Development of Concurrent Constraint Languages for multiparadigm programming

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This Talk

CCP LANGUAGES

• Basic CCP
• Deep CCP (AKL)
• Higher Order CCP (Oz)
• Integration of Search, Concurrent Objects and Higher Order

Many thanks to fiends from SICS and DFKI, specially Sverker Janson and Johan Montelius SICS and Gert Smolka and Christian Schulte DFKI
Concurrent Constraint Programming

• combines ideas from
  - concurrent logic programming
  - constraint logic programming
  - functional programming
  - concurrency theory

• aims at
  - concurrent symbolic programming
  - problem solving with constraints and search
  - combination of the above
  - parallel implementation
  - transparent distribution
CCP Important developments

Flat CCP

• FGHC ICOT (Ueda, Chikayama) 1985

• Michael J. Maher. Logic semantics for a class of committed-choice programs. 1987.

• Vijay A. Saraswat. Compositional Syntax, the notion of constraint store, ask and tell operations.

• Yang/Warren/Haridi. Introduction of nondeterminism and global search. The notion of determinism driven execution

Deep CCP

• Haridi/Janson. AKL (Agents Kernel Lang). Model for guard execution, integration of search and concurrency, the notion of stability, encapsulated search.

• AKL, ports (named streams), essential for integration of concurrent object oriented programming, and encapsulation of mutable state.
CCP Important developments 2

- Smolka et al, DFKI, Oz. Higher order CCP. Record datatypes, names: subsumes functional programming, modules as special case of usage of records and HO CCP.
- Oz, Cells as simplification of AKL/ports, concurrent object-oriented programming based on prototypes.
- Oz, controlled encapsulated search using the solve combinator. Search is programmable at the user level.

Future
AGENTS II, SICS/DFKI

Add: Distribution aspects (language for distributed applications)

- persistence, real-time, groups for concurrent exception handling, continuous operation and resource management.
- efficient implementation
Agents *tell* constraints to a shared constraint store and may *ask* if constraints are entailed by the store.
A flat language (cc flavour)

\[
E ::= \phi \quad \text{constraint}
| p(x) \quad \text{call}
| E_1 \quad E_2 \quad \text{composition}
| x \ \text{in} \ E \quad \text{hiding}
| \text{or} \ C_1 \mid \ldots \mid C_n \ \text{end} \quad \text{disjunction}
| \text{if} \ C_1 \mid \ldots \mid C_n \ \text{else} \ E \ \text{end} \quad \text{conditional}
\]

\[
C ::= x \ \text{in} \ \phi \rightarrow E \quad \text{clause}
\]

\[
D ::= \text{proc} \ p(x) \ E \ \text{end} \quad \text{definition}
\]

C entailed by \(\psi\) iff \(\psi\) implies \(\exists x \phi\)

C disentailed by \(\psi\) iff \(\psi\) implies \(\neg \exists x \phi\)
Reduction Rules Flat CCP

• $\phi \Rightarrow \text{tell } \phi \text{ and halt if store is unsatisfiable}

• $E_1 \land E_2 \Rightarrow E_1 \land E_2$

• $\exists x \in E \Rightarrow E[y/x]$  if $y$ are fresh new variables.

• $p(y) \Rightarrow E[y/x]$  if $\text{proc } p(x) \ E \ \text{end}$ is in program

proc {$p \ X}$ E end

• if $C_1 \mid \ldots \mid C_n \ \text{else} \ E \ \text{end} \Rightarrow \langle C_k \rangle$ if $C_k$ entailed

• if $C_1 \mid \ldots \mid C_n \ \text{else} \ E \ \text{end} \Rightarrow E$ if $C_1, \ldots, C_n$ disentailed

$\langle \exists x \in \phi \Rightarrow E \rangle \equiv \exists x \in (\phi \ E)$
Examples

This language is basically KL1 if the domain is trees:

```
proc append(xs, ys, zs)
  if  xs = [] → zs = ys
  |  x,xr,zr in xs = [x | xr] →
      zs = [x | zr]
      append(xr,ys,zr)
  end
end
```

or in functional notations

```
fun append(xs, ys)
  if  xs = [] → ys
  |  x,xr in xs = [x | xr] →
      [x | append(xr,ys)]
  end
end
```
Examples 2

```
proc merge(xs, ys, zs)
    if xs = [] → zs = ys
    l ys = [] → zs = xs
    l x,xr,zr in xs = [x | xr] →
        zs = [x | zr]
        merge(xr, ys, zr)
    l y,yr,zr in ys = [y | yr] →
        zs = [y | zr]
        merge(xs, yr, zr)
    end
end
```
Reduction of Disjunction

\[ \text{or } C_1 \mid \ldots \mid C_n \text{ end } \Rightarrow \langle C_k \rangle \text{ if } \]

all \( C_i \) different from \( C_k \) are disentailed

\[
\text{proc } \text{length}(xs, n) \\
\text{or } \hspace{1cm} x = [] \quad n = 0 \rightarrow \text{true} \\
\mid x, x_r, n_r \text{ in } \hspace{1cm} x = [x | x_r], n = S(n_r) \rightarrow \\
\text{length}(x_r, n_r) \\
\text{end} \\
\text{end}
\]

will be determinacy driven:

\[
\text{xs}=[x_1, x_2, x_3] \hspace{0.5cm} \text{length}(xs, n) \\
\text{produces } n = S(S(S(0)))
\]

\[
\text{length}(xs, n) \hspace{0.5cm} n = S(S(S(0))) \\
\text{produces } \text{xs}=[x_1, x_2, x_3]
\]
NONDETERMINISM

\[ \text{or } C_1 \mid \ldots \mid C_n \text{ end } , E \Rightarrow \]

\[ (\langle C_1 \rangle \land E) \lor \ldots \lor (\langle C_n \rangle \land E) \]

if no other reduction is possible

flat+det:

flat+nondet:
Deep CCP

- Local agents see local and external constraints.
- Scope of nondeterminism is local.
- Enables encapsulated search with reactive top-level.
- Supports negation and general conditions.
- The AGENTS implementation of AKL offers record constraints and FD constraints.

Flat vs deep

<table>
<thead>
<tr>
<th></th>
<th>&quot;det&quot;</th>
<th>nondet</th>
</tr>
</thead>
<tbody>
<tr>
<td>flat</td>
<td>KL1, Janus, ...</td>
<td>cc, Andorra-I Pandora, ...</td>
</tr>
<tr>
<td>deep</td>
<td>CP, GHC, Parlog, ...</td>
<td>AKL, Oz</td>
</tr>
</tbody>
</table>
Deep CCP (AKL)

\[ E ::= \begin{array}{l}
\phi \quad \text{constraint} \\
p(x) \quad \text{call} \\
E_1 \ E_2 \quad \text{composition} \\
x \ \textbf{in} \ E \quad \text{hiding} \\
or \ C_1 \ | \ldots \ | \ C_n \ \textbf{end} \quad \text{disjunction} \\
\textbf{if} \ C_1 \ | \ldots \ | \ C_n \ \textbf{else} \ E \ \textbf{end} \quad \text{conditional} \\
\textbf{bagof}(x, E_1, y) \quad \text{aggregate}
\end{array} \]

\[ C ::= x \ \textbf{in} \ E_1 \rightarrow E_2 \quad \text{clause} \]

\[ D ::= \textbf{proc} \ p(x) \ E \ \textbf{end} \quad \text{definition} \]

\[ \text{not} \ E =_{\text{def}} \ \textbf{if} \ E \ \text{then} \ false \ \text{else} \ true \ \text{end} \]
Computation Spaces

- Blackboard
  - Stores expressions to be executed
  - Stores constraints and local variables
  - Expressions are reduced to constraints
  - Information increases monotonically

- Agents associated with expressions
  - read information from blackboard
  - reduce when sufficient information is available
  - upon reduction might add new constraints and spawn new agents
Local Computation Spaces

- Agents may have local computation spaces.
- Information local to a local space is invisible outside.
- Information at higher computation spaces are visible to local computation spaces.
Semantics 3 (Deep)

Conditional expression:

- \textbf{if} \ C_1 \mid \ldots \mid C_n \textbf{else} E \textbf{end}

\textbf{where}

\[ C_i \ ::= \ x_i \ \textbf{in} \ G_i \rightarrow B_i \]

- Spawn a local computation space for each \( G_i \)
- Suspend the conditional agent
- Start an agent for each \( G_i \)
Stability

An expression $E$ is stable if

$$\text{For all satisfiable constraints } \phi, \quad \phi \land E \text{ is not reducible with 'determinate' rules.}$$

A nondeterminate step is allowed in a stable expression.

NONDETERMINISM (choice splitting)

or $C_1 \mid \ldots \mid C_n \textbf{end}, E_r \Rightarrow$

$$(C_1 \land E_r) \lor \ldots \lor (C_n \land E_r)$$

if the computation space is stable

- The computation space is copied into several copies.
- If the top level computation space is used for external communication then it is always unstable and therefore choice splitting is not allowed.
Example (stability)

\[ \text{bagof} \quad l, k, u \]
\[ l = [A|k] \]

or \( x=A \rightarrow \text{true} \)
true \( \rightarrow \text{mem}(x, k) \)
end

\[ \text{bagof} \quad l, k, u \]
\[ l = [A|k] \]

\[ x=A \]
\[ \text{mem}(x, k) \]

\( l, u, k \) in bagof(x, mem(x, l), u) \( l=[A|k] \)

**proc** mem(x, l)

or

\[ l = [x | \_] \rightarrow \text{true} \]
\[ \mid l_{1} \text{ in } l = [\_ | l_{1}] \rightarrow \text{mem}(x, l_{1}) \]
end

end

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Higher-Order CCP (Oz)

\[ E ::= \begin{align*} & \phi \quad \text{constraint} \\
 & \text{proc } y(x) \text{ E end } \quad \text{definition} \\
 & y(x) \quad \text{call} \\
 & E_1 \quad E_2 \quad \text{composition} \\
 & x \text{ in } E \quad \text{hiding} \\
 & \text{or } C_1 | \ldots | C_n \text{ end } \quad \text{disjunction} \\
 & \text{if } C_1 | \ldots | C_n \text{ else } E \text{ end } \quad \text{conditional} \\
 & \text{solve}(x:E_1, y) \quad \text{solve} \end{align*} \]

\[ C ::= x \text{ in } E_1 \rightarrow E_2 \quad \text{clause} \]

- Subsumes \( \lambda \)-calculus.
- Elegant support for modules and objects.
- Enables exciting new view of search.
- Introduces the notion of names in addition to variables (\( \gamma \) calculus)
Higher order (functional) programming

fun map(xs, p)
    if xs = [] → []
    | x,xr in xs = [x |xr] →
    [p(x) | map(xr, p)]
end
end

• Procedures are first class citizens
• Lexical scoping and local definitions
• Work on partial information (incremental)
Objects (Ports)

- AKL introduces the notion of ports:

Persistent references (names) to the end of a stream:

**Basic port operations**
- `new_port(port, stream)`
  
  `port` is a new name associated with `stream`

- `send(msg, port)`
  
  appends `msg` to the stream associated with `port` reassociate port with the tail of the stream.

**Derived port operations**
- `send(msg, p0,p1)`
  
  `p1` is bound to `p0` after `msg` is appended to the stream associated with `p0`
Basic object-oriented style:

```
proc object(port)
local state, stream in
    create_state(state)
    open_port(port, stream)
    obj(stream, state)
end
end

proc obj(ms, state0)
if msg, mr, s1 in ms = [msg | mr] ->
    dispatch(msg, state0, state1)
    obj(mr, state1)
else true
end
```
Properties (Ports)

• Objects have unique identifiers given by their associated port.

• Objects are active concurrent entities, e.g. in the sense of actors.

• The state is serialised and is not available to the next message until the dispatch operation is performed.

• State is encapsulated.
Concurrent Objects (Style)

- class is a record structure its features are the name of messages and its values are the corresponding methods:

  \[
  \text{Class}(\text{msg}_1: \text{method}_1, \ldots, \text{msg}_n: \text{method}_n)
  \]

**example**

\[
\text{Class}(\text{Inc}: \\
  \text{proc} (\text{msg, s, ns}) \\
  \quad x = s.\text{Val}, \text{adjoin}(\text{Val}:x+1,s,ns) \\
  \quad \text{end})
\]

**proc** object(o, class)

local

**proc** generic_object(str, state)

local msg, str1, l in

if str = [msg | str1] →

label(msg,l)

(class.l)(msg,state,new_state)

generic_object(str1, new_state)

end

end

end

stream, state in

new_port(o,stream)

create_state(state, class, o)

generic_object(stream, state)

end

end
Object (Sugared Syntax)

object counter
    from ur_object
    attrs  val  with Set(0) end
    meth Set(v)  val ← v  end
    meth Inc  val ← @val + 1 end
    meth Get(v) v ← @val end
end

Inc^counter
Inc^counter
Properties of Object System

- Encapsulated State
  - implementation optimised due to single reference property
- Multiple inheritance/differential
- Method delegation
- Private methods and attributes (due to local names)
- Meta-object protocol
  - constraints on message acceptance can be inherited and/or refined
- Methods
  - as first class objects
  - state threading
  - late binding (default)
Controlled Encapsulated Search


- Search should not be first principle
- Different strategies should be expressible, including one solution, all solutions, best solution (B&B), and demand driven search
- Problem specification (declarative) and search strategy (operational) should be describable by different programs
Solve Combinator

\[
\text{solve}(x:E, u) \Rightarrow
\]

Failed

\[
\text{solve}(x:\text{false}, u) \Rightarrow u=\text{Failed}
\]

Solved

\[
\text{solve}(x:E, u) \Rightarrow u = \text{Solved}(\text{proc} (x) E \text{ end})
\]

Stable

\[
\text{solve}(x : (\text{or} A \mid B \text{ end }, C), u) \Rightarrow
\]

\[
\text{Distributed}(\text{proc} (x) A C \text{ end}, \text{proc} (x) B C \text{ end})
\]
Depth-First Search

\[
\text{proc depth}(q, u) \\
\text{ local } v \text{ in} \\
\text{ solve}(q, v) \\
\text{ if } v = \text{Failed} \rightarrow u = \text{Failed} \\
\text{ | } s \text{ in } v = \text{Solved}(s) \rightarrow u = \text{Solved}(s) \\
\text{ | } l, r, v_1 \text{ in } v = \text{Distributed}(l, r) \rightarrow \\
\text{ \quad depth}(l, v_1) \\
\text{ \quad if } v_1 = \text{Failed} \rightarrow \\
\text{ \quad \quad depth}(r, u) \\
\text{ \quad else } u = v_1 \\
\text{ end} \\
\text{ end} \\
\text{ end}
\]
One Solution Search

proc one(q, u)
  local v in
    solve(q, v)
    if v = Failed → u = Failed
    | s in v = Solved(s) → u = Solved(s)
    | l,r,v1 in v = Distributed(l,r) →
      if s in one(l, Solved(s)) →
        u = Solved(s)
      | s in one(r, Solved(s)) →
        u = Solved(s)
      else
        u = Failed
    end
  end
end
end
Bagof Aggregate Search (Ordered)

.proc bagof(q, a)
  local
    proc bagof1(q, u,w)
      local v in
      solve(q, v)
      if v = Failed → u = w
      | s in v = Solved(s) →
        x in s(x), u = [x | w]
      | l,r,m in v = Distributed(l,r) →
        bagof1(l, u, m)
        bagof1(r, m, w)
  end
  end
end

in bagof(q, a, [])
end