Ingénierie du logiciel dans les réseaux informatiques

Chapter 2

The LOTOS Language

LOTOS Basic Principles

Language **O**f **T**emporal **O**rdering **S**pecification

Process Algebra (CCS & CSP) + Abstract Data Types (ACT ONE)

ISO Standard: IS 8807

Based partially on the LOTOS tutorial by Bolognesi & Brinksma [BoB87]

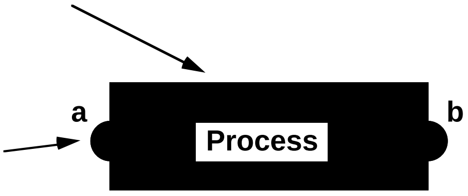
In LOTOS, a distributed, concurrent system is represented by a **process**, possibly consisting of sub-processes.

Process = **black box** able to **interact** with other processes (its environment) and / or to perform internal actions.

Atomic interactions are called **events**

Atomic = instantaneous, one at a time

An event occurs at an **interaction point**, or **gate**



An event may involve the exchange of data

Events imply **process synchronization**

When an event occurs, at least two processes participate in, or experience, that event -> **rendezvous**

[BoB87] T. Bolognesi and E. Brinksma.
Introduction to the ISO Specification Language LOTOS.
Computer Networks and ISDN Systems 14 (1) 25-59 (1987).

Basic LOTOS - Process Definition

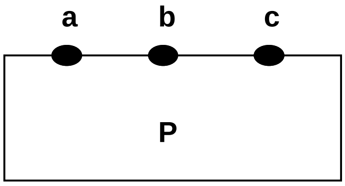
Basic LOTOS is a simplified version of LOTOS without data types.
In Basic LOTOS, an event is just a gate name (or the internal event i)

Process <process_id> <parameter_part> **:=**

<behaviour_expression>

endproc

Ex. : **process** P [a,b,c] := … **endproc**



process_id : an identifier which designates a process, that is a **process name**

parameter_part : in Basic LOTOS, a list of interaction points or gates

behaviour_expression : an expression defining the behaviour of the process, i.e. the allowed orderings of events

Such expressions are built up from more elementary expressions by using LOTOS operators.

Inaction

A basic behaviour expression : **stop**

process inaction [a,b] :=
    stop
endproc

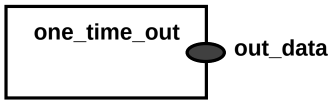
This process cannot perform any event

Action prefix

Prefixing a behaviour expression by an event **g ; B**

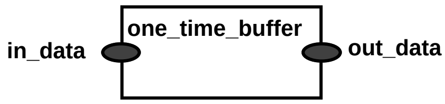
- B : a behaviour expression
- g : an event

process one_time_out [out_data] :=
    out_data **; stop**
endproc



The event 'out_data' prefixes the behaviour expression **stop**

process one_time_buffer [in_data,out_data] :=
    in_data **;** out_data **; stop**
endproc



The event 'in_data' prefixes the behaviour expression (out_data ; **stop)**

Choice operator

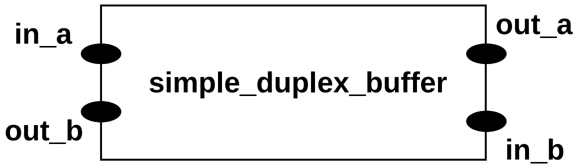
Let $\mathbf{B_1}$ and $\mathbf{B_2}$ be two behaviour expressions

=> the behaviour expression ($\mathbf{B_1}$ **[]** $\mathbf{B_2}$) defines a process that behaves either like B_1 or like B_2. The choice offered is **resolved by the environmen**t.

If the environment offers an initial action of B_1 (which is not in B_2), then B_1 is selected.

If the environment offers an initial action of both B_1 and B_2, then the selection is **non deterministic**.

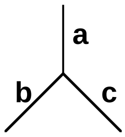
```
process simple_duplex_buffer [in_a,in_b,out_a,out_b] :=
in_a; (in_b ; (out_a ; out_b ; stop
                [] out_b ; out_a ; stop)
       [] out_a; in_b ; out_b ; stop)
[]
in_b; (in_a; (out_b ; out _a ; stop
               [] out_a ; out_b ; stop)
       [] out_b ; in_a ; out_a ; stop)
endproc
```



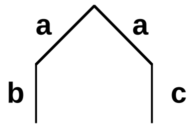
Nondeterminism

a **; (**B_1 **[]** B_2 **)** and a **;** B_1 **[]** a **;** B_2 model different behaviours

process one [a,b,c]
 a; (b; **stop**
  []
  c; **stop**)
endproc



process two [a,b,c]
 a; b; **stop**
 []
 a; c; **stop**
endproc



The choice of 'a' is not determined

Examples of nondeterministic behaviours:

a; B_1 **[] a;** B_2

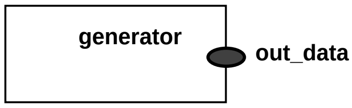
The internal action **i** is also a source of nondeterminism

i; B_1 **[] i;** B_2

a; B_1 **[] i;** B_2

Recursion - Process instantiation

process generator [out_data] :=
    out_data **;**
    generator [out_data]
endproc



Process instantiation: process name + list of actual gates

process one_slot_buffer [in_a, out_a] :=
    in_a **;**
    out_a **;**
    one_slot_buffer [in_a, out_a]
endproc

process one_slot_buffer [in_a, out_a] :=
    in_a; one_slot_buffer [out_a, in_a]
endproc

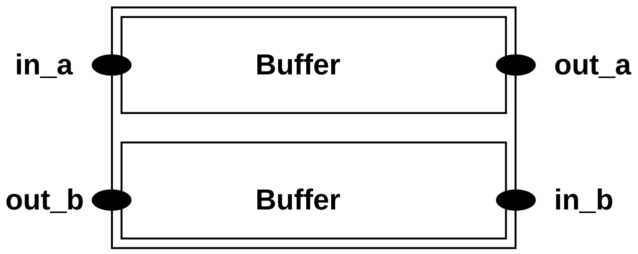
Instantiation with ≠ gates

Parallel composition without interaction (pure interleaving)

B_1 ||| B_2

```
process duplex_buffer [in_a,in_b,out_a,out_b] :=
    buffer [in_a,out_a]
    |||
    buffer [in_b,out_b]

    where
    process buffer [in, out] :=
    in; out; stop
    endproc
endproc
```



No interaction between B_1 and B_2 is possible

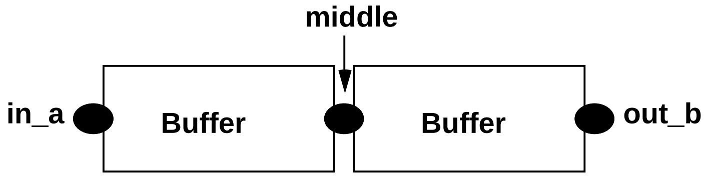
Parallel composition with interaction

B_1 |[a_1,...,a_n]| B_2

```
process two_buffers [in_a, middle, out_b] :=
    buffer [in_a,middle]
    |[middle]|
    buffer [middle,out_b]

    where
    process buffer[in, out] :=
    in; out; stop
    endproc

endproc
```

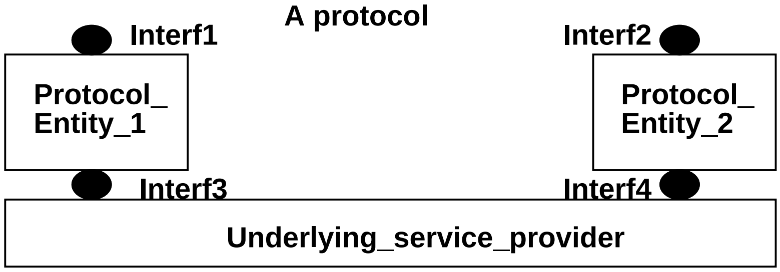


Every interaction **a_i** is performed **simultaneously** in both processes **B_1** and **B_2**

Actions not in a_1,...,a_n are not synchronized.

Examples of parallel architectures

A protocol



2 solutions

Process
Protocol [interf1, interf2, interf3, interf4] :=

Protocol_entity_1 [interf1, interf3]
|[Interf3]|
Underlying_service_provider [interf3, interf4]
|[Interf4]|
Protocol_entity_2 [interf2, interf4]

endproc

Process
Protocol [interf1, interf2, interf3, interf4] :=

(Protocol_entity_1 [interf1, interf3]
 |||
 Protocol_entity_2 [interf2, interf4]
)
|[interf3, interf4]|
Underlying_service_provider [interf3, interf4]

endproc

Multiway-rendezvous

It is easy to describe the synchronization of more than two processes

Example:

B_1 [g] || B_2 [g] || B_3 [g]   where || means the synchronization on all gates

Three processes synchronize on g:
g occurs if the three processes are ready to perform g

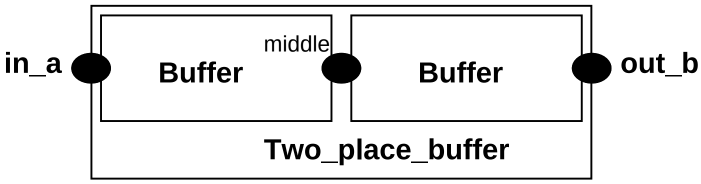
Hiding

hide a_1,..., a_n in B

Hiding conceals the observable actions **a_1,....,a_n** present in **B** from the environment.

These actions are thus made **unavailable for synchronization** with other processes.

process two_place_buffer [in_a, out_b] **:=**
  hide middle **in**
    (buffer [in_a,middle]
    |[middle]|
     buffer [middle,out_b])
where
  process buffer[in, out] **:=**
    in; out; **stop**
  endproc
endproc



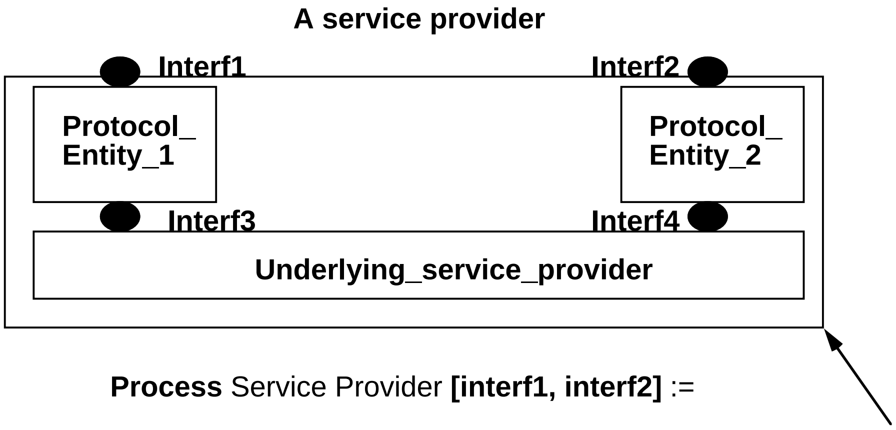
Equivalent sequential process

```
process  two_place_buffer [in,out] :=
    in; one_message_in_left [in,out]
where
    process one_message_in_left [in,out] :=
    i; (in; two_messages_in [in,out]
       []
       out; two_place_buffer [in,out])
    where
            process two_messages_in [in,out] :=
            out; one_message_in_left [in,out]
            endproc
    endproc
endproc
```

Internal action:

This is the hidden action 'middle'

Use of hiding in architectural design




```
Process Service Provider [interf1, interf2] :=

hide interf3, interf4 in
((Protocol_entity_1 [interf1, interf3]
  |||
  Protocol_entity_2  [interf2, interf4]
 )
 |[interf3, interf4]|
 Underlying_service_provider [interf3, interf4]
)
endproc
```

This external box represents hiding (or abstraction)

Successful termination of a process

No successful termination

```
process one_slot_buffer [in_a,out_a] :=
in_a ; out_a ;
one_slot_buffer [in_a,out_a]
endproc
```

Unsuccessful termination : stop

```
process one_time_buffer [in_a,out_a] :=
in_a ; out_a ; stop
endproc
```

Successful termination : exit

```
process connection_phase [CR,CC] :=
CR ; CC ; exit
endproc
```

Sequential composition

B_1 » B_2

B_2 is enabled iff B_1 terminates successfully (**exit** construct)

process sender [ConReq, ConConf, Data] :=
Connection_phase [ConReq, ConConf]
» Data_phase [Data]
where
process connection_phase [ConReq, ConConf] :=
ConReq; ConConf ; **exit**
endproc
process Data_phase [Data] :=
Data; Data_phase [Data]
endproc
endproc

When B1 is composed of several parallel sub-processes, B1 terminates successfully iff all parallel sub-processes terminate successfully

Disabling - Disruption

B_1 [> B_2

B_1 can be disrupted at any time by B_2

```
process Data_transfer [DatReq, DatConf, DisReq] :=
    normal_transfer [DatReq, DatConf ]
    [> disconnect_phase [DisReq]
where
    process normal_transfer [DatReq, DatConf ] :=
    DatReq; DatConf; normal_transfer [DatReq, DatConf ]
    endproc

    process disconnect_phase [DisReq] :=
    DisReq; stop
    endproc
endproc
```

Full LOTOS

Observable events have a finer structure

An observable event = a gate name **+ a list of values (or value expressions)**

Examples: g<5> g<true> g<3,false> g<>

The representations of **data values** (e.g. 3) and **value expressions** (e.g. 3+5) in LOTOS are derived from the specification language for **abstract data types** (ADT) **ACT ONE.**

Principles of ACT ONE will be presented later.

Extended action-prefix - Part 1: Value declarations

g!E; B

E = value expression = an expression describing a data value

Examples:

!(3+5) , !(x+1) , !true , !'toto' , !not(x) , !min(x,y)

In Basic LOTOS, **g; B** is a process that offers **g** and then behaves like **B**:

Formally: **g; B —g**→ **B**

In (full) LOTOS, **g!E; B** is a process that offers **g<value(E)>** and then behaves like **B**:

Formally: **g!E; B —g<value(E)>**→ **B**

Ex. : g!(3+5); B —g<8>→ B

Extended action-prefix - Part 2: variable declaration

g?x:t; B

x is a variable name

t is a sort identifier. It indicates the domain of values over which **x** ranges

Examples: ?x:integer ?text:string ?x:boolean

g?x:t; B (x) is a process that offers **all** events g<v> where v is any value in the domain of sort t and then behaves like B (v)

g?x:nat; B (x) thus allows all events in the set {g<0>, g<1>, g<2>, ...}

Formally: **g?x:t; B —g<v>→ [v/x] B**

for every v in the domain of sort t where **[v/x] B** is the result of the replacement by v of every free occurrence of x in B.

Ex. : g?x:integer; h!(x+1); **stop**—g<3>→ h!(3+1); **stop**

g?x:integer; h!(x+1); **stop** —g<5>→ h!(5+1); **stop**

Scope of variables

(sap1?x:int; sap2!x; **stop**) ll (sap3!x; **stop**)

scope of
?x:int

binding
occurrence
of x

free occurrence
of x

Usual rules for nested scopes apply

Synchronization between two processes
Interprocess communication
1. Value matching

process A	process B	Synchron. condition	Type of interaction	Effect
g!E1	g!E2	value(E1) = value(E2)	value matching	synchronization

Example:

g is a gate modelling a service interface
sap_id is a value representing the **s**ervice **a**ccess **p**oint identifier

g!sap_id; B models interaction at the SAP identified by sap_id at the interface g

Synchronization between two processes
Interprocess communication
2. Value passing
3. Value generation

process A	process B	Synchron. condition	Type of interaction	Effect after synchron.
g?x:t "intput"	g!E "output"	value (E) is (in domain) of sort t	value passing	x = value(E)
g?x:t "negotiation"	g?y:u	t = u	value generation	x = y = v and v is some value (in domain) of sort t

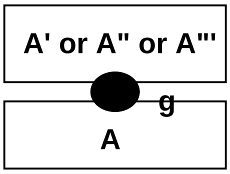
Extended action-prefix: several attributes

Example: **g!sap_id?x:primitive ; B**

Synchronization conditions in presence of several attributes

- Same number of attributes in both action offers
- Synchronization conditions for every pair of attributes

A := g!3?x:primitive; B



A' := g!3!connect_request; B'	can synchronize with A
A'' := g!3!true; B''	cannot synchronize with A
A''' := g!4!connect_request; B'''	cannot synchronize with A

Selection Predicate

A **selection predicate** can be associated with an action denotation.

g1?x:nat [x<3]; g2!x; stop

Predicate

This predicate may contain variables that occur in the **variable declarations** (**?x:t**)
It imposes restrictions on the values that may be bound to these variables.

g1?x:nat [x<3]; g2!x; stop has the following three possible transitions:

—g1<0>→ g2!0; stop

—g1<1>→ g2!1; stop

—g1<2>→ g2!2; stop

A value negotiation between two processes

g?qos:nat [qos ≤ max]; B_1 (qos)

|[g]|

g?qos:nat [qos ≥ min]; B_2 (qos)

=

g?qos:nat [(qos ≤ max) and (qos ≥ min)];
(B$_1$ (qos)
|[g]|
B$_2$ (qos))

Constraint-oriented style

Guarded Expressions

Any behaviour expression may be preceded by a guard (i.e. a predicate + an arrow).

Interpretation:
If the predicate holds, the behaviour expression that follows the guard is possible
Otherwise, the whole expression is equivalent to 'stop'

Example 1

[x>0] -> g!x; next_process [...] (x,..)
[]
[x<0] ->g!-x; next_process [...] (x,..)

si x=1: g!1; next_process [...] (1,...)
si x=-2: g!2; next_process [...] (-2,...)
si x = 0: stop

Example 2

[x>0] -> processus1
[]
[x=5] -> processus2
[]
[x>3] -> processus3

Predicates need not be mutually exclusive

Parametric process and instantiation

Process declaration:

```
process compare [in,out] (min,max:int) :=
in?x:int;
    ([min<x<max] -> out!x; compare [in,out] (min,max)
    []  [x≤min] -> out!min; compare [in,out] (x,max)
    []  [x≥max] -> out!max; compare [in,out] (min,x))
endproc
```

Process instantiation: compare [one,two] (x,2∗x)

Formal parameters are replaced by value expressions.
Name clashes are avoided by a suitable renaming.

compare [one,two] (x,2∗x) has the same behaviour as:

```
one?y:int;
     ([x<y<2∗x] -> two!; compare [one,two] (x,2∗x)
    [] [y≤x] -> two!x ; compare [one,two] (y,2∗x)
    [] [y≥2∗x] ->  two!2∗x; compare [one,two] (x,y))
```

Sequential composition with value passing

Connection_phase […](…)
>>
Data_phase […](…)

One would like to express that the behaviour of the Data_phase depends on parameters that are established in the Connection-Phase.

• Data_phase will be specified as a parametric process

• We need a mechanism for instantiating these parameters when the first process terminates and enables the second.

Succesful termination with value offers

The **exit** process can have a finite list of value expressions added to it.

gate1?x:int; gate2?y:int; gate3?z:int; **exit** (x,y,z)

tsap!cei ?qual:int ?exp_data: bool [qual>min]; **exit** (qual, exp_data)

Accepting values from the Enabling Process

Connection_Phase […] (…)
>> **accept qos: qos_sort in** Data_Phase […] (**qos**)

Requirement:

The sort **qos_sort** must match the sort of the value expression that Connection_Phase exits

This implies that in an expression like **B1 >> accept** $\mathbf{x_1{:}t_1, \ldots\ x_n{:}t_n}$ **in B2**

B1 always exits the same number of value expressions of the same sorts.

This leads to the definition of the **functionality** of a process.

The functionality of a process

Functionality = the list of the **sorts** of the values offered at successful termination

Process connect1 [gate1, gate2, gate3] **: exit (int, int, int)** :=
gate1?x:int; gate2?y:int; gate3?z:int; exit (x,y,z)
endproc

Functionality

Processconnect2 [tsap] (tcei: tcei_sort, min: int) **: exit (int, bool)** :=
tsap!cei ?qual:int ?exp_data: bool [qual > min]; exit (qual, exp_data)
endproc

The construct **exit (any sort_id)** is used when

• a value must be passed on successful termination because the next process is expecting one,

BUT

• the process does not care about the value to be passed on successful termination

Rules on the functionality Examples

funct (stop) =	noexit	
funct (exit) =	exit	
funct (g; B) =	funct (B)	
funct (B_1 [] B_2) =	funct (B_1)	if funct (B_1) = funct (B_2) or funct (B_2) = noexit
	funct (B_2)	if funct (B_1) = noexit
	undefined	otherwise (static semantic error)
funct (B_1 |[…]| B_2) =	funct (B_1)	if funct (B_1) = funct (B_2)
	noexit	if funct (B_1) = noexit or funct (B_2) = noexit
	undefined	otherwise (static semantic error)
funct (B_1 [> B_2) =	funct (B_1)	if funct (B_1) = funct (B_2) or funct (B_2) = noexit
	funct (B_2)	if funct (B_1) = noexit
	undefined	otherwise (static semantic error)
funct (B_1 >> B_2) =	funct (B_2)	if funct (B_1) ≠ noexit
	noexit	otherwise

Generalized choice

B_1 [] B_2 expresses the choice among **two** behaviours

By associativity of the choice operator, one can express the choice among a **finite number** of behaviours as follows:

B_1 [] B_2 [] … [] B_n

The generalized choice operator allows one to specify the choice among a **possibly infinite set** of behaviours as follows:

Let B(x) be a behaviour expression that depends on the (free) variable x of sort nat:

Choice x:nat [] B(x) expresses the choice among the behaviours B(v) for all v of sort nat.

In other words, it is equivalent to: **B(0) [] B(1) [] B(2) [] …**

General form : choice x_1:t_1, … x_n:t_n [] B (x_1, … x_n)

Let operator

It allows the association of value expressions to free variables:

let x_1:t_1 = E_1, … x_n: t_n = E_n **in** B (x_1, … x_n)

The x_i's are free variables in B

The t_i's are the sorts of these variables

The E_i's are the value expressions associated with the x_i's

Abstract data types
The ACT ONE langage

- **Notion of abstract data type**
- **Specification of an ADT**
- **Combining of ADT**
- **Usage of ADT**

Notion of abstract data type

Classical data types

Ex: "Unsigned integers, declared **unsigned**, obey the laws of arithmetics modulo 2^n, where n is the number of bits in the representation."

C Language Definition, X/OPEN Portability Guide

Abstract Data Types (= ADT)

- Formal (mathematical) definition —> no ambiguity.
- No reference to implementation.
- (Almost) no "built-in" law - all properties are written.

What is to be defined ?

- Sets of data values = **sorts**

  Ex: booleans, natural numbers, …
- Functions to handle these values = **operations**

  Ex: addition over naturals, negation over booleans, …

  These are abstract mathematical objects — No physical organization is defined !

Specification of an ADT: sorts and operations

Specification of an ADT in ACT ONE

In three parts: **sorts**, **operations** and **equations**

I. Specification of sorts

sorts *Nat* *(* definition of a new sort "Nat" *)*

—> introduces a domain whose content remains to be defined.

II. Specification of operations

```
opns   succ : Nat       -> Nat    (* successor of a Nat is a Nat *)
       0 :              -> Nat    (* constant 0 is a Nat *)
       _+_ : Nat, Nat   -> Nat    (* "+" is used in infix notation *)
```

sorts + operations (over these sorts) = a **signature**

Combining operations yields **terms**

= <u>representations</u> of values contained in the sorts.

Ex: *0, succ(0), 0+0, 0+succ(0), succ(0+0)…*

A priori *succ(0) ≠ 0+succ(0) ≠ succ(0+0)* —> we must add **equations**.

Specification of an ADT: equations

III. specification of equations

eqns	***forall*** *x, y : Nat*	*(* for all terms x, y of sort Nat *)*
	ofsort *Nat*	*(* sort of sides of equations *)*
	x + 0 = x ;	*(* x+0 denotes the same value as x *)*
	x + succ(y) = succ(x+y) ;	

Conditional equations are allowed:

y = 0 => x + y = x ; *(* if y = 0 then x + y = x *)*

Equations define an **equivalence relation** between terms.

Each **equivalence class** corresponds to a single value that all terms of this class denote.

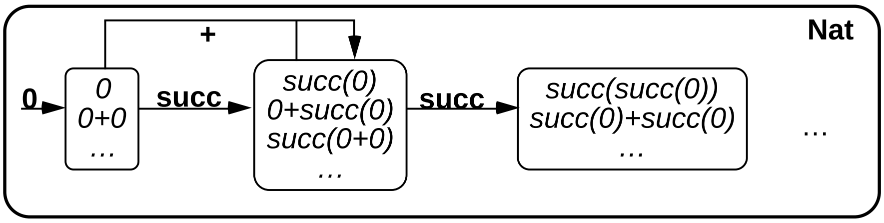
Ex: the (abstract) value 1 is defined by the class (of terms)

{ *succ(0)*, *succ(0)+0*, *succ(0+0)*, … }

Specification of an ADT: complete definition

I + II + III = specification of a data type

type *NaturalNumber* ***is***
  sorts *Nat*
  opns *succ : Nat -> Nat*
    0 : -> Nat
    _+_ : Nat, Nat -> Nat
  eqns ***forall*** *x, y : Nat*
    ofsort *Nat*
    x + 0 = x ;
    x + succ(y) = succ(x+y) ;
endtype



Combining of ADT: inheritance

type *natural_number* ***is***
    sorts *nat*
    opns *0 :* *-> nat*
        succ : nat *-> nat*
endtype

type *nat_number_with_addition* ***is*** *nat_number*
    opns *+ : nat, nat* *->nat*
    eqns ***forall*** *x,y : nat*
        ofsort *nat*
        x + 0 *= x ;*
        x + succ(y) *= succ(x+y) ;*
endtype

nat_number_with_addition inherits sorts, operations and equations of *natural_number.*

Permits structuring of definitions in a hierarchical manner.

Combining of ADT: library, renaming

library *Boolean, NaturalNumber, Bit* ***endlib***

Only one predefined library, containing various base types:

Boolean, Element, NaturalNumber, Set, String,

DecimalDigit, HexGigit, OctDigit, Bit,

DecimalString, HexString, OctString, BitString, Octet, OctetString.

cf. annex A of ISO IS 8807.

```
type bit is boolean renamedby
    sortnames  bit      for  bool
    opnnames   0        for  false
               1        for  true
endtype
```

Creates a new type with same structure as source type (isomorphic).

Combining of ADT: parametrized types

```
type data is
    formalsorts data
    formalopns error_data :              -> data
endtype


type queue_data is data
    sorts  queue
    opns   empty_queue :                 -> queue
           add : data, queue             -> queue
           first : queue                 -> data
    eqns   forall x, y : data, q : queue
           ofsort data
           first(empty_queue)            = error_data ;
           first(add(x,empty_queue))     = x ;
           first(add(x,add(y,q)))        = first(add(y,q)) ;
endtype
```

The formal sorts, operations and equations define <u>necessary conditions</u> that parameters must fulfill.

Combining of ADT: actualization

type *nat_number_queue* ***is*** *queue_data*
    actualizedby *nat_number* ***using***
  sortnames *nat* ***for*** *data*
    natqueue ***for*** *queue*
  opnnames *0* ***for*** *error_data*
endtype

The formal elements of *queue_data* are actualized by elements of *nat_number*, according to the given bindings.

Remarks:

- a binding may be omitted if formal and actual elements have the same name.
- a binding for a non-formal element is considered as a renaming

  (Ex: *queue* —> *natqueue*)

Usage of ADT: structure of a specification

specification *<specification-identifier> <parameter-list>*
    …
    type *…* ***endtype***
    library *…* ***endlib***
    type *…* ***endtype***
    …
behaviour *<behaviour-expression>*
where
    process *<process-identifier> < parameter-list > :=*
    < behaviour-expression >
    where *…*
    endproc
    …
    type *…* ***endtype***
    library *…* ***endlib***
    …
    process *< process-identifier > < parameter-list > :=*
    < behaviour-expression >
    where *…*
    endproc
endspec

Usage of ADT: ADT in behaviour expressions

• action denotation	*g !v ?x:s; B(x)*
• selection predicates	*g ?x:s [x = y]; B(x)*
	g ?x:s [predicate (x)]; B(x)
• guards	*[x = y] -> B*
	[predicate] -> B
• parameters and functionality	***process*** *P [g] (x:s) :* ***exit****(s) := B(x)* ***endproc***
	P [g] (v) >> ***accept*** *x:s* ***in*** *B(x)*
• generalized choice	***choice*** *x:s [] B(x)*
• local value	***let*** *x:s = v* ***in*** *B(x)*

Remark: *s* is the name of a <u>sort</u>, not of a type !

A type = a collection of sorts, operations and equations, useful only for structuring and organizing the ADT definitions.

LOTOS summary

- **Mathematically well-defined :** developed from a well-established body of theory
  Process algebra + Abstract Data Types
  Operational semantics
- **Constructive: Symbolically executable**
- **Expressive: allows the description of**
  - Architectures
  - Dynamic behaviours of processes
    Concurrency
    Nondeterminism
    Synchronous and asynchronous communications
  - But no explicit time, no priorities
- **Supports various levels of abstractions**
- **Supports the description of large systems**