</td>
<td>✔</td>
<td></td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JIProlog</td>
<td>trace</td>
<td></td>
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<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>
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<td></td>
<td></td>
</tr>
<tr>
<td>XSB</td>
<td>trace</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>YAP</td>
<td>trace</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Many other features!

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

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  - Multi-threading.
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  - ...

However,

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  - Can mostly be bridged (c.f., Paolo Moura’s work), but a real nuisance.
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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, 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.
- ...
Further analysis of current status and outlook
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- Safety (garbage collection, no NullPointerException exceptions, ...).
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- Comparatively small user base.
- Fragmented community with limited interactions.
- Active developer community with constant new implementations, features.
- Further fragmentation of Prolog implementations.
- New programming languages.
- Post-desktop world of JavaScript web-applications.
- The perception that it is an “old” language.
- Wrong image due to “shallow” teaching of the language.

- Many weaknesses already addressed by different systems. → continue cooperative/competitive evolution (vs. going for single system).
- But, good forum needed for discussion.
- Also, bring together community across systems.
- Again, improved teaching.
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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, ...
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  - ..., arg(N,T,A), ...
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→ 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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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:
     ● As much as possible at compile-time;
     ● else, run-time tests generated.
   ▶ Achieve high performance:
     ● Eliminate run-time checks at compile time.
     ● Unboxing, specialization, slicing, automatic parallelization, ...

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

   • Provides the flexibility of dynamic languages, but with
   • guaranteed safety, reliability, and efficiency.

   • Quite popular nowadays: gradual typing, Racket, liquid Haskell, etc.
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The Ciao Integrated Approach to Specification, Debugging, Verification, Testing, and Optimization
### Discussion: Comparison with Classical Types

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Demo! (See slides at the end.)
Teaching (and preaching) Prolog
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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 has to be done right!
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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!
▶ 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).
▶ Discuss advantages and disadvantages of search rules (time, memory). Motivate the choices made for Prolog benchmarking actual executions.
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Characterization of the search tree
Depth-First Search

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

- System types:
  - 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:
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Final thoughts

- The classical characteristics of Prolog are still unique and demanded.
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Regarding system coordination: despite the intense evolution, differences between systems are not fundamental. To progress:

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

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

» At literal 1 could not verify assertion:
   partition(Y,F,Y1,Y2).
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) :-  
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append([], Xs, Xs).
append([X|Xs], Ys, [X|Zs]) :-  
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```
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
:- pred qsort(+list(num),-list(num)) + is_det.

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

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

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

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

```prolog
:- 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 \(=\langle/2\) with \(<\langle/2\) Ciao warns that \(\text{partition}/3\) can fail (cannot prove \(\text{not\_fails}\)):

```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,\text{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).
```

Manuel Hermenegildo – Some Reflections on Prolog’s Evolution, Status, and Future on its 50th Anniversary (ICLP’22/FLoC’22, Aug. 4, 2022) 48
Example: qsort

If we replace \(\geq/2\) with \(>/2\) Ciao warns that \(\text{partition}/3\) is not deterministic (cannot prove \text{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 =\(\leq\) 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 `nrev/2` is of course quadratic, not linear:

```prolog
:- 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_ub(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:

```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) ]
```
Example: 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/2], [assertions,fsyntax,nativeprops]).

:- pred nrev(A,B) : {list, ground} * var \arrow list(B)
    + ( not_fails, is_det, steps_o( \texttt{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) ].
\end{verbatim}
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:

```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)) ).
   > 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).
```
Example: nrev

With the cost expression fixed all properties are now verified:

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

:- pred nrev(A,B) : 
  (list(A), 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/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) ).
```