30 Years of AI (1977-2007):

Development of Safe and Efficient Programs using Abstract Interpretation

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~~30~~ 22 Years of AI (~~1977~~ 1985-2007):

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The Original Challenge / Early Steps: Parallelization

- The original problem: program parallelization (circa 1985 in US: UT Austin, MCC):
  - Detecting dependencies (pointer "sharing") among proc. calls, statements, etc.
  - Traditional approach (ad-hoc dataflow analysis [Chang, Despain, Degroot '85]) often incorrect — we wanted something *rigorous and more powerful*.
- Initial inspiration – [CC'77]? Nah... can't claim we understood CC'77 then. :-)
  - Actually, [Mycroft'80] "Abstract Interpretation and Optimizing Transformations for Applicative Programs" (but very FP oriented!)
  - [Mellish ICLP'86]: pointed the way (but not dealing w/ variable/pointer aliasing).
- Our first "obsession:" correctness/practicality –does AI really work?
  Built system [Warren, Debray, Herme. "MA3 system" ICSLP'88]:
  - Correct management of (variable/pointer) "aliasing" (correctness).
  - Top-down ("context sensitive").
  - Use of memo-tables (efficiency).
  - "Abstract compilation."
  - Actual implementation w/perf. results, connected to parallelizer –a first?

The Fixpoint Algorithm and the PLAI Generic Framework

- Bruynooghe's framework [87-91]: multivariance + genericity of framework –parametric on the domains– (but no tabling or efficient fixpoint).
- The fixpoint algorithm and PLAI analyzer: efficient, context sensitive, multivariant, parametric analysis! [Muthukumar, Herme. NACLP'89]
  - Tabling, multiple call–success pairs (efficient multivariance).
  - Dependency tracking to avoid recomputation —faster convergence.
  - Interprocedural, dealing with mutual recursion, etc. (project/extend).
- Many useful extensions (1990 on, Spain, mostly at UPM; also UNM):
  - Incremental framework [Herme, Puebla, Marriott, Stuckey ICLP'95, SAS'96, TOPLAS'00].
  - Extension to CLP [G. de la Banda, Herme., Bruynooghe, et al. ILPS'93, TOPLAS'96]
  - Extension to analysis of concurrent programs (dynamic scheduling) [G. de la Banda, Marriott, Herme., Stuckey POPL'94, ILPS'95, SAS'96],
  - Extension to Java/Java bytecode [Méndez-Lojo, Navas, Herme. BYTECODE'07, FTfJP 2007]. Intermediate representations [LOPSTR'07].

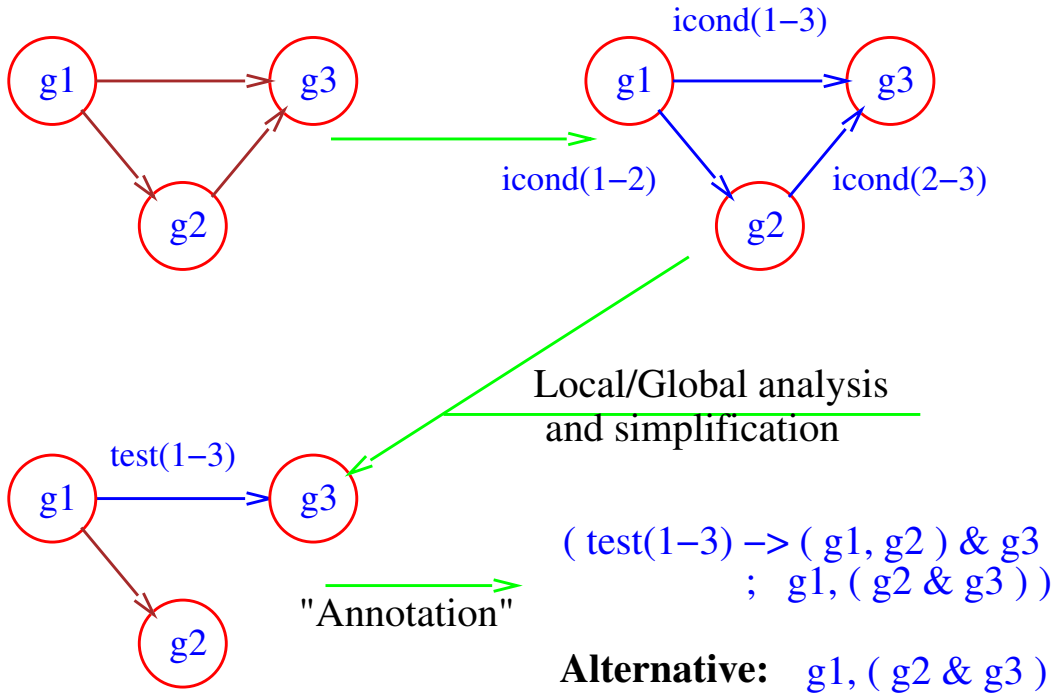
Some Achievements in Parallelization

- Fully automatic parallelizers for logic programs
  – arguably the most powerful parallelizers for "irregular" applications.
  [Herme. and Warren, CAN'87, Bueno, G. de la Banda, and Herme. ICLP'94, TOPLAS'99]
  - Parallelization using non-strict independence [Cabeza and Herme. SAS'94]
  - Parallelization of constraint programs [G. de la Banda and Herme. PLILP'96]
- Perhaps the first fully implemented, practical application of AI?
- Prompted considerable domain development:
  - Set sharing. [Jacobs-Langen NACLP 89, Muthukumar and Herme. NACLP'89 (abstr. unif.)]
  - Set sharing and freeness. [Muthukumar and Herme. ICLP'91]
  - Def (propositional horn clauses) [G. de la Banda and Herme. WSA'92]
  - Combinations with depth-k, shape analysis (regular types), etc.
  - Set sharing for Java [Méndez-Lojo, Herme. VMCAI'08]
- Prolog (Ciao, (C)LP) very useful languages: allow dealing with the most complex problems (pointers, irregular computations, irregular data, dynamic heap, dynamic dispatch, complex control flow, etc.) but in a much better structured context.

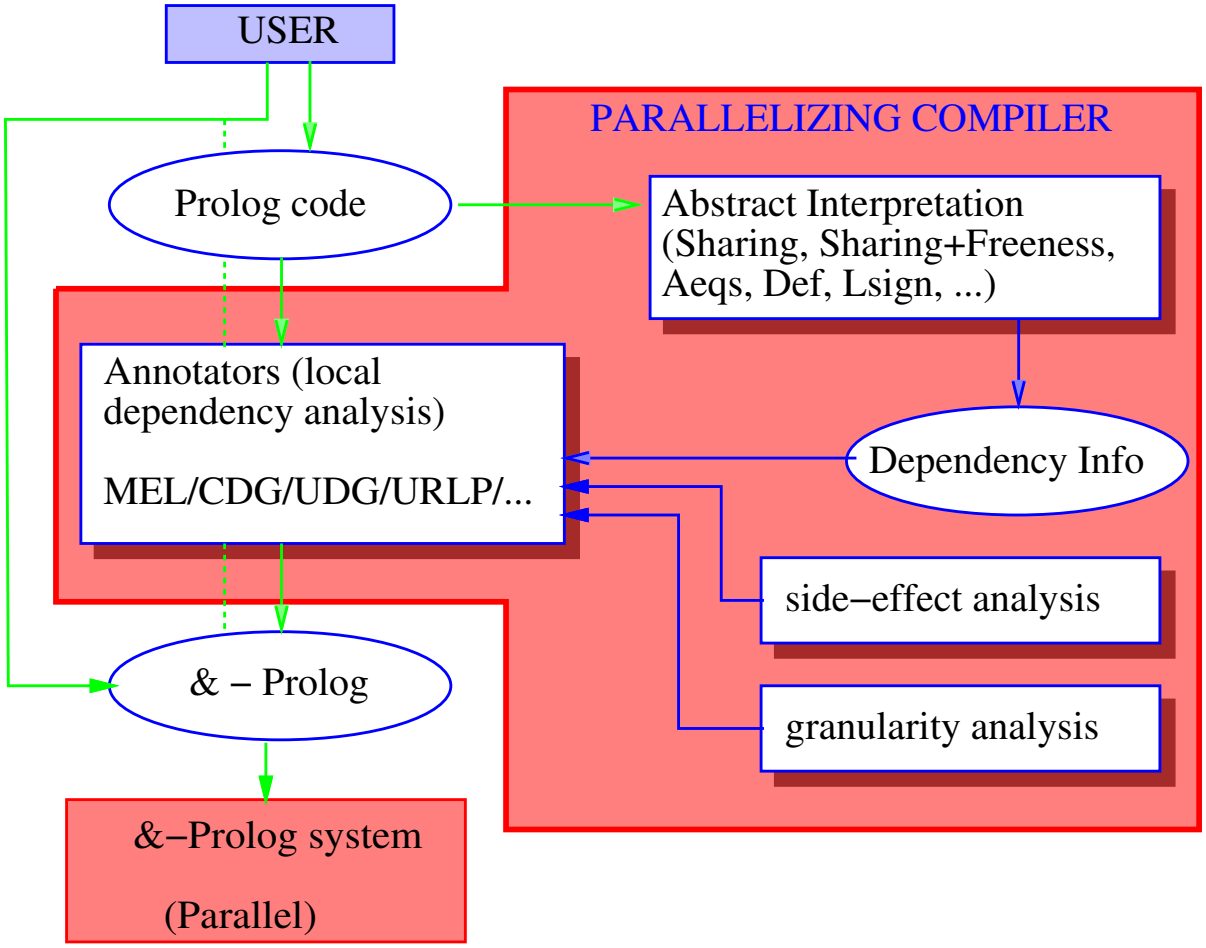
Parallelization Process

- Conditional dependency graph (of some segment, e.g., a clause):
  - vertices are possible tasks (statements, calls,...),
  - edges=possible dependency (labels=conditions needed for independence).
- Local or global analysis used to reduce/remove checks in the edges.

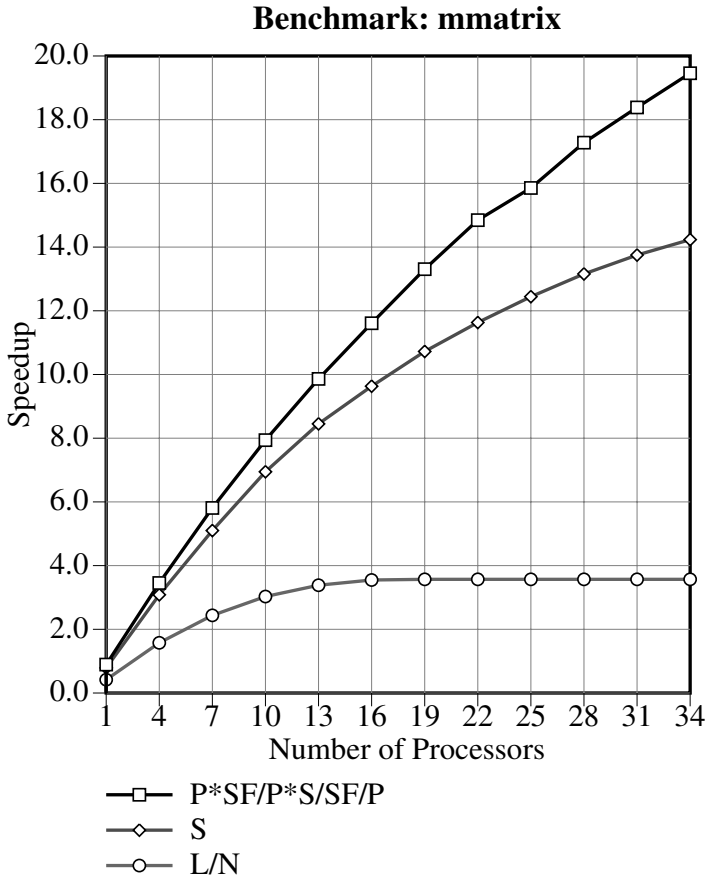
```
foo(...)  :-
     g1(...),
     g2(...),
     g3(...).
```

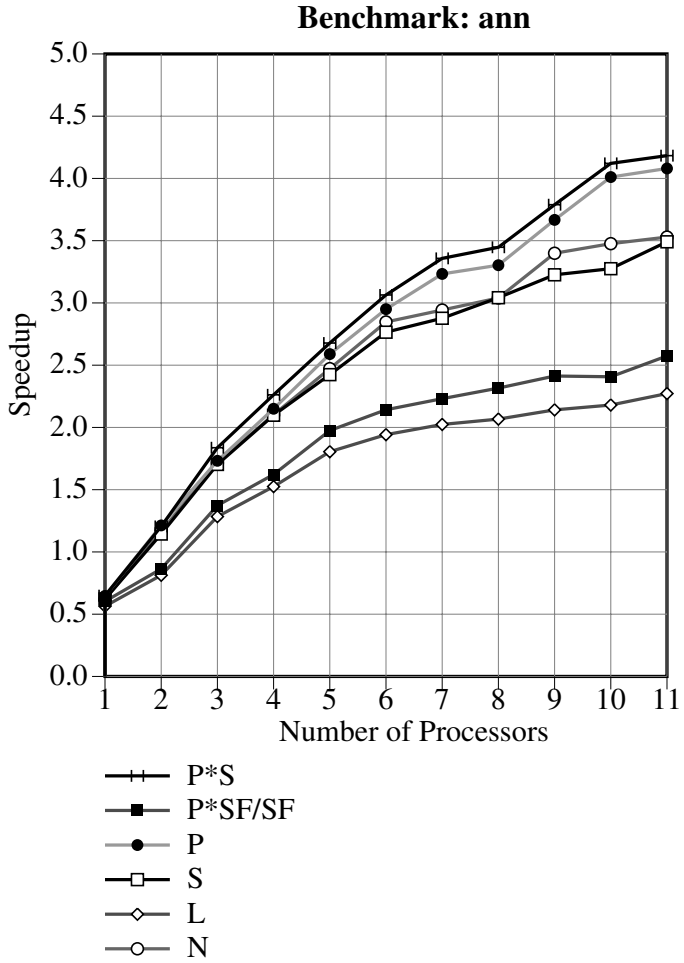


&-Prolog (and, later, CIAO) Parallelizer Overview –circa 1988



Some Speedups (Using Different Abstract Domains)



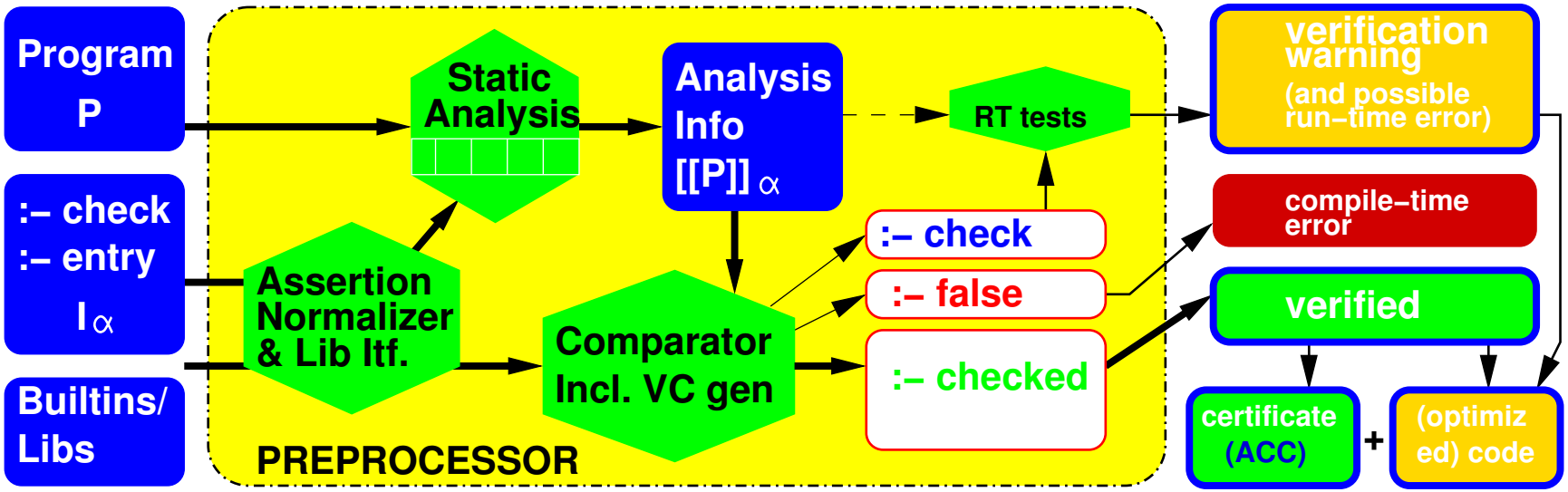


(ann is the parallelizer parallelizing itself;
1-10 proc.: actual speedups on Sequent Symmetry; 10+ simulator projections from execution traces)

The Second Phase: Program Development using AI

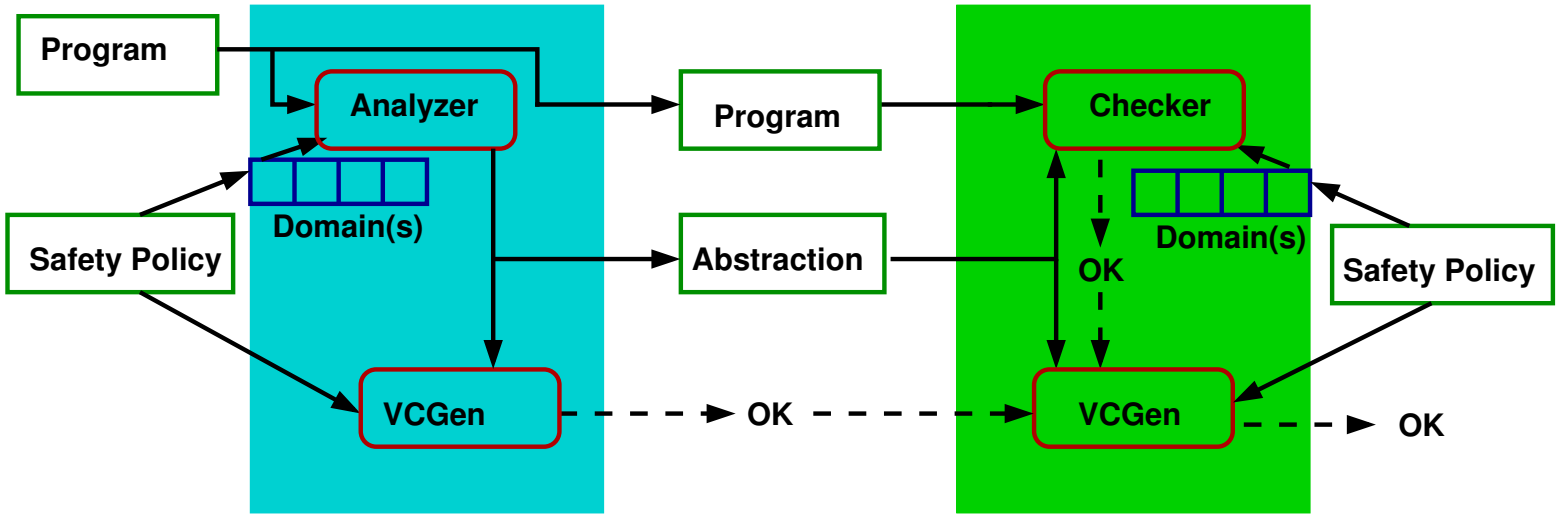
- The next stage:
  - not just optimization (parallelization, abstract partial evaluation, ...), but
  - **program development** fundamentally based on abstract interpretation.
- Ideas lurking for a long time, crystallized in first prototypes in 1994-97 [PPCP'94, Ciao system design], and:
  - Overall design [ILPS'97, AADEBUG'97, ICLP'99, LOPSTR'99, SAS'03, SCP'05]
  - Assertion language [LNCS 1870]
  - Modular extensions [Pietrzak, Correas, Puebla, Herme. LPAR'06]
  - Abstract diagnosis [Alpuente, Comini, Escobar, Falaschi, Lucas, LOPSTR'02] [Gallardo, Merino, Pimemtel, SAS'02] [Pietrzak, Herme. ICLP'07]
  - Extensions to Java [Albert, Gómez-Zamalloa, Hubert, Puebla PADL'07]
- Great influence of AI in **programming language design**:
  the "Ciao" language design is based on an *AI-based* compiler / env.
  (assertion based vs. strongly-typed, type systems as domains, etc.).
- Also, led us to the idea of Abstraction Carrying Code (ACC).

The CiaoPP Verification/Diagnosis Framework [AADEBUG'97]



- I_α (partial specification) provided via a language of *optional* assertions.
  - State properties at relevant points.
  - Talk about properties which can be predefined or user-defined.
    Types, cost, data sizes, termination, pointer aliasing, no-except, ...
- Implemented for Ciao and (less mature) for Java and Java bytecode.

The Abstraction Carrying Code (ACC) Scheme



$[\![P]\!]_\alpha = \text{Analysis} = \text{lfp}(analysis\_step)$ | Certificate $\subset [\![P]\!]_\alpha$ | Checker $= analysis\_step$

- Basic proposal [Albert, Puebla, Herme. COCV'04, LPAR'04, ICLP'04, PPDP'05, NGC'08]
- Incremental version [Albert, Arenas, Puebla LPAR'06]
- Certificate reduction (fixpoint compression) [Albert, Arenas, Puebla, Herme. ICLP'06]
- MOBIUS project [TGC'06].
- Incorporated in `CiaoPP` for types, modes, shapes, sizes, cost, det, termination, non-failure, resources, etc.

Combination with Partial Evaluation; Optimization; Scalability

- Combination with Partial Evaluation:
  - Abstract executability. Multiple abstract specialization [Puebla, Herme. PEPM'95]; application in parallelization [LOPSTR'97, JLP'99]
  - Full integration of Partial Evaluation and AI [Puebla, Albert, Herme. SAS'06]

  $\longrightarrow$ important contribution to the AI-based program development model.
- Application to program optimization (other than parallelization): abstract machines and native compilation [Morales, Carro, Herme. PADL'04, ICLP'05, LOPSTR'06]; embedded systems [Carro, Morales, Muller, Puebla, Herme. CASES'06].
- Modularity, Scalability, Practicality Issues:
  - Efficient, incremental intermodular analysis / fixpoint calculation [Bueno, G. de la Banda, Herme., Marriott, Puebla, Stuckey, Correas LOPSTR'01, LOPSTR'04, LOPSTR'05].
  - Widening of set-sharing [Navas, Bueno, Herme. PADL'06]
  - Dealing with the full ISO-Prolog standard [Bueno, Cabeza, Herme., Puebla ESOP'96]
- Domain combinations, goal-dependent vs. goal indep. analysis (flow sensitivity) [Codish, Mulkers, Bruy., G. de la Banda, Herme. PEPM'93, LPAR'94, TOPLAS'95, JLP'97]

Inference Resource-related and other Complex Properties

- Cost, resources (motivated by granularity control –lots of AI!):
  - Upper bounds (execution steps); application to granularity control [Debray, Lin, Herme., PLDI'90].
  - Lower bounds (execution steps) [w/López-García, ILPS'97, SAS'94].
  - Extension to Java bytecode [Albert, Arenas, Genaim, Puebla, Zanardini ESOP'07].
  - Execution times [Mera, López-García, Puebla, Carro, Herme., PADL'07].
  - User-definable resources for LP [Navas, Mera, López-García, Herme., ICLP'07].
  - Heap space analysis (Java bytecode) [Albert, Genaim, Gómez-Zamalloa, ISMM '07].
- Non-failure / no exceptions [Bueno, Debray, López-García, Herme. ICLP'97]; multivariant version [FLOPS'04].
- Determinacy analysis [Bueno, López-García, Herme. LOPSTR'04].
- Heap / shape analysis (C++/Java) [Marron, Herme., Kapur, Stefanovic LCPC'06, PASTE'07, CC'08]; Type domains, type widenings [Vaucheret, Bueno SAS'02].
- Termination analysis (Java) [Albert, Arenas, Codish, Genaim, Puebla, Zanardini WST'07].

Some Other Notable Facts

- Numerous PhD. theses:
  - 7 finished (C. Ochoa, D. Cabeza. P. López, G. Puebla, F. Bueno, M. G. de la Banda, K. Muthukumar). and 6 more to be finished in 2008/2009 (J. Correas, E. Mera, J.F. Morales, J. Navas, M. Méndez, A. Casas).

  + Many MS theses.
- Invited talks/keynotes, and tutorials:
  - On Abstract Interpretation: ICLP'92, WSA'92.
  - On Parallelism: EUROPAR'97, EUROPAR'04, DAMP'06, DAMP'07.
  - On Verification/Debugging using AI: AADEBUG'97, ILPS'97, ICLP'99, CL'00, ICALP'02, SAS'03, ACM SAC'06.
  - On Cost and Resource Analysis: SAS'94, PPDP'05.
  - On Abstraction Carrying Code: MoveLog'05, EAAI'06, TGC'06.
  - On the Combination w/Partial Evaluation: PEPM'03.
- Summer schools: LP'90, ESLLI'96, NMSU'99, ...
- Many national and EU projects (but no EU network!), even several babies...

Final Thoughts / The Next 30/22 Years!

- Go mainstream, make it an everyday tool! –coll. w/Industry (e.g., ES_PASS).
- Further work on scalability, modularity, domains, widenings, ...
- A big push to parallelization.
- Improve diagnosis.
- Emphasis on resource-related properties; specially *user-defined* (much current work on this).
- Develop ACC further, apply in practice to, e.g., small devices (MOBIUS).
- Develop new, even more dynamic high-level languages, getting correctness and real speed (without cheating), thanks to AI.
- Come work at the IMDEA-Software Development Technology Institute in Madrid!

But mainly, thanks Radhia and Patrick for opening such a wonderful space for us to do research –we look forward to the next 30 together!