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

Manuel Hermenegildo\textsuperscript{1,2}
ICLP’22 (FLoC’22), August 4, 2022

\textsuperscript{1}T. U. of Madrid (UPM)
\textsuperscript{2}IMDEA 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!

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prologyear.logicprogramming.org
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• 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
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).
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Early Prologs and main milestones (∼ up to ISO)

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1973
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( FGCS → MCC → ECRC → ESPRIT → EU research programs, and others. )
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- 1973: Prolog I
- 1975: DEC-10 Prolog
- 1975: CDL Prolog
- 1982: C-Prolog, MU-Prolog
- 1983: WAM
- 1985: Quintus
- 1986: SICStus

- WAM optimizations (Quintus, SICStus, BIM, YAP, ...), GC, ...
→ 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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Early Prologs and main milestones (≈ up to ISO)

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- 1973 Prolog I
- 1975 DEC-10 Prolog
- 1975 CDL Prolog
- 1982 Prolog II
- 1982 C-Prolog, MU-Prolog
- 1983 WAM
- 1985 Quintus
- 1986 - SICStus &-Prolog (Ciao)
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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, Lassæz/Jaffar/Maher, DHD Warren, Tamaki/Sato, DS Warren, ...
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- 1975 CDL Prolog
- 1982 C-Prolog, MU-Prolog
- 1983 WAM
- 1985 Quintus
- 1985 YAP
- 1986 SICStus
- 1986 Prolog II
- 1986 CLP(∀)
- 1986 SB Prolog
- 1986 WAM (Ciao)
- 1987 Prolog II
- 1988 CHIP
- 1988 SWI Prolog
- 1988 CP Prolog
- 1989 C-Prolog
- 1990 ISO Prolog
- 1992 wamcc
- 1992 BinProlog
- 1992 Ciao
- 1993 YAP
- 1993 SWI Prolog
- 1993 SB Prolog
- 1993 Ciao
- 1994 XSB
- 1994 B-Prolog
- 1994 SYT
- 1994 GNU
- 1995 ECLIPS

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

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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

B-Prolog

SB-Prolog

XSB
tabling

GNU
fd/indexicals

tuProlog
JVM, interoperability

BinProlog
binarization

SWI

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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, ...
## Support status for selected features - 1

<table>
<thead>
<tr>
<th>System</th>
<th>Open Src.</th>
<th>Modules</th>
<th>Non-Std. Data Types</th>
<th>Foreign Language Interfaces</th>
</tr>
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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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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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</tbody>
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Many other features!

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

Manuel Hermenegildo – Some Reflections on Prolog’s Evolution, Status, and Future on its 50th Anniversary (ICLP’22/FLoC’22, Aug. 4, 2022)
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).
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  - Program analysis (Abstr. Interp., Set-Based Anal., Datalog, energy, gas, ...).
  - Domain-specific languages.
  - Heterogeneous data integration.
  - Natural language processing.
  - Efficient inference (expert systems, theorem provers), symbolic AI, ...
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.
- Fast development, REPL (Read, Execute, Print, Loop), debugging, ...
- Commercial and open-source systems (some very substantive and mature!).
- Active developer community with constant new implementations, features, etc.
- Sophisticated tools: analyzers, partial evaluators, parallelizers, ...
- Many books, courses, and learning materials.
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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).
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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), ...
  
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→ Flexibility, compactness, rapid prototyping, scripting, ..., but

  ▶ Most errors only detected at run time.

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

- Compiler statically checks *types*.

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- 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...
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   - But voluntary: provided up front, gradually, or not at all.

2. Then, **advanced program analysis** (abstract interpretation) is used to:
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     - As much as possible at compile-time;
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The Ciao Integrated Approach to Specification, Debugging, Verification, Testing, and Optimization

The diagram illustrates the workflow of Ciao's approach, starting with the program P and proceeding through various stages of analysis and verification. The steps include:

1. **Static Analysis**
2. **Analysis Info**
3. **Comparator (Incl. VCgen)**
4. **RT Check**
5. **Unit Test**
6. **Possible run-time error**
7. **Verification warning**
8. **Compile-time error**
9. **Verified**
10. **Certificate (ACC)**
11. **(Optimized) code**

The workflow integrates different aspects such as trust, test, and execution, ensuring a comprehensive approach to program verification and optimization.
**Discussion: Comparison with Classical Types**

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  - Suitable assertion language
  - Powerful abstract domains
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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,
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  (and maybe also in other majors and maybe in schools –cf. Prolog Year?)

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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).
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Characterization of the search tree
Depth-First Search
Breadth-First Search

infinite failure

solution

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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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• “Prolog is a strange language.”
  ➤ Show that Prolog subsumes functional and imperative programming (after SSA). It is simply that and more.
  (This idea useful for analysis of other languages!)
  ➤ Show that it is completely normal if used in one direction and there is only one definition per procedure.
  ➤ But it can also have several definitions, search, run backwards, etc.
  ➤ In addition to a stack of forward continuations, as every language, to know where go when a procedure returns (succeeds), it also has a stack of backwards continuations to go if there is a failure (previous choice point).

• “Prolog has no applications / interest / nobody uses it.”
  ➤ The TIOBE index disagrees...
  ➤ 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” (probably, but in any case, some functional would have done...).
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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.
    - 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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    Show serious, competitive language.
  ► Playgrounds and notebooks
    (e.g., SWISH, Ciao Playgrounds/active manuals, \(\tau\)-Prolog).
    • Server-based.
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    Can be attractive for beginners, young students.
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    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

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    Most appropriate for more advanced students / “real” use.
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Final thoughts

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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!):
Example: qsort

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

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

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

partition([], _, [], []).  % Partition into greater and lesser
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).
```

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Example: qsort

Adding useful entry information Ciao can infer that $\leq/2$ 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), _).

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).
```

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

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

define qsort([], []).  
define 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).

> 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.

define append([],Xs,Xs).  
define append([X|Xs],Ys,[X|Zs]) :-  
    append(Xs,Ys,Zs).
Example: qsort

If we replace \(<\leq/2\) with \(<\leq/2\) 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,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).
```

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Example: qsort

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

\[\text{):- pred } \text{qsort}(+\text{list(num)},-\text{list(num)} \}) \ + \ \text{is \_det}.\]

\begin{verbatim}
qsort([], []).
qsort([First|Rest], Result) :-
    partition(Rest, First, Sm, Lg),
    qsort(Sm, SmS),
    qsort(Lg, LgS),
    append(SmS, [First|LgS], Result).
\end{verbatim}

\[\text{):- pred } \text{partition}(+\text{list(num)},+\text{num},-\text{list(num)},-\text{list(num)} \}) \ + \ (\text{is \_det, not \_fails}).\]

\begin{verbatim}
partition([],_,[],[],[]).
p
artition([X\ Y], F, [X\ Y1], Y2) :-
    X <= F,
    partition(Y, F, Y1, Y2).
p
artition([X\ Y], F, Y1, [X\ Y2]) :-
  X \geq F,
  partition(Y, F, Y1, Y2).
\end{verbatim}

\[\text{):- pred } \text{append}(+\text{list(num)},+\text{list(num)},-\text{list(num)} \}) \ + \ \text{is \_det}.\]

\begin{verbatim}
append([], Xs, Xs).
append([X|Xs], Ys, [X|Zs]) :-
    append(Xs, Ys, Zs).
\end{verbatim}
Example: \texttt{nrev} (using the functional syntax package)

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

\begin{verbatim}
 module(_, [nrev/2], [assertions.fsyntax.nativeprops]).

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

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

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

 pred conc(A, B, C) :- {terminates, is_det, steps_o(length(A))}.
\end{verbatim}
Example: nrev

Ciao reminds us that \texttt{\textcolor{red}{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:
  \[\text{generic\_comp covered, is\_det, mut\_exclusive, not\_fails, steps\_lb(0.5*exp(length(A) }\]
  \[2+1.5*length(A)+1), steps\_ub(0.5*exp(length(A), 2)+1.5*length(A)+1)\]

- 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: \texttt{nrev}

With the cost expression fixed all properties are now verified:

\begin{verbatim}
:- 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]) := \negconc(~nrev(L),[H]).

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

conc([],L) := L.
conc([H|L],K) := [H | \negconc(L,K)].
\end{verbatim}
If we change the assertion for \texttt{conc/3} from complexity order \((\_o)\) to upper bound \((\_ub)\) then Ciao flags that \texttt{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: 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:

```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] ).

:- 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,mot_exclusive,not_fails,steps_lb(length(A)+1),steps_ub(length(A)+1)

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

With the cost expression fixed all properties are now verified:

\begin{verbatim}
:- module(_, [\texttt{nrev/2}, \texttt{assertions,fsyntax,nativeprops}]).

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

nrev( [] ) := [].
nrev( [H|L] ) := \texttt{\textasciitilde conc( \texttt{\textasciitilde nrev(L)},[H] )}.

:- pred conc(A,B,C) + ( terminates, is det, steps ub(length(A)+1) )).

conc( [], L ) := L.
conc( [H|L], K ) := [ H | \texttt{\textasciitilde conc(L,K) }].
\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) ).

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