Computational Logic
Distributed/Internet Programming
Can Logic and Constraint Logic Programming be an attractive alternative for Internet/WWW programming?

Shared with other net programming tools:
- dynamic memory management,
- well-behaved structure (and pointer!) manipulation,
- robustness, compilation to architecture-independent bytecode, ...

In addition:
- powerful symbolic processing capabilities,
- dynamic databases,
- search facilities,
- grammars,
- sophisticated meta-programming / higher order,
- easy code (agent) motion,
- well understood semantics, ...
LP/CLP, the Internet, and the WWW

- Most public-domain and commercial LP/CLP systems:
  - either already have Internet connection capabilities (e.g., socket interfaces),
  - or it is relatively easy to add it to them (e.g., through the C interface)
  (e.g., Quintus, LPA, PDC, Amzi!, IF-Prolog, Eclipse, SICStus, BinProlog, SWI, PrologIV, CHIP, Ciao, etc.)

- Some additional “glue” needed to make things really convenient:
  - We present several techniques for “filling in these gaps”
    (many implemented as public domain libraries).

- In doing this we also work towards answering the question:
  - Is there anything fundamental missing in current LP/CLP systems?

- Commercial systems add packages that provide higher-level functionality.
- Additional motivation: the WWW can be an excellent showcase for LP/CLP applications!
Outline

• (PART I: WWW programming)

• PART II: Distributed/agent programming
  ◦ (Modeling and accessing information servers –active modules).
  ◦ A simple distributed LP/CLP language using “worker teams”.
  ◦ Communicating via Blackboards.
  ◦ Implementing distributed variable-based communication using attributed variables.

• Different concurrent/distributed execution scenarios:
  ◦ Request/provide remote services in a distributed network
    (including database servers, WWW servers, etc.)
  ◦ (Distributed) networks of concurrent, communicating agents
  ◦ Coarse-grained Parallelism (granularity control required)

• Most functionality can be obtained using current LP/CLP systems!
  (again, concurrency in the underlying engine is very useful)
Distributed Teams of Workers (Ciao)

- Team: set of workers (threads) that share the same code and cooperate to run it.
- Concurrency and/or parallelism occurs between workers.
- Worker management:
  - add_worker: Add (possibly remote) worker to the team. Intuition:
    * The system starts with one worker.
    * If a worker is added at a remote site, it makes it possible to run goals at that site (similar to opening a file).
    * If more than one worker is added (locally or at a given remote site) it is often either to achieve parallelism (in multiprocessor machines) or fairness (giving “gas” to different goals).
  - delete_worker: Delete (possibly remote) worker from the team
- The workers are kept coherent from the point of view of code management, global state, etc.
Some Concurrency & Parallelism Operators (Ciao)

- Objective: express concurrency, independent and-parallelism, dependent and-parallelism, etc. (and support a notion of fairness), within a team of workers.

- Basic operators (in addition to sequential conjunction, etc.):
  - $A \&$ – Schedules goal $A$ for execution (when a worker is free).
  - $A \&\&$ – “Fair” version of the $\&/1$ operator: if there is no idle worker, it creates one to execute $A$ (new thread).
  - $A \,@ \, Id$ – Placement operator: goal $A$ is to be executed on worker $Id$ (which may be remote). Can be combined with the other operators.
  - $A \&> \, H$ – Schedules goal $A$, returns in $H$ a handler.
  - $H \,<&$ – waits for end of execution of goal pointed to by $H$, back-unifies bindings.
  - $A \& B$ – Schedules $A$ and $B$, waits for the execution of both to finish.
  - Last one can be implemented using previous two:
    $$A \& B \,:=\, B \&> \, H, \, A, \, H \,<& \,.$$
  - Bindings in shared variables not guaranteed to be seen until threads join.
  - Full support for backtracking.
Using Basic Concurrency & Parallelism Operators

- move(red), move(green).
- move(red) &, move(green).
- add_worker(I), move(red) &, move(green).
- delete_workers, move(red) &&, move(green).
- delete_workers, add_worker(alba,I), move(green) @ I.
Using Parallelism: Examples

main :-
    read_input_list(L),
    collect_unloaded_hosts(Hosts),
    add_workers(Hosts, _Ids),
    process_list(L),
    halt.

process_list([]).
process_list([H|T]) :-
    process(H) &
    process_list(T).

add_workers([Host|Hosts],[Id|Ids]) :-
    add_worker(Host,Id),
    add_workers(Hosts,Ids).
add_workers([],[]).
Using Parallelism: Examples

- One of the Ciao libraries is a parallelizing preprocessor
- Uses source-to-source transformation
- Includes some automatic granularity control
- Possible alternative using granularity control:

```prolog
process_list([]).
process_list([H|T]) :-
    ( H < 5 ->
      process_list(T), process(H)
    ;   process(H) & process_list(T) ).
```
Implementation Issues

- Creating workers / threads:
  - In standard systems: standard process creation primitives (e.g., “fork”, “rsh”, etc.) can be used.
  - Better approach (for local threads): use engine capable of supporting multiple workers natively in an efficient way.
  - The machines developed for parallel systems provide exactly the required functionality (e.g., RAP-WAM, ACE-WAM, DASWAM, etc., and even Aurora, Muse, ...).
    Also starting to appear in other Prolog systems (e.g., BinProlog, SICStus).
  - Interesting issue: how to support several independent executions without creating too many “stack sets”.
    The “marker” models used in parallel systems address this issue.
  - Scheduling: classical goal stacks and goal stealing strategies still appear most suitable.
  - Distributed scheduling: through sockets (or blackboards)
Communication: Using Blackboards

- Blackboards (linda stile): basic but very useful means of communication and synchronization (higher level than using sockets directly)

- Present in many systems: SICStus, BinProlog/μ²-Prolog, &-Prolog/Ciao, ...

- Basic features:
  - `out/1`: write tuple
  - `rd/1`: read tuple
  - `in/1`: remove tuple
  - `rd_noblock/1` and `in_noblock/1`
  - `in/2` and `rd/2` (on disjunctions)

- Sometimes, several (possibly hierarchical) blackboards allowed – then, extra argument to primitives specifies which blackboard.
Producer–Consumer: Linda Version

*(using Ciao / SICStus BB primitives)*

?- create_bb(B,local), N=10,
   lproducer(N,B) @ alba &, lconsumer(B).

lproducer(N,B) :-
    lproducer(N,1,B).

% second argument is message order
lproducer(0,C,B) :- !,
    linda:out(message(end(C)),B).

lproducer(N,C,B) :-
    N>0,
    linda:out(message(C,N),B),
    N1 is N-1,
    C1 is C+1,
    lproducer(N1,C1,B).
Producer–Consumer: Linda Version

lconsumer(B) :-
    lconsumer(1,B).

lconsumer(C,B) :-
    linda:rd([message(end(C)),
             message(_,C)], T, B),
    lconsumer_data(T,B).

lconsumer_data(message(end(_)),B).

lconsumer_data(message(N,C),B) :-
    C1 is C+1,
    lconsumer(C1,B).
Implementation Issues

- Implementation approaches and techniques:
  - Blackboard can be a Prolog process. Tuples maintained via assert/retract. Communication, e.g., via sockets (allows Internet-wide use of the blackboard).
  - Support blackboard internally in system (possibly, in conjunction with asserted database).
  - Mixed approach: local vs. remote blackboards.
  - The blackboard can also be a completely special purpose program (e.g., BinProlog’s “Java blackboard”).
Other Forms of Communication: Shared Variables

- Variable sharing/communication:
  - `share(X)` – bindings on the variables of `X` (tells) will be exported to other workers in the team
  - `unshare(X)` – bindings on the variables of `X` (tells) will be local
  - `wait(X)` – Suspends the execution until `X` is bound (also, `d_wait(X)`)
  - `ask(C)` – Suspends the execution until the constraint `C` is satisfied

- Example:
  `share(X), (move(red), X=done) & , move(green), wait(X).`
A Simple Producer/Consumer Program (using Shared Vars)

```prolog
go(L) :-
    share(L),
    consumer(L) &,
    producer(3,L).

producer(0,T) :- !, T = [].
producer(N,T) :- N > 0, 
    T = [N|Ns],
    N1 is N-1,
    report(N,produced),
    producer(N1,Ns).

consumer(L) :-
    ask(L=[]), !.
consumer(L) :-
    ask(L=[H|T]),
    report(H,consumed),
    consumer(T).
```

Implementation Issues

- Shared variables can be implemented using attributed variables [Huitouze ’90, Neumerkel ’90] + blackboard:
  - variables involved in a parallel call are marked as a “communication” variable (i.e., shared)
  - done by attaching an attribute
  - communication variables are given unique identifiers
  - “shared” character is inherited during unification
  - standard tells done in place, tells to comm. variables posted on blackboard
  - asks do a blocking rd (read) on the blackboard

- All implementation done at source (Prolog) level (see our ICLP’95 paper)

- Blackboard-based systems and shared variable communication-based systems – “different camps:” they can be easily unified using this technique!
Other Issues

- Code and heap structure caching and coherence maintenance in distributed environments:
  - Very interesting work being done in the context of the OZ language, using techniques related to those used in multiprocessor cache coherence.
  - BinProlog and LogicWeb also support a form of code caching.
- Security: only a few proposals (e.g., BinProlog’s)
- Alternative means of communication: Ports ([AKL], related to sockets), direct use of sockets, ...
- Logical views of reactivity? Use of linear logic, or condition-action rules as proposed by Kowalski?
Other Conclusions/Issues

- Some concurrency and parallelism operators proposed.
- Several forms of communication: blackboards, active objects, shared variables, sockets, ports, ...
- Attributed variables can be used for implementing distributed shared variable communication.
- All implementation can be done at source (Prolog) level.
- Native support for concurrency in underlying system very useful (e.g., in the Ciao run-time system, the &-Prolog abstract machine is used; similarly in BinProlog).
- Security, caching...

- Ciao code provided as public domain Prolog libraries (http://www.clip.dia.fi.upm.es)
- Put your LP/CLP-agent applications on the WWW!
Appendix: The Ciao System and its Libraries

- Ciao is an LP/CLP system developed at UPM, in collaboration with several other industrial and academic centers.

- In the Ciao project:
  - We try to design useful extensions of LP and CLP for distributed execution, WWW programming, concurrency, higher-order, powerful debugging, ...
  - We try to keep as much as possible compatibility with ISO-Prolog.
  - We develop the extensions as much as possible in the form of libraries.
  - We build public domain versions of these libraries for standard LP/CLP systems.
  - We identify aspects that are difficult or inefficient and for which native engine support is needed.
  - We develop abstract machine modifications and advanced compilation and support technology.

- I.e., we try to answer the question of what really needs to be added to/changed in current systems.
PiLLoW and Other Ciao Libraries

- For concreteness we will often refer to PiLLoW and other Ciao system libraries.
- Ciao Libraries (freely available, and in different stages of development) include:
  - PiLLoW: WWW/HTML interface
  - prolog shell: Prolog shell scripts
  - Distribution: blackboards, concurrency, agents, ...
  - PLAI: Global analysis (including type checking/inferencing)
  - APC: Global optimization (source to source, including specialization and parallelization)
Examples of transformations/techniques used:

- Supporting CLP via attributed variables.
- Distributed execution on standard CLP/LP.
- Supporting CC on standard CLP/LP systems (with delay).
- Supporting the Andorra model in CLP/LP systems.
- Functions/higher order.

Analyses used / characteristics:

- Top-down framework with efficient dynamic fixpoint (PLAI).
- Modes, types, sharing (aliasing), independence, etc.
- Several domains over Herbrand: $SH$, $SH+FR$, $ASub$, $SH+ASub$, $SH+FR+ASub$, $Path$, $Types$, ...
- Over constraints: $Def$, $Fr$, $FD$, $LSign$, $DiffLSign$, ...
- Support for dynamic scheduling (concurrency).
- Support for incremental analysis.
- Support for full languages (e.g., ISO-prolog).
Cost analysis (upper and lower bounds).

- Examples of optimizations performed:
  - Compile-time elim. of run-time tests via (abstract) PE.
  - Multiple (abstract) specialization (e.g., loop invariants).
  - LP/CLP/CC parallelization.
  - Optim. of synchronization / sched. anal. (for delays and CC).
  - Goal and constraint reordering (optimization of search).
  - Granularity control.
Ciao and Other CC Systems

- Input from other LP/CC systems:
  - CC: entailment-based synchronization.
  - NU-Prolog/Par NU-Prolog: transformation to delay declaration for support of Ciao on conventional systems.
  - AKL: encapsulation.
  - OZ: modules, applications of records.
  - Shared with QE-Janus: “quiche eating” implementation approach.

- Main differences:
  - “Sequential by default” vs. “concurrent by default.”
  - Explicit concurrency (and parallelism) operators (“threads”).
  - Distributed implementation.
  - Extensive global analysis and optimization (e.g., automatic static parallelization, suspension reduction).
  - Designed to be portable to conventional LP/CLP systems.

- Other issues:
Active modules.
WWW interface.
Functions, HO, scripts, ...
Language Visions?

- On the future LP Language: can Ciao offer some interesting ideas?
  - Backwards compatible with LP/CLP (ISO standard).
  - Can use existing implementation technology.
  - Incorporates some language solutions:
    * Sequential operator.
    * Separation of parallelism and concurrency.
    * Explicit request for fairness.
    * Distribution primitives.
    * Active modules/objects.
    * Separation of control rules (e.g., Andorra) from parallelism and optimizations.
    * Integration of several in the same framework.
    * ...
  - Final thoughts – minor things matter, e.g., in Ciao:
    * tcl/tk interface.
    * Stand-alone executables, linkables, and scripts.
* Small executables.
* *html* interface.
* ...