eCSP – a domain-adapted, higher order, concurrent programming language

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What’s a value-added telephone service? Examples....
  - Find-me (autoforwarding)
  - Answerphone
  - Voting
  - (Multimedia) Conference call
  - (Virtual) Callcentre (emergency) call
  - Download a flick

What happens when you dial a VA service access number?
  - Caller-side switch forwards the call to an IN centre via POTN
  - POTN does switching, message handling, digit-collecting, ...
  - The INC instructs the network to do the right thing(s)

How are these kinds of service evolving?
  - They’re getting more complicated
  - So is the business model (viz. independent service provision)
  - Advent of broadband “edutainmunication” complicates context

What techniques are used to implement them?
  - (Yes, Virginia) Finite State Machines!

What’s wrong with that?
diamond Marconi’s original goals for the project
diamond A domain-adapted language with adequate expressive power
diamond High degree of service-wide and system-wide predictability
diamond A prototype design environment

diamond Our original plan

diamond Investigate existing service specs and implementations

diamond Ponder for a while

diamond Prototype design of a “little” language to make programs which could sit within the existing IN architecture.

diamond Proof-of-concept to be by case studies of existing services.

diamond But not all went according to plan – in our ignorance we started designing services of our own and realized that

Concurrency is unavoidable if you want to simplify the descriptions of useful and interesting services

diamond But could we persuade the Marconistas of this?
ML style primitive data, linearly extensible free datatypes and
records (with subtyping)

    DATA  DefiniteAnswer = Yes + No
    DATA   Answer       = DATA  DefiniteAnswer + Maybe

    TYPE Coord2D       = {l x:INT; y:INT l}
    TYPE Coord3D       = Coord2D + {l z:INT l}

Finite sets, sequences, relations, mappings, tuples

    VAR forwardto: SUBSCR +> [PHONENUMBER]
    VAR owns:     SUBSCR <-> PHONENUMBER

    VAR cache:    [INT]#100     = [(FOR i IN 0#100) fib(i) ]
    VAR defaults: [(STRING, STRING)] = []

Pattern guards

    PROC result:DefiniteAnswer := improve(ans:Answer) IS
    DO
        ans IS Maybe -> ans := PromptReadAnswer("Please be definite")
    OD
    IF ans
    IS Yes -> result := Yes
    OR No  -> result := No
    FI

Procedures, conventional guarded commands

    PROC a,b: T := sort(a,b: T) IS
    IF a<=b   -> SKIP
    OR b<a   -> a, b := b, a
    FI

    ...

    m, n := sort(m, n)
A channel connects a t-input-port (?t) to a t-output-port (!t)

Simple ports can be used only in one direction

PROC Buffer(left:?INT, right:!INT) IS
LET CHAN middle:INT IN
   DO left?x -> middle!x OD || DO middle?y -> right!y OD
END

PROC Buffer2(left:?INT, right:!INT) IS
LET CHAN middle:INT IN
   Buffer(left, middle) || Buffer(middle, right)
END

Ports can be “bundled” into interfaces.

TYPE Interface = {l raw:?RAW, ckd:!CKD l}

The worker sees one end of the bundle — that of type Interface

PROC worker(client:Interface) IS
   DO client.raw?x -> client.ckd!cook(x) OD

The complementary end of the bundle has type -Interface

PROC client(worker: -Interface) IS
   ... worker.raw!question ...
   ... worker.ckd?answer ...

Bundles can be built with a CHANNELS declaration

LET CHANNELS bundle: Interface
IN client(bundle) || worker(bundle)
...

Channels can carry ... ports.

fromBroker : ? Interface
...
fromBroker?client -> worker(client)
◊ A process farm

TYPE Interface = {l raw:?RAW, ckd:!CKD }
TYPE Farmer  = (Interface, [-Interface]) -> ()
TYPE Worker  = (Interface)  -> ()

PROC farmer(client: Interface, chans:[-Interface]) IS
LET  VAR free = [(FOR i IN 0#chans) TRUE]
IN
  DO
  OR (FOR i IN 0#chans)
    ~free(i) & chans(i).ckd?y -> free(i):=TRUE; client.ckd!y
  OR
  OR (FOR i IN 0#chans)
    free(i) & client.raw?x  -> free(i):=FALSE; chans(i).raw!x
  OD
END

PROC Farm (size:INT, farmer:Farmer, worker:Worker, client:Interface) IS
LET  CHANNELS chans : [ Interface ]#size
IN
  farmer(client, chans) || ||(FOR i IN 0#size) worker(chans(i))
END

◊ Process families can be specialized (by partial application)

CON twoworkers: Worker = Farm(2, farmer, worker)
CON fourworkers: Worker = Farm(2, farmer, twoworkers)
CON dozenworkers: Worker = Farm(3, farmer, fourworkers)

...

LET
  CHANNELS interface: Interface
IN
  client(interface) || dozenworkers(interface)
END
Client-use and Server-use of shared channels are independent critical sections

SHARED CHANNELS bus: CalculationService

CLIENT bus IN
   ... bus.request!Pi; bus.reply?answer ...
END

SERVER bus IN
   bus.request?x -> bus.reply!SINE(x)
END

Shared Channels are meeting-places for clients and servers

LET SHARED CHANNELS bus: CalculationService IN
   ServerA(bus) || ServerB(bus) || ClientX(bus) || ClientY(bus)
END

A dynamic server: ready to be introduced to clients by a broker

PROC Service(system:?Config, frombroker: ? SHARED -CalculationService) IS
   DO frombroker?client ->
      LET VAR state:ONLINE|OFFLINE|TERMINATED = OFFLINE IN
      DO state ISNT TERMINATED ->
         IF system?TERMINATE     -> state := TERMINATED
         OR system?ON            -> state := ONLINE
         OR system?OFF           -> state := OFFLINE
         OR
            state = ONLINE & SERVER client IN
            client.request?x -> client.reply!SINE(x)
         END
      FI
   OD
OD
Suppose $T \subseteq T'$, i.e. a $T$ will do when a $T'$ is expected.

- **Output ports:** $!T \not\subseteq !T'$, to forestall nasty surprises at input port.

  **Example:**

  ```
  TYPE pt2 = {x:INT, y:INT |}
  TYPE pt3 = pt2 + {z: INT |}

  PROC send2(out: !pt2, x: pt2) IS out!x
  
  LET CON   x2: pt2 = {x=3, y=4 |}
  CHAN c3: pt3
  IN
      send2(c3, x2)  
  END

  -- is badly-typed

  "!c?y3" \rightarrow .... y3:pt3 is a pt2.... -- NASTY SURPRISE
  ```

- **Arrays:** $[T] \subseteq [T']$

  **“Smuggling” counterexample**

  ```
  PROC mangle(f2:[pt2]) IS LET CON x2:pt2 = ... IN f2[0]:=x2 END -- prevent this

  VAR f3:[pt3] ... mangle(f3) ... f3[0]:pt3 is a pt2 ... -- NASTY SURPRISE
  ```

  Elementwise assignment interpreted as whole-array assignment makes it impossible to “smuggle”.

  ```
  PROC f2:[pt2] := mangle(f2:[pt2]) IS LET CON x2:pt2 = ... IN f2[0]:=x2 END
  VAR f3:[pt3] ... f3 := mangle(f3) ... -- is badly typed
  ```

- **Mappings to:** $U \not\rightarrow T \subseteq U \not\rightarrow T'$ (ditto)

- **Mappings from:** $T \not\rightarrow U \not\rightarrow T'$ \not\rightarrow U -- guess!
Domain-specific features of eCSP

◊ Database liaison for services is via abstract table descriptions
  ◦ Table accesses are translated to eCSP communications with DB
  ◦ The translation schemes (in the compiler) are configurable
  ◦ Simple interface essential for automatic load prediction

◊ A simple translation service with two kinds of access

SERVICE FollowMe
  VAR translate: Number -> Number

  ASPECT Route (caller, callee: Number; network: NetworkAdapter) IS
  "... network!Connect(caller, translate(callee)) ...."
  END;

  ASPECT Edit (caller, callee: Number; network: NetworkAdapter) IS
  "... translate(callee) := newtranslation ...."
  END
END

◊ The translate mapping is the sole interface to the database.
◊ Explicit scoping of shared structure supports optimisation.
◊ An ASPECT is a process invoked by the infrastructure when an IN call is made.
◊ Its parameters are the sole interface to the network.
◊ Module Language permits late binding of parts of implementation, and thereby supports generic designs ("frameworks").

◊ IN-specific feature implementation needs some work from Marconi.

◊ Current prototype translates full eCSP into Java.

◊ Channels are implemented in ways which depend on whether their endpoints reside in the same or in different address spaces.

◊ Subsets are translateable into occam 2, C++-threads, etc.

◊ We are designing a family of lightweight eCSP virtual machines which are considerably simpler than the JVM.

◊ Why Java first?
  ◦ We were attracted by the existing Java class library (esp: GUI and Networking)
  ◦ We were using Java in another domain and found the lack of a serious statically-enforceable discipline of concurrent Java programming alarming
  ◦ We wanted to explore some ideas about mixed-paradigm programming based on the strong duality between free datatype channels and object interfaces.

◊ What can be thrown away?
But why didn't you use .....?

◦ occam 3
  ◦ We agonized (BS was a consultant for occam 3)
  ◦ High-level model of concurrent programming
    but ...
  ◦ rather low-level model of data

◦ Java
  ◦ Intrinsic concurrency features are very low-level
    ... and weren’t soundly implemented when we started
  ◦ Nonexistent discipline of concurrent Java programming

◦ Occam-in-Java
  ◦ No safe implementation existed when we started.
  ◦ Notational incoherence (collection of idioms).
  ◦ Hard to identify efficiently-compileable subsets.

◦ Concurrent ML
  ◦ Well thought-out module system
    but ...
  ◦ Notational incoherence (collection of idioms).
  ◦ No subtyping
  ◦ Very hard to identify efficiently-compileable subsets.

and anyway, language design is fun!
Note 1 (p1)
Such a number isn’t necessarily “special”, it might simply be that of a friend who has enabled a particular feature on his line.

Note 2 (p1)
BT have two of these intelligent networking centres UK-wide.
Capacity is about 10m calls per minute! Performance is an issue.

Note 3 (p1)
It nearly always needs to consult a database. A lot of hard work has gone into designing these databases for speed.

Note 4 (p2)
Brief chronology

◊ Early 1996 Marconi “officially” recognises limitations of FSM
◊ Mid 1996: Marconi meet with Tony Hoare and Bernard Sufrin
◊ Later: BS meets with Marconi management to work out a project proposal for which OUCL will tender.

Note 5 (p2)
They were thinking of a special-purpose library embedded in C or C++ which are the languages in which the substrate IN code is written.
We realized that we had to investigate the semantics of existing and proposed services in order to help us understand what “adequate” meant. The result of this investigation surprised and alarmed us at first (see later)

Note 6 (p2)
Lack of this in the FSM

Note 7 (p2)
“But we realize that this is research and that you may want to change the goalposts”.

Note 8 (p2)
Specs were highly stylized which lent them an air of formality, but they were so
prolix as to be virtually incomprehensible to folk other than the requirements teams (salespeople).

Implementations were "inside" an environment which meant that they had to be viewed through the relatively narrow (form-based, by and large) keyhole offered by the UI of the environment.

Only two real levels of abstraction possible in paper descriptions: “the whole thing”, or “the whole state machine”

Although this was a difficult phase of the work, in retrospect it was a stroke of good luck that for various reasons we didn’t have their environment available to us. It meant we had to start thinking up services off our own bat, unconstrained by what we knew of the limitations of the implementation machinery.

Note 9 (p2)
We were definitely thinking of a sequential language when we first wrote the plan.

Note 10 (p2)
Certainly nothing less than pseudo-concurrency is satisfactory.

Note 11 (p2)
The answer turned out (over the next three months) to be "yes". But first we had to have a first cut a a design of a service that wouuld be convince them of this, and a first cut at the design of a useful design notation for it.

We started with an eclectic mixture of features from ML, Z, and Occam 3.¹ Not considering it formally a language at all but merely a notation in which to express our intentions.

Note 12 (p3)
DefiniteAnswer is a subtype of Answer which means that a DefiniteAnswer can appear wherever an Answer is required.

On the other hand, Coord3D is a subtype of Coord2D which means that a Coord3D can appear wherever an Coord2D is required. Finally, {z:INT} is not a subtype of Coord3D.

Note 13 (p3)

¹We used semantic concepts from Occam 3: the occam family has an abominable concrete syntax.
DO
  ans IS Maybe -> ans := PromptReadAnswer("Please be definite")
OD
result := ans

Note 14 (p3)
Here (as it happens) is a procedure with a pair of value/result parameters. The notation for the call is echoed in the procedure heading, and this means we need no explicit notation for parameter mode (value/result/reference/value-result).

Note 15 (p6)
Static communication topologies are safe, but require full resource-commitment up-front. In reality systems go through phases, and resources can be better utilized if they're committed as needed.

Most systems evolve dynamically: new components are downloaded and expect to use the existing infrastructure. We can't afford to rebuild the software for a switch just to add a single service or feature. Plug-and-play demands dynamic introduction of resources to each other.

Note 16 (p6)
The SERVER construct may be used as an input guard in an input alternation.

The architecture is fixed here. The system expects to have two fixed channels to this server, and to repeatedly send a client channel to the service then instruct the service about its performance.