Collaborative Activity ISC-CAN-65
between the Canada and the European Union

EUCALYPTUS-2

A European/Canadian LOTOS Protocol Tool Set

Final Report — 1996

Contents

1 Introduction

This technical report summarizes the main facts about the EUCALYPTUS-2 project for the two years 1995 and 1996. It is organized as follows:

- Section 2 reports about the management of the EUCALYPTUS-2 project.
- The next three sections 3, 4 and 5 report about the technical activities carried out in EUCALYPTUS-2. These sections reflect the decomposition in tasks provided by the workplan attached to the Contract:
  - Task 1: Application of the EUCALYPTUS tools to industrial case studies
  - Task 2: Improvement of the EUCALYPTUS tools
  - Task 3: Contribution to the standardization work on Extended-LOTOS
- Section 6 presents the efforts made for disseminating the results of EUCALYPTUS-1 and EUCALYPTUS-2 projects.
- Finally, Section 7 gives our conclusions for EUCALYPTUS-2.

2 Management report

2.1 Participants

The EUCALYPTUS-2 project involved the following scientists:

For Grenoble: At INRIA Rhône-Alpes / VERIMAG, six researchers have contributed to the EUCALYPTUS-2 project:

- Dr. Hubert Garavel: project management, improvement of the CÆSAR and BCG tools, and contribution to the development of E-LOTOS
- Dr. Laurent Mounier: improvement of the ALDÉBARAN tool
- Dr. Alain Kerbrat: improvement of the ALDÉBARAN tool
- Marius Bozga: development of the EVALUATOR tool
- Radu Mateescu: improvement of the BCG and XTL tools
- Mihaela Sighireanu: contribution to the definition of E-LOTOS

For Liège: At University of Liège, six researchers have contributed to the EUCALYPTUS project:

- Pr. André Danthine: project management

- Dr. Guy Leduc: project management, contribution to the definition of E-LOTOS
- France Bierbaum: writing of the user manual of the user interface
- Olivier Bonaventure: application of the EUCALYPTUS tools to the verification of security protocols
- Clarence Filsfils: management of the EUCALYPTUS server
- François Germeau: application of the EUCALYPTUS tools to the verification of security protocols
- Luc Léonard: contribution to the definition of E-LOTOS
- Charles Pecheur: improvement of APERO and the graphical user interface, contribution to the definition of E-LOTOS

For Ottawa: The Ottawa participation in EUCALYPTUS is supported by the Telecommunications Research Institute of Ontario (TRIO). The following researchers have contributed to EUCALYPTUS:

- Pr. Luigi Logrippo: project management
- Jacques Sincennes: tool development coordinator
- Patrick Bihan-Faou: application of EUCALYPTUS tools to an ATM example
- Brahim Ghribi: specification and validation with the EUCALYPTUS tools of telephony applications (GPRS)
- Jalel Kamoun: specification and validation with the EUCALYPTUS tools of telephony applications (Intelligent Network and Feature Interactions)
- Bernard Stepien: contributions to the definition of E-LOTOS, specification and validation with the EUCALYPTUS tools of telephony applications (Feature Interactions and GPRS)
- Randy Tuok: application of tools to develop and validation of Mobile Telephony (GSM) specifications.

For Montréal: The Montréal participation in EUCALYPTUS was originally supported by the Hewlett-Packard/NSERC/CITI Industrial Research Chair on Communications Protocols at the University of Montréal of which Gregor v. Bochmann is the chairholder. This support was approved by the steering committee of the chair in March 1993. Since November 1994, the Montréal participation is supported by Bochmann's NSERC research grant. The following researchers have contributed to EUCALYPTUS:

- Pr. Gregor v. Bochmann: project management
- Pr. Rachida Dssouli: collaboration
- Daniel Ouimet: supervision
- Omar Bellal: improvement of the TETRA tool

The joint Grenoble-Ottawa action: The goals of the EUCALYPTUS-2 project, as described in the Technical Annex of the EUCALYPTUS-2 contract, imply some significant work in terms of software development and maintenance. Unfortunately, the EUCALYPTUS-2 contract, on its European side, provides no manpower for these tasks.

To achieve the aforementioned goals, Grenoble and Ottawa decided to intensify their cooperation by launching a joint action on their own budgets. This joint action involved the exchange of three 3rd-year students of the ENSIMAG[1] engineering school:

- Xavier Etchevers,
- Jean-Michel Frume,
- and Mark Jorgensen

The joint action targeted at improving the integration of Grenoble's and Ottawa's tools within the EUCALYPTUS toolset (see Section 4.2 for technical details). The three students work on this project in Grenoble (from November 1995 to March 1996), then went to Ottawa (from April 1996 to June 1996) to complete the project.

Co-operation with external partners: Two research teams, not directly involved in the EUCALYPTUS-2 consortium, have expressed interest in the project and proposed to integrate their own tools in the EUCALYPTUS toolset:

- The research group of Pr. Ana Cavalli (INT, Evry, France), which developed the TESTGEN tool for generating test sequences from Labelled Transition Systems;
- The research project PAMPA of IRISA (Rennes, France) — especially Claude Jard and Thierry Jéron — which developed the VISCOPE tool for 3-dimensional display of Labelled Transition Systems.

2.2 Management and meetings

Management and administration were carried out by Grenoble, with a deliberate attempt to avoid excessive administrative overhead and not to slow down the research and development activities.

An important part of communication between the EUCALYPTUS partners took place using electronic mail. A FTP server, located in Liège, served as a common repository for storing the last releases of the EUCALYPTUS tools and reports.

In addition to electronic communication, four EUCALYPTUS-2 meetings were held (in order to optimize travel expenses, these EUCALYPTUS-2 meetings were combined with ISO meetings devoted to the standardization of the E-LOTOS language):

- The first meeting took place in Ottawa (July 25, 1995),

[1] Ecole Nationale Supérieure d'Informatique et de Mathématiques Appliqués de Grenoble

- the second one in Liège (December, 20, 1995),
- the third one in Kansas City (May, 16, 1996),
- the fourth one in Grenoble (December, 13, 1996).

2.3 Reports

[EUCA/GR/11] H. Garavel, *Minutes of the* EUCALYPTUS*-2 meeting – Ottawa, July 25, 1995*. 4 pages.

[EUCA/GR/12] EUCALYPTUS-2: Periodic Progress Report — 1995. 19 pages.

[EUCA/GR/13] EUCALYPTUS-2: Final Report — 1996.

2.4 External support

It is fair to mention that parts of the work described in this Report could not have been accomplished in the framework of EUCALYPTUS-2 only, due to the fact that the European part of EUCALYPTUS-2 provides no manpower and only covers travel expenses. In particular, Task 1 ("Application of the EUCALYPTUS toolset to industrial case studies") and Task 2 ("Improvement of the EUCALYPTUS tools") could not have been performed without both the existence of national sources of fundings for research and the existence of industrial contracts.

3 Application of the EUCALYPTUS tools to industrial case studies (Task 1)

The purpose of EUCALYPTUS-1 and EUCALYPTUS-2 is not to study formal methods for their mathematical perfection only, nor to develop software as a side academic activity. All EUCALYPTUS-2 partners are involved in industrial projects in which they must demonstrate that using the LOTOS language and the EUCALYPTUS tools can bring significant improvements to real-life developments.

We give here a list of projects in which the EUCALYPTUS tools have been applied:

1. Grenoble used the EUCALYPTUS tools to study the correctness of the LOTOS descriptions of CCR[2] Service and Protocol, two descriptions considered for standardization by ISO (ISO standard 9804 and 9805). In these LOTOS descriptions (1,400 and 3,000 lines), several errors were found and reported to the Editor.

[2]Concurrency, Commitment and Recovery

2. Similarly, Grenoble applied the EUCALYPTUS tools to the OSI-TP[3] Protocol, a database protocol under revision by ISO (ISO standard 8326). In this large LOTOS description (15,400 lines), 11 errors were found and reported to ISO by AFNOR, the French standardization Institute.

3. Grenoble used also the EUCALYPTUS tools to verify the correctness of the COOPSCAN environment, a platform for co-operative, synchronous applications developed by Bull-Imag (a joint academic/industrial research unit in Grenoble). Also, Bull-Imag used the EUCALYPTUS tools to validate three groupware protocols for failure recovery in groups allowing dynamic connections and disconnections.

4. Grenoble is currently involved in a close co-operation with Bull for the formal verification of Bull's hardware algorithms. In 1995, the EUCALYPTUS tools were successfully applied to the study of the bus arbiter used in Bull's multi-processor workstations. The bus arbiter was formally described in LOTOS and its correctness was established using the EUCALYPTUS tools.

   This co-operation continued in 1996. The EUCALYPTUS tools were applied to the analysis of the cache memory algorithm of PegaKid (PegaKid is the name of Bull's new parallel architecture based on PowerPC processors).

5. Liège used the EUCALYPTUS tools to develop and validate a formal description in LOTOS of the ODP[4] Trader. Liège used also LOTOS (with appropriate time extensions) to model the behaviour of an ODP Binding Object.

6. Since November 1995 and until October 1997, Liège is involved in the ACTS project number 051 ("OKAPI") dealing with security, cryptography and authentication in computer networks. In this project, Liège is specifying the EQUICRYPT protocol in LOTOS. This is a Trusted Third Party (TTP) protocol, which involves three parties: Users' Access Control Units, Video on Demand Service Providers and a TTP.

   In this context, Liège used the EUCALYPTUS toolset to verify the security of the EQUICRYPT protocol. Using the model-based verification tools from the EUCALYPTUS toolset, several unexpected attacks against this protocol have been discovered.

7. Ottawa has a good experience in applying LOTOS to software development in telecommunications. Ottawa is involved in several industrial projects related to telecommunications, many of which involve Canadian telecommunication industries, such as Bell Northern Research. The EUCALYPTUS tools are used to validate the LOTOS descriptions which have been elaborated in these projects. They are also used to derive execution scenarios and test cases from the formal descriptions. These projects are:

   - Asynchronous Transfer Mode (ATM): the EUCALYPTUS toolset was used in order to develop a specification of Q.931 signaling. It was shown that the specification satisfies certain user requirements specified in temporal logic.

[3] Transaction Processing
[4] Open Distributed Systems

- Intelligent Network (IN): Ottawa completed in 1996 the work reported in 1995 of specifying Intelligent Network features and detecting interactions between them (J. Kamoun's Master thesis). The EUCALYPTUS toolset was used to create an abstract, executable model of Intelligent Network feature creation facilities, at the Distributed Functional Plane level. Work is going on to specify in LOTOS different aspects of the Intelligent Network model, especially the Capability Set 2 (CS-2) features.
- Mobile telephony: In 1995, a complete, "high-level" specification of the protocols of the mobile telephony GSM standard (including the MAP protocol) was developed in LOTOS by using the EUCALYPTUS tools (Randy Tuok's Master Thesis).

  In 1996, Hichem Ben-Fredj worked on using the CÆSAR and TESTGEN tools to generate test cases for the MAP protocol from its formal description in LOTOS. At the end of 1996, this work was near completion.

  Ottawa also started to work on GPRS, a mobile data feature for GSM currently developed within ETSI. Closely following the design of this protocol, Ottawa is developing increasingly detailed formal specifications for GPRS. This work has the purpose of eventually producing a validated formal specification for GPRS protocols.

All these case-studies are positively contributing to the dynamics of the EUCALYPTUS-2 cooperation. Many of them led to publications in international conferences (see Section 6.1).

A Web page summarizing these case-studies (and many others) is under construction: it can be consulted at `http://www.inrialpes.fr/vasy/cadp.html`.

Besides these industrial projects, the EUCALYPTUS tools have been used for teaching purpose in many Universities (see Section 6.4).

4 Improvement of the EUCALYPTUS tools (Task 2)

4.1 Tool improvement

During EUCALYPTUS-2 (from January 1995 to December 1996), the EUCALYPTUS-2 partners improved their tools significantly:

- Liège maintained and improved its APERO tool developed in EUCALYPTUS-1. A new version 2.02 of APERO was released, which incorporates new data type extensions and runs on Sparc stations running either SunOS 4.1.* or Solaris 2.* operating systems.
- Ottawa improved its XELUDO tools in several ways and released the current version 5.0a. A random walk functionality was added and the Goal-Oriented Execution tool for

full LOTOS was improved. Ottawa also took part in developing tool interfaces between XELUDO and the tools developed in Grenoble.

- Grenoble significantly improved its CADP[5] tools. Starting from the version "Z-c" of CADP (which was demonstrated in December 1995, during the final review of the EUCALYPTUS-1 project), Grenoble developed several new beta-versions of CADP (successively named Z-a, Z-b, Z-c, ..., Z-r, Z-s, Z-t). This continuous work culminated with the release of version Z of CADP in December 1996.

  Version Z introduces a lot of new features and major improvements:

  - The CÆSAR and CÆSAR.ADT compilers integrate a garbage collection mechanism for abstract data types, which allows larger descriptions to be processed.
  - The size of the C code generated by CÆSAR for large LOTOS descriptions was significantly reduced.
  - A new verification tool, named EVALUATOR, was added. This tool allows formulas of the branching-time μ-calculus to be evaluated on-the-fly on LOTOS programs.
  - Grenoble added a new tool, named BCG_EDIT. This tool is an interactive, graphical editor, which allows the modification of the PostScript representation of Labelled Transition Systems generated by the BCG_DRAW tool.
  - The OPEN/CÆSAR programming interfaces were simplified and all OPEN/CÆSAR tools were improved or rewritten.
  - A new tool for compositional verification (PROJECTOR) was added to the CADP toolbox.
  - A connection was established between the BCG format used by the CADP and the FC2 format defined the CONCUR2 ESPRIT project.
  - Grenoble continued the development of the XTL compiler. XTL[6] is a meta-language for specifying algorithms for temporal logics evaluation. In 1995, a first prototype of the XTL compiler was achieved. It is not distributed yet, but has been used successfully for several projects.
  - Grenoble completed in 1996 the adaptation of the CADP tools to the new version of Sun's operating system, Solaris 2.5. In the future, it should be easier to port the CADP tools to other platforms (HP-UX, AIX, Linux, etc.), since provision for multi-architecture support has been taken.
  - Finally, a lot of documentation and manual pages were added, together with a detailed installation procedure.

4.2 Tool integration

In addition to individual tool improvements, the integration of the different tools within the EUCALYPTUS toolset was strengthened, due to a close collaboration between the partners.

[5] CÆSAR/ALDÉBARAN Development Package
[6] eXecutable Temporal Logic

The "common trace format", defined in EUCALYPTUS-1 and used by many EUCALYPTUS tools, was enhanced. This format allows the execution sequences generated by some tools to be replayed by other tools. A new version of this format was defined and enriched with new constructs, such as regular expressions, that enhance its expressiveness.

The existing tools were adapted to support the new version of the common trace format: this includes Grenoble's tools (ALDÉBARAN, CÆSAR, TERMINATOR, EXECUTOR, and EXHIBITOR) as well as Ottawa's goal-oriented execution tool (GOAL). The benefits of the new trace format are twofold:

- Firstly, the pattern language currently used for goal-oriented execution is significantly improved by the use of regular expressions.
- Secondly, the new format allows a two-ways communication between Grenoble's and Ottawa's tools: for instance, it is possible to replay, using Ottawa's tools, an execution sequence generated with Grenoble's tools.

4.3 Graphical user interface improvement

The development of the Graphical User Interface (GUI) developed in EUCALYPTUS-1 has also progressed during EUCALYPTUS-2.

Work on the GUI demonstrated at the final review of EUCALYPTUS-1 has continued. Several new versions have been elaborated (versions 0.998, 0.9991, 0.9992, 0.9993, 0.9994, 0.9995). Version 1.0 of the GUI was released in June 1996, followed by version 1.1 (July 1996) and version 1.2 (November 1996). In addition to bug fixes, the following improvements were brought:

- Liège wrote a User Manual for the EUCALYPTUS toolset.
- Grenoble wrote an Installation Manual for the EUCALYPTUS toolset.
- The GUI was modified to integrate the VISCOPE and TESTGEN tools (see Section 2.1). This work was done by Grenoble, in collaboration with INT and IRISA.
- A demonstration example (the Plain Old Telephony System) was added.
- The GUI was ported under Solaris 2.* operating system.

However, the EUCALYPTUS-2 partners faced problems when maintaining and improving the GUI. The main cause for these problems was the fact that the GUI was based on the XTPANEL tool, an interface generator developed at Stanford University. However, in the meantime, the authors of XTPANEL left Stanford. Although one of the authors provided us valuable assistance in porting XTPANEL on Solaris 2.*, it was clear that the future of

XtPanel was compromised and that one would face problems in adapting the GUI to new machines and operating systems.

For this reason, it was decided to rewrite entirely the GUI using the Tcl/Tk toolkit, a popular interface generator developed at the University of Berkeley and Sun Microsystems, which was found to be extremely powerful and convenient. This work was done by Jean-Michel Frume and Hubert Garavel in the framework of the joint action between Grenoble and Ottawa. Version 2.0 of the GUI was released in October 1996, followed by version 2.1 in December 1996.

5 Contribution to the standardization work on Extended-LOTOS (Task 3)

A revision of the Lotos standard is currently in progress within ISO (ISO/IEC JTC1/SC21/WG7 New Work Item on "Extended Lotos"). This standardization project aims at enhancing Lotos with new features suitable for the new generations of communication protocols and distributed systems.

During the Eucalyptus-1 project (1993–1994), the Eucalyptus partners contributed to the work on E-Lotos. This long-term effort was continued during Eucalyptus-2 and led to the publication of the E-Lotos Committee Draft (February 1997), the first official document to be submitted to an international ballot in 1997.

The contribution of Eucalyptus-1 and Eucalyptus-2 projects to the definition of E-Lotos was acknowledged as a very positive fact by the ISO E-Lotos Committee.

In 1995 and 1996, the Eucalyptus partners have attended (or in several cases, hosted) five ISO meetings:

- the first one in Paris (6th-8th of February 1995),
- the second one in Ottawa (20th–26th of July 1995),
- the third one in Liège (18th-21th of December 1995),
- the fourth one in Kansas City (13th-17th of May 1996),
- the firth one in Grenoble (9th-12th of December 1996).

They have provided significant contributions for these meetings, as illustrated by the following list of inputs documents (numbered [PARi], [OTTi], [LGi], [KCi], and [GRi] for the Paris, Ottawa, Liège, Kansas City, and Grenoble meetings respectively):

- [PAR2]: *Generalized Termination, Enabling and Disabling* (Spanish and Canadian experts)

- [OTT2]: *An ET-LOTOS Description of an ODP Binding Object* (Belgian experts)
- [OTT3]: *Belgian Comments on ISO/IEC JTCS1/SC21/WG7 N1001* (Belgian experts)
- [OTT4]: *Towards a proposal for Datatypes in* E-LOTOS (Belgian and UK experts)
- [OTT6]: *French-Romanian Proposal for a Correct Flattening of* LOTOS *Parameterized Types* (French and Romanian experts)
- [OTT7]: *Contribution to the Design of Datatypes in* E-LOTOS (French experts)
- [LG1]: *Defect report regarding IS8807 (*LOTOS*) and Proposal for a Correct Flattening of* LOTOS *Parameterized Types* (French and Romanian experts)
- [LG2]: *Application of the proposed* E-LOTOS *Datatype Language to the Description of OSI and ODP Standards* (French and Romanian experts)
- [LG3]: *French-Romanian Comments regarding some Proposed Features for* E-LOTOS *Data Types* (French and Romanian experts)
- [LG4]: *A Proposal for the Datatype Part of* E-LOTOS *Applicable to the Formal Description of OSI and ODP Standards* (French and Romanian experts)
- [LG5]: *A Wish List for the Behaviour Part of* LOTOS (French experts)
- [LG8]: *Compositional Specification of ODP Binding Objects* (Belgian and French experts)
- [LG11]: *Specifying the Suspend-Resume Behaviour with Time in* LOTOS (Canadian experts)
- [LG12]: *The Suspend-Resume Operator Application to Action Interrupts* (Canadian experts)
- [KC2]: *Position statement regarding* E-LOTOS *user language* (French-Romanian experts)
- [KC3]: *French-Romanian Integrated Proposal for the User Language of* E-LOTOS (French-Romanian experts)
- [KC4]: *French-Romanian Proposal for Capture of Requirements and Expression of Properties in* E-LOTOS *Modules* (French-Romanian experts)
- E-LOTOS *User Language*. H. Garavel and M. Sighireanu. Chapter 2 of ISO/IEC JTC1/SC21 Third Working Draft on Enhancements to LOTOS (1.21.20.2.3) output document of the edition meeting, Kansas City (French-Romanian experts)
- E-LOTOS Core Language. A. Jeffrey and G. Leduc. Chapter 3 of ISO/IEC JTC1/SC21/WG7 N1173: Revised Working Draft on Enhancements to LOTOS (V4), Sept. 96, 72 p.

- [GR2]: *On the definition of Modular* E-LOTOS (French-Romanian experts)
- [GR3]: *A proposal for co-routines and suspend/resume* (French-Romanian experts)
- [GR4]: *Position statement regarding E-LOTOS progression of work* (French-Romanian experts)

Moreover, part of this work on E-LOTOS led to international publications (see Section 6.1).

6 Dissemination of results

6.1 Publications and theses

The EUCALYPTUS project has a good international visibility, as indicated by the list of our most recent publications and theses:

[ABBL95] D. Amyot, F. Bordeleau, R. J. A. Buhr, L. Logrippo. *Formal support for design techniques: A Timethreads-LOTOS approach.* In Proceedings of the 8th International Conference on Formal Description Techniques FORTE'95, Montreal, Canada, October 17-19, 1995.

[CDH*97] J.P. Courtiat, P. Dembinski, G. Holzmann, L. Logrippo, R. Rudin. P. Zave. *Formal Methods after 15 years: Status and Trends.* To appear in Computer Networks and ISDN Systems.

[CGM*96] Ghassan Chehaibar, Hubert Garavel, Laurent Mounier, Nadia Tawbi, and Ferruccio Zulian. *Specification and Verification of the PowerScale Bus Arbitration Protocol: An Industrial Experiment with LOTOS.* In Reinhard Gotzhein and Jan Bredereke, editors, Proceedings of the Joint International Conference on Formal Description Techniques for Distributed Systems and Communication Protocols, and Protocol Specification, Testing, and Verification FORTE/PSTV'96 (Kaiserslautern, Germany), pages 435-450. IFIP, Chapman & Hall, October 1996. Full version available as INRIA Research Report RR-2958.

[Fac95] Mohammed Faci, *Detecting Feature Interactions in Telecommunications Systems Designs.* PhD Thesis, University of Ottawa, 1995.

[FGK*96] Jean-Claude Fernandez, Hubert Garavel, Alain Kerbrat, Radu Mateescu, Laurent Mounier, and Mihaela Sighireanu. *CADP (CAESAR/ALDEBARAN Development Package): A Protocol Validation and Verification Toolbox.* In Rajeev Alur and Thomas A. Henzinger, editors, Proceedings of the 8th Conference on Computer-Aided Verification (New Brunswick, New Jersey, USA), volume 1102 of Lecture Notes in Computer Science, pages 437-440. Springer Verlag, August 1996.

[FL96] M. Faci and L. Logrippo, *An Algebraic Framework for the Feature Interaction*

Problem. In Proceedings of the 3rd AMAST Workshop on Real-Time Systems, Salt Lake City, 1996, 280-294.

[FLS97] M. Faci, L. Logrippo, and B. Stepien. *Structural Models for Specifying Telephone Systems*. To appear in Computer Networks and ISDN Systems.

[FNLL96] A. Février, E. Najm, G. Leduc, L. Léonard, *Compositional Specification of ODP Binding Objects*. In: Information Network and Data Communication, Chapman & Hall, London (1996).

[FNLL97] A. Février, E. Najm, G. Leduc, L. Léonard, *QoS specification of ODP Binding Objects*. Telektronikk, vol. 93 (1) (1997), 42-49. Invited paper.

[Gar95] H. Garavel, *On the Introduction of Gate Typing in E-LOTOS*. In P. Dembinski and M. Sredniawa, eds., Proceedings of the 15th IFIP International Workshop on Protocol Specification, Testing and Verification (Warsaw, Poland), June 1995.

[Gar96] H. Garavel. *An Overview of the Eucalyptus Toolbox*. In Z. Brezocnik and T. Kapus, editors, Proceedings of the COST 247 International Workshop on Applied Formal Methods in System Design (Maribor, Slovenia), pages 76-88. University of Maribor, Slovenia, June 1996.

[GM97] H. Garavel and L. Mounier, *Specification and Verification of various Distributed Leader Election Algorithms for Unidirectional Ring Networks*. To appear in Science of Computer Programming, Special issue on Industrially Relevant Applications of Formal Analysis Techniques, 1997. Detailed version available as INRIA Research Report RR-2986.

[GS96] Hubert Garavel and Mihaela Sighireanu. *On the Introduction of Exceptions in LOTOS*. In Reinhard Gotzhein and Jan Bredereke, editors, Proceedings of the Joint International Conference on Formal Description Techniques for Distributed Systems and Communication Protocols, and Protocol Specification, Testing, and Verification FORTE/PSTV'96 (Kaiserslautern, Germany), pages 469-484. IFIP, Chapman & Hall, October 1996.

[Haj95] Mazen Haj-Hussein, *Guided Search Technique for LOTOS*. PhD Thesis, University of Ottawa, 1995.

[Kam96] Kamoun J. *Formal Specification and Feature Interaction Detection in the Intelligent Network*. Master Thesis, University of Ottawa, 1996.

[KB95a] Khendek, F. and Bochmann, G. v., *Merging behavior specifications*, in Journal of Formal Methods in System Design, Vol. 6, No. 3, pp. 259-293, June 1995.

[KB95b] Khoumsi, A. and Bochmann, G. v., *Protocol synthesis using basic LOTOS and global variables*, in International Conference on Network Protocols (ICNP) 1995.

[KHB96] Kant, C., Higashino, T. and Bochmann, G. v., *Deriving protocol specifications from service specifications written in LOTOS*, to be published in Distributed Computing.

[KL96] J. Kamoun and L. Logrippo. *Spécification formelle et détection d'interaction entre les services dans les Réseaux Intelligents.* In: A. Bennani, R. Dssouli, A. Benkiran, O. Rafiq (eds.) CFIP'96: Colloque Francophone sur l'Ingénierie des Protocoles, ENSIAS, Rabat, Maroc, 1996, pp. 165-182.

[Led95] G. Leduc, *Failure-based congruences, unfair divergences and new testing theory.* Protocol Specification, Testing and Verification, XIV, Chapman & Hall, London (1995), 252-267.

[Leo96] L. Léonard, *An operational characterisation of may- and must-test in ET-LOTOS*, presented at: COST 247 Meeting, Antalya, Turkey, 4 Nov. 1996.

[Leo97] L. Léonard, *An Extended LOTOS for the Design of Time-Sensitive Systems*, PhD Thesis, Université de Liège, Institut Montefiore B28, B-4000 Liège 1, Belgique, April 1997.

[LBK*96] G. Leduc, O. Bonaventure, E. Koerner, L. Léonard, C. Pecheur, D. Zanetti, *Specification and Verification of a TTP Protocol for the Conditional Access to Services*, in: Proc. of 12th Jacques Cartier Workshop on "Formal Methods and their Applications: Telecommunications, VLSI and Real-Time Computerized Control System", Montréal, Canada, Oct. 96, 13 p. Invited paper.

[LL95] L. Léonard, G. Leduc, *An Extended LOTOS for the Design of Real-Time Systems.* Invited talk, Workshop on Design and Analysis of Real-Time Systems, Brussels, Belgium, 9–10 November 1995

[LL97] L. Léonard, G. Leduc, *An introduction to ET-LOTOS for the description of time-sensitive systems.* In Computer Networks and ISDN Systems 29 (3) (1997) 271-292.

[Pec96] C. Pecheur, *Improving the Specification of Data Types in LOTOS*, PhD Thesis, Université de Liège, Institut Montefiore B28, B-4000 Liège 1, Belgique, Nov. 1996.

[SFL96] B. Stepien, K. Farooqui, and L. Logrippo. *An Experience Modelling Telecommunication Systems using ODP-DLcomp.* In Proceeding of FMOODS'96, Formal Methods for Open Object-based Distributed Systems. ENST, Paris, 1996, 223-238.

[SL95a] Stepien, B., and Logrippo, L. *Representing and Verifying Intentions in Telephony Features Using Abstract Data Types.* In: Cheng, K.E., and Ohta, T. (Eds.) Feature Interactions in Telecommunications, III (1995). IOS Press, 141-155.

[SL95b] Stepien, B., and Logrippo, L. *Feature Interaction Detection Using Backward Reasoning with LOTOS.* In: S. Vuong (ed.) Protocol Specification, Testing, and Verification, XIV (Proc. of the 14th International Symposium on Protocol Specification, Testing, and Verification, organized by IFIP WG 6.1, Vancouver), 1995, pp. 71-86.

[TPB95] Tan, Q. M., Petrenko, A. and Bochmann, G. v., *Modeling Basic LOTOS by FSMs for Conformance Testing*, Proceedings of the 15th International Symposium on Protocol Specification, Testing and Verification (PSTV 15), Poland, June 1995, pp.137–152.

[Tuo96] Tuok, R. *Modelling and Generation of Scenarios for a Mobile Telephony System in LOTOS*. Master Thesis, University of Ottawa, 1996.

[UvdS95] Ural, H. and van der Schoot, H., *Data flow oriented test selection for LOTOS*, in Computer Networks and ISDN Systems , vol. 27(7), pp. 1111-1136, May 1995.

6.2 Toolset demonstration

The EUCALYPTUS tools have been presented and demonstrated in several international conferences, including:

- CFIP'95: Colloque Francophone sur l'Ingénierie des Protocoles (Rennes, France, May 1995).
- PARADIS'95: 2nd Summer School on Parallel and Distributed Systems (Sinaia, Romania, August 1995).
- IWPTS'95: International Wokshop on Protocol and Test Systems (Evry, France, September 1995).
- Rencontres Inria-industrie (Paris, France, September 1995)
- FORTE'95: 8th International Conference on Formal Description Techniques (Montréal, October 1995).
- COST-247: 6th Management Committee Meeting (Budapest, Hungary, October 1995)
- COST-247: 7th Management Committee Meeting (Madrid, Spain, February 1996)
- TACAS'96 (Passau, March 1996)
- First International Workshop on Applied Formal Methods in System Design (Maribor, Slovenia, June 17-19, 1996)
- CAV'96 (New Brunswick, August 1996)
- FORTE/PSTV'96 (Kaiserslautern, October 1996)

6.3 Industrial use of the toolset

Several case-studies have been tackled using the EUCALYPTUS, either with industrial partners such as Bull (France and Italy) and Bell Northern Research, or in the framework of European projects (e.g., ACTS). A comprehensive list of these case-studies is given in Section 3.

6.4 Academic use of the toolset

The EUCALYPTUS tools are heavily used in academic laboratory exercises, mostly to explain the principles of protocol engineering, formal specification and verification. We only list the examples for which we have precise information (but there are many other uses):

- At the University of Montréal, the EUCALYPTUS toolset is used in the course "Sujets avancés en télé-informatique".
- At the University Joseph Fourier of Grenoble, the EUCALYPTUS toolset is used in the course "Verification and Performance Evaluation of Distributed Systems".
- At ENSIMAG[7], the EUCALYPTUS toolset is used in the "Real-Time" course.
- At ENSERG[8], the EUCALYPTUS toolset is used the course "Specification and Verification of Protocols".
- At the University of Liège, the EUCALYPTUS toolset is used in the courses "Protocoles de réseaux d'ordinateurs" and "Ingénierie des systèmes informatiques répartis" where students apply it to medium-size case-studies (e.g. ATM switch, Token Ring);
- At ENST[9], the EUCALYPTUS toolset is used in the course "Specification and Verification of Protocols".

6.5 Internet and World-Wide Web

Following the recommendations made by the experts during the EUCALYPTUS-1 final review, several WWW (World-Wide Web) pages have been created to describe the EUCALYPTUS tools individually, the EUCALYPTUS toolset as a whole, and the EUCALYPTUS project itself. These pages are located at the following addresses:

- The APERO Home Page:

  `http://www-run.montefiore.ulg.ac.be/research-topics/LOTOS/apero.html`

- The CADP Home Page:

  `http://www.inrialpes.fr/vasy/cadp.html`

- The XELUDO Home Page:

[7] Ecole Nationale Supérieure d'Informatique et de Mathématiques Appliquées de Grenoble
[8] Ecole Nationale Supérieure d'Electronique et de Radioélectricité de Grenoble
[9] Ecole Nationale Supérieure des Télécommunications (Paris)

`http://www.csi.uottawa.ca/~lotos`

- The EUCALYPTUS Home Page in Grenoble:

  `http://www.inrialpes.fr/vasy/eucalyptus.html`

  This Web page presents a summary of the EUCALYPTUS-1 and EUCALYPTUS-2 projects, provides access to the yearly reports and to the overview publication [Gar96] describing the EUCALYPTUS toolset.

- The EUCALYPTUS Home Page in Liège:

  `http://www-run.montefiore.ulg.ac.be/projects/EUCALYPTUS.html`

- The EUCALYPTUS Home Page in Ottawa:

  `http://www.csi.uottawa.ca/~lotos/Euca`

7 Conclusion

In this Report, we have presented the achievements of the EUCALYPTUS-2 project. EUCALYPTUS-2 allowed the work undertaken during the EUCALYPTUS-1 project (1993–1994) to be continued in 1995 and 1996. As EUCALYPTUS-2 is now completed, one can measure the significant progresses made in the three tasks of the project (see Sections 3, 4 and 5) and in the dissemination of results (see Section 6):

- The software tools constituting the EUCALYPTUS toolset have been maintained and improved during EUCALYPTUS-2. The integration of Canadian and European tools was strengthened due to the adoption of a common trace format. Also, the graphical user-interface developed during EUCALYPTUS-1 was entirely rewritten, leading to a better product.

- The EUCALYPTUS tools have been applied with success to several "real-life" case-studies, either in the framework European projects or in co-operation with industrial such as Bull and Bell Northern Research. The have proven their usefulness in different application areas, including telecommunications, hardware systems, and security protocols.

- The EUCALYPTUS-2 partners are playing an active role in the definition of the Extended-LOTOS language. They have provided many contributions to this on-going standardization effort, many of which are integrated in the E-LOTOS Committee Draft, the first official ISO document on E-LOTOS issued in February 1997.

- The EUCALYPTUS-2 project achieves a good visibility, through scientific publications and tool demonstrations in international conferences. Morever, the EUCALYPTUS tools are used in many Universities and engineering schools for teaching purpose.
- Following the recommendations made by the European experts after the evaluation of EUCALYPTUS-1, an overview paper [Gar96] describing the EUCALYPTUS toolset was written and several World-Wide Web pages related to EUCALYPTUS have been developed.