INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Project-Team Metalau

Methods, Algorithms and Software for Systems and Control

Rocquencourt

THEME 4A

Activity Report

2003

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2. Overall Objectives

The objectives of the project are the design, analysis and development of new methods and algorithms for identification, simulation and control of dynamical systems. The project has been particularly active in the following areas:

- the classical theory of dynamical systems
- optimal deterministic, stochastic and robust control
- failure detection in dynamical systems
- network control and monitoring
- hybrid systems, in particular the development of Scicos
- the theory of maxplus linear systems

The methods and algorithms developed in the project are usually implemented in automatic control software, in particular Scilab which is an open-source scientific software package developed in the project. This task has been facilitated thanks to the creation of a new development project which has taken over some of the engineering tasks such as maintenance, porting, testing, etc.

The project is actively involved in the development of control, signal processing, optimization and simulation tools in Scilab, in particular Scicos, a modeler and simulator for dynamical systems which is based on research on hybrid systems. Encouraged by the interest in Scicos, expressed both by the academia and industry, developing a robust user-friendly Scicos has become an important objective of the project. A lot of effort is put on the development of Scicos within the project.

As theory and applications enrich mutually, many of the objectives of the project can be seen through the applications:

- modeling and simulation of physical systems (mechanical, electrical, fluids, thermodynamics,...) based on the theory of implicit systems
- modeling, simulation and code generation of control systems based on the theory of hybrid systems
- modeling, analysis and control of transportation systems using the maxplus algebra
- in agronomy in particular through the modeling of the growth of plants as linear systems of varying state size and with delay
- in failure detection and default localization for space systems, civil structures and other dynamical systems through the use of robust control theory, and finite element models for identification purposes

3. Scientific Foundations

3.1. Classical System Theory

3.1.1. Systems, Control and Signal Processing

Participants: F. Delebecque, S. Steer, R. Nikoukhah.

Systems, control and signal processing constitute the main foundations of the research work of the project. We have been particularly interested in numerical and algorithmic aspects. This research which has been the driving force behind the creation of Scilab has nourished this software over the years thanks to which, today, Scilab contains most of the modern tools in control and signal processing. Scilab has been a vehicle by which theoretical results of the project concerning areas such as classical, modern and robust control, signal processing and optimization, have been made available to industry and academia.

Ties between this fundamental research and Scilab are very strong. Indeed, even the design of the software itself, elementary functions and data structures are heavily influenced by the results of this research. For example, even elementary operations such as basic manipulation of polynomial fractions have been implemented using a generalization of the the state-space theory developed as part of our research on implicit systems. These ties are of course normal since Scilab has been primarily developed for applications in automatics.

Scilab has created for our research team new contacts with engineers in industry and other research groups. Being used in real applications, it has provided a guide for choosing new research directions. For example, robust control tools in Scilab have been developed in cooperation with industrial users. Similarly, Scilab's LMI toolbox has been developed with the help of other research groups. It should also be noted that most of the basic systems and control function in Scilab are based on algorithms developed in the European research project Slicot in which Metalau has taken part.

3.1.2. Implicit Systems

Participants: R. Nikoukhah, F. Delebecque, S.L. Campbell.

Implicit systems are a natural framework for modeling physical phenomena. We work on theoretical and practical problems associated with such systems in particular in applications such as failure detection and dynamical system modeling and simulation.

Constructing complex models of dynamical systems by interconnecting elementary components leads very often to implicit systems. An implicit dynamical system is one where the equations representing the behavior of the system are of the algebraic-differential type. If ξ represent the "state" of the system, an implicit system is often described as follows:

$$F(\dot{\xi}, \xi, z, t) = 0, \tag{1}$$

where $\dot{\xi}$ is the time derivative of ξ, t is the time and the vector z contains the external variables (inputs and outputs) of the system. Indeed it is an important property of implicit systems that outside variables interacting with the system need not be characterized a priori as inputs or outputs, as it is the case with explicit dynamical systems. For example if we model a capacitor in an electrical circuit as a dynamical system, it would not be possible to label a-priori the external variables, in this case the currents and voltages associated with the capacitor, as inputs and outputs. The physical laws governing the capacitor simply impose dynamical constraints on these variables. Depending on the configuration of the circuit, it is sometimes possible to specify some external variables as inputs and the rest as outputs (and thus make the system explicit) however in doing so system structure and modularity is often lost. That is why, usually, even if an implicit system can be converted into an explicit system, it is more advantages to keep the implicit model.

It turns out that many of the methods developed for the analysis and synthesis of control systems modeled as explicit systems can be extended to implicit systems. In fact, in many cases, these methods are more naturally derived in this more general setting and allows for a deeper understanding of the existing theory. In the past few years, we have studied a number of systems and control problems in the implicit framework.

For example in the linear discrete time case, we have revisited classical problems such as observer design, Kalman filtering [15][11][12], residual generation [13] to extend them to the implicit case or have used techniques from implicit system theory to derive more direct and efficient design methods. Another area where implicit system theory has been used is failure detection. In particular in the mutli-model approach where implicit systems arise naturally from combining multiple explicit models.

We have also done work on nonlinear implicit systems [3]. For example nonlinear implicit system theory has been used to develop a predictive control system [20] and a novel nonlinear observer design methodology. Research on nonlinear implicit systems continues in particular because of the development of the "implicit" version of Scicos (see Section 7.2).

3.2. Failure detection in dynamical systems

Participants: R. Nikoukhah, M. Goursat, S.L. Campbell.

3.2.1. Active failure detection

Participants: R. Nikoukhah, S.L. Campbell.

Failure detection has been the subject of many studies in the past. Most of these works are concerned with the problem of *passive failure detection*. In the passive approach, for material or security reasons, the detector has no way of acting upon the system; the detector can only monitor the inputs and the outputs of the system and then decides whether, and if possible what kind of, a failure has occurred. This is done by comparing the measured input-output behavior of the system with the "normal" behavior of the system. The passive approach is often used to continuously monitor the system although it can also be used to make periodic checks.

In some situations however failures can be masked by the operation of the system. This often happens in controlled systems. The reason for this is that the purpose of controllers, in general, is to keep the system at some equilibrium point even if the behavior of the system changes. This robustness property, desired in control systems, tends to mask abnormal behaviors of the systems. This makes the task of failure detection difficult. An example of this effect is the well known fact that it is harder for a driver to detect an under-inflated or flat front tire in a car which is equipped with power steering. This tradeoff between detection performance and controller robustness has been noted in the literature and has lead to the study of the integrated design of controller and detector.

But the problem of failures being masked by system operation is not limited to controlled systems. Some failures may simply remain hidden under certain operating conditions and show up only under special circumstances. For example, a failure in the brake system of a truck is very difficult to detect as long as the truck is cruising down the road on level ground. It is for this reason that on many roads, just before steep downhill stretches, there are signs asking truck drivers to test their brakes. A driver who ignores these signs would find out about a brake failure only when he needs to brake going down hill, i.e., too late.

An alternative to passive detection which could avoid the problem of failures being masked by system operation is *active detection*. The active approach to failure detection consists in acting upon the system on a periodic basis or at critical times using a test signal in order to detect abnormal behaviors which would otherwise remain undetected during normal operation. The detector in an active approach can act either by taking over the usual inputs of the system or through a special input channel. An example of using the existing input channels is testing the brakes by stepping on the brake pedal.

The active detection problem has been less studied than the passive detection problem. The idea of injecting a signal into the system for identification purposes has been widely used. But the use of extra input signals in the context of failure detection has only been recently introduced.

The specificity of our approach to solving the problem of auxiliary signal design is that we have adopted a deterministic point of view in which we model uncertainty using newly developed techniques from H_∞ control theory. In doing so, we can deal efficiently with the robustness issue which is in general not properly dealt with in stochastic approaches to this problem. This has allowed us in particular to introduce the notion of *guaranteed failure detection*.

The active failure detection method considered is illustrated in Figure 1. The auxiliary signal v is injected into the system to facilitate detection; it can be part or all of the system inputs. The signal u denotes the remaining inputs measured on-line just as the outputs y are measured online. In some applications the time trajectory of u may be known in advance but in general the information regarding u is obtained through sensor data in the same way that it is done for the output y.

Suppose we have only one possible type of failure. Then we have two sets of input-output behaviors to consider and hence two models. The set $\mathcal{A}_0(v)$ is the set of normal input-outputs $\{u, y\}$ from Model 0 and the set $\mathcal{A}_1(v)$ is the set of input-outputs when failure occurs. That is, $\mathcal{A}_1(v)$ is from Model 1. These sets represent possible/likely input-output trajectories for each model. Note that Model 0 and Model 1 can differ greatly in size and complexity but they have in common u and y.

The problem of auxiliary signal design for guaranteed failure detection is to find a "reasonable" v such that

$$\mathcal{A}_0(v) \cap \mathcal{A}_1(v) = \varnothing.$$

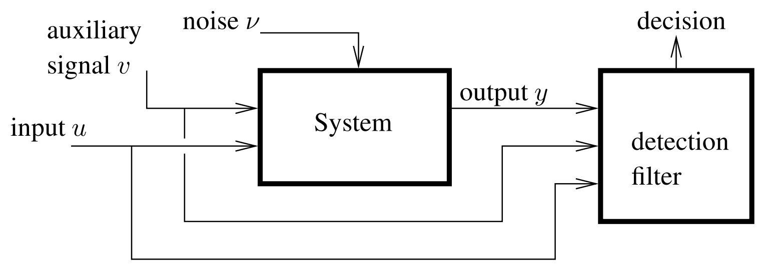

Figure 1: Active failure detection.

Figure 1.

That is, any observed pair $\{u, y\}$ must come only from one of the two models. Here reasonable v means a v that does not perturb the normal operation of the system too much during the test period. This means, in general, a v of small energy applied over a short test period. However, depending on the application, "reasonable" can imply more complicated criteria.

Depending on how uncertainties are accounted for in the models, the mathematics needed to solve the problem can be very different. For example guaranteed failure detection has been first introduced in [14] where unknown bounded parameters were used to model uncertainties. This lead to solution techniques based on linear programming algorithms. But in most of our works, we consider the types of uncertainties used in robust control theory. This has allowed us to develop a methodology based on established tools such as Riccati equations that allow us to handle very large multivariable systems. The methodology we develop for the construction of the optimal auxiliary signal and its associated test can be implemented easily in computational environments such as Scilab. Moreover, the online detection test that we obtain is similar to some existing tests based on Kalman filters and is easy to implement in real-time. The results of our research can be found in the book [21].

3.2.2. Passive failure detection: Modal analysis and diagnosis

Participant: M. Goursat.

We consider mechanical systems with the corresponding stochastic state-space models of automatic control.

The mechanical system is assumed to be a time-invariant linear dynamical system:

$$\begin{cases} M\ddot{\mathcal{Z}}(t) + C\dot{\mathcal{Z}}(t) + K\mathcal{Z}(t) & = & \nu(t) \\ Y(t) & = & L\mathcal{Z}(t) \end{cases}$$

where the variables are : $\mathcal{Z}$: displacements of the degrees of freedom, M, C, K: mass, damping, stiffness matrices, t: continuous time; ν: vector of external (non measured) forces modeled as a non-stationary white noise; L: observation matrix giving the observation Y (corresponding to the locations of the sensors on the structure). The modal characteristics are: μ the vibration modes or eigen-frequencies and ψ_μ the modal shapes or eigenvectors. They satisfy:

$$(M\mu^2 + C\mu + K)\Psi_\mu = 0 \qquad , \quad \psi_\mu = L\Psi_\mu$$

By stacking Z and $\dot{\mathcal{Z}}$ and sampling at rate $1/\delta$, i.e.,

$$X_k = \begin{bmatrix} \mathcal{Z}(k\delta) \\ \dot{\mathcal{Z}}(k\delta) \end{bmatrix} \quad , \quad Y_k = Y(k\delta)$$

we get the following equivalent state-space model:

$$\begin{cases} X_{k+1} &= FX_k + V_k \\ Y_k &= HX_k \end{cases}$$

with

$$F = \exp(A\delta) \quad , \quad H = \left[\begin{array}{cc} L & 0 \end{array}\right] \quad \text{and} \quad A = \left[\begin{array}{cc} 0 & I \\ -M^{-1}K & -M^{-1}C \end{array}\right]$$

The mechanical systems under consideration are vibrating structures and the numerical simulation is done by the finite element model.

The objectives are the analysis and the implementation of statistical model-based algorithms, for modal identification, monitoring and (modal and physical) diagnosis of such structures.

For modal analysis and monitoring, the approach is based on subspace methods using the covariances of the observations: that means that all the algorithms are designed for in-operation situation, i.e., without any measurement or control on the input (the situation where both input and output are measured is a simple special case).

The identification procedure is realized on the healthy structure.

The second part of the work is to determine, given new data after an operating period with the structure, if some changes have occurred on the modal characteristics.

In case there are changes, we want to find the most likely localization of the defaults on the structure. For this purpose we have to do the matching of the identified modal characteristics of the healthy structure with those of the finite element model. By use of the different Jacobian matrices and clustering algorithms we try to get clusters on the elements with the corresponding value of the "default criterion".

This work is done in collaboration with the INRIA-IRISA project SIGMA2 (see the website of this project for a complete presentation and bibliography) and with the project MACS for the physical diagnosis (on civil structures).

3.3. Exotic Systems

3.3.1. Hybrid dynamical systems

Participant: R. Nikoukhah.

Originally motivated by problems encountered in modeling and simulation of failure detection systems, the objective of this research is the development of a solid formalism for efficient modeling of hybrid dynamical systems.

A hybrid dynamical system is obtained by the interconnection of continuous time, discrete time and event driven models. Such systems are common in most control system design problems where a continuous time model of the plant is hooked up to a discrete time digital controller.

The formalism we develop here tries to extend methodologies from Synchronous languages to the hybrid context. Motivated by the work on the extension of Signal language to continuous time, we develop a formalism in which through a generalization of the notion of event to what we call *activation signal*, continuous time activations and event triggered activations can co-exist and interact harmoniously. This means in particular that standard operations on events such as subsampling and conditioning are also extended and operate on activation signals in general paving the way for a uniform theory.

The theoretical formalism developed here is the backbone of the modeling and simulation software Scicos. Scicos is the place where the theory is implemented, tested and validated. But Scicos has become more than just an experimental tool for testing the theory. Scicos has been successfully used in a number of industrial projects and has shown to be a valuable tool for modeling and simulation of dynamical systems.

Encouraged by the interest in Scicos, expressed both by the academia and industry, beyond the theoretical studies necessary to ensure that the bases of the tool are solid, the project has started to invest considerable effort on improving its usability for real world applications. Developing a robust user-friendly Scicos has become one of the objectives of the project.

3.3.2. Maxplus Algebra, Discrete Event Systems and Dynamic Programming

Participants: G. Cohen, S. Gaubert, J.P. Quadrat.

In the modeling of human activities, in contrast to natural phenomena, quite frequently only the operations max (respectively min) and $+$ are needed (this is the case in particular of some queuing or storage systems, synchronized processes encountered in manufacturing, traffic systems, when optimizing deterministic dynamic processes, etc.).

The set of real numbers endowed with the operation max (respectively min) denoted $\oplus$ and the operation $+$ denoted $\otimes$ is a nice mathematical structure that we may call an idempotent semi-field. The operation $\oplus$ is idempotent and has the neutral element $\varepsilon = -\infty$ but it is not invertible. The operation $\otimes$ has its usual properties and is distributive with respect to $\oplus$. Based on this set of scalars we can build the analogue of a module and write the general (n, n) system of linear maxplus equations:

$$Ax \oplus b = Cx \oplus d,$$

using matrix notation where we have made the natural substitution of $\oplus$ for $+$ and of $\otimes$ for $\times$ in the definition of the matrix product.

A complete theory of such linear system is still not completely achieved. In recent development we try to have a better understanding of image and kernel of maxplus matrices.

System theory is concerned with the input (u)-output (y) relation of a dynamical system ($\mathcal{S}$) denoted $y = S(u)$ and by the improvement of this input-output relation (based on some engineering criterium) by altering the system through a feedback control law $u = F(y, v)$. Then the new input (v)-output (y) relation is defined implicitly by $y = S(F(y, v))$. Not surprisingly, system theory is well developed in the particular case of linear shift-invariant systems. Analogously, a min-plus version of this theory can also be developed.

In the case of SISO (single-input-single-output) systems, u and y are functions of time. In the particular case of a shift-invariant linear system, S becomes an inf-convolution:

$$y = h \,\square\, u \overset{\text{déf}}{=} \inf_s [h(s) + u(\cdot - s)]$$

where h is a function of time called the impulse response of system $\mathcal{S}$. Therefore such a system is completely defined by its impulse response. Elementary systems are combined by arranging them in parallel, series and feedback. These three engineering operations correspond to adding systems pointwise ($\oplus$), making inf-convolutions ($\otimes$) and solving special linear equations ($y = h \otimes (f_1 \otimes y \oplus f_2 \otimes v)$) over the set of impulse responses. Mathematically we have to study the algebra of functions endowed with the two operations $\oplus$ and $\otimes$ and to solve special classes of linear equations in this set, namely when $A = E$ in the notation of the first part.

An important class of shift-invariant min-plus linear systems is the process of counting events versus time in timed event graphs (a subclass of Petri nets frequently used to represent manufacturing systems). A dual theory based on the maxplus algebra allows the timing of events identified by their numbering.

The Fourier and Laplace transforms are important tools in automatic control and signal processing because the exponentials diagonalize simultaneously all the convolution operators. The convolutions are converted into multiplications by the Fourier transform. The Fenchel transform ($\mathcal{F}$) defined by:

$$[\mathcal{F}(f)](p) = \sup_x [px - f(x)],$$

plays the same role in the min-plus algebra context. The affine functions diagonalize the inf-convolution operators and we have:

$$\mathcal{F}(f \,\square\, g) = \mathcal{F}(f) + \mathcal{F}(g).$$

A general inf-convolution is an operation too complicated to be used in practice since it involves an infinite number of operations. We have to restrict ourselves to convolutions that can be computed with finite memory. We would like that there exists a finite state x representing the memory necessary to compute the convolution recursively. In the discrete-time case, given some h, we have to find (C, A, B) such that $h_n = CA^nB$, and $y = h \,\square\, u$ is then 'realized' as

$$x_{n+1} = Ax_n \oplus Bu_n, \;\; y_n = Cx_n.$$

SISO systems (with increasing h) which are realizable in the min-plus algebra are characterized by the existence of some λ and c such that for n large enough:

$$h_{n+c} = c \times \lambda + h_n.$$

If h satisfies this property, it is easy to find a 3-tuple (A, B, C).

This beautiful theory is difficult to be applied because the class of linear systems is not large enough for realistic applications. Generalization to nonlinear maxplus system able to model general Petri nets is under development.

Dynamic Programming in the discrete state and time case amounts to finding the shortest path in a graph. If we denote generically by n the number of arcs of paths, the dynamic programming equation can be written linearly in the min-plus algebra:

$$X_n = A \otimes X_{n-1},$$

where the entries of A are the lengths of the arcs of the graph and X_n denotes the matrix of the shortest lengths of paths with n arcs joining any pair of nodes. We can consider normalized matrices defined by the fact that the infimum in each row is equal to 0. Such kind of matrices can be viewed as the min-plus analogue of transition matrices of a Markov chain.

The problem

$$v_x^n = \min_u \left[\sum_{i=n}^{N-1} \phi(u_i) + \psi(x_N) \mid x_n = x \right], \; x_{i+1} = x_i - u_i$$

may be called dynamic programming with independent instantaneous costs (ϕ depends only on u and not on x). Clearly v satisfies the linear min-plus equation:

$$v^n = \phi \,\square\, v^{n+1}, \;\; v^N = \psi$$

(the Hamilton-Jacobi equation is a continuous version of this problem).

The Cramer transform ($\mathcal{C} \overset{\text{déf}}{=} \mathcal{F} \circ \log \circ \mathcal{L}$), where $\mathcal{L}$ denotes the Laplace transform, maps probability measures to convex functions and transform convolutions into inf-convolutions:

$$\mathcal{C}(f * g) = \mathcal{C}(f) \,\square\, \mathcal{C}(g).$$

Therefore it converts the problem of adding independent random variables into a dynamic programming problem with independent costs.

These remarks suggest the existence of a formalism analogous to probability calculus adapted to optimization that we have developed.

The theoretical research in this domain is currently done in the maxplus project. In the Metalau project we are more concerned with applications to traffic systems of this theory.

4. Application Domains

4.1. Transport

Participants: P. Lotito, E. Mancinelli, J.P. Quadrat.

Traffic modeling is a domain where maxplus algebra appears naturally : – at microscopic level where we follow the vehicles in a network of streets, – at macroscopic level where assignment are based on computing smallest length paths in a graph, – in the algebraic duality between stochastic and deterministic assignments.

We develop free computing tools and models of traffic implementing our experience on optimization and discrete event system modeling based on maxplus algebra.

4.1.1. Microscopic Traffic Modeling

Following [61] let us consider a circular road with places occupied or not by a car symbolized by a 1. The dynamic is defined by the rule $10 \to 01$ that we apply simultaneously to all the parts of the word m representing the system. For example, starting with $m_1 = 1010100101$ we obtain the sequence of works (m_i):

$$\begin{aligned} m_1 &= 1010100101, \\ m_2 &= 0101010011, \\ m_3 &= 1010101010, \\ m_4 &= 0101010101, \\ m_5 &= 1010101010, \\ \text{etc.} \end{aligned}$$

For such a system we can call density d the number of cars divided by the number of places called p that is $d = n/p$. We call flow $f(t)$ at time t the number of cars at this time period divided by the place number. The fundamental traffic law gives the relation between $f(t)$ and d.

If the density is smaller than $1/2$, after a transient period of time all the cars are separated and can go without interaction with the other cars. Then $f(t) = n/p$ that can be written as function of the density as $f(t) = d$

on the contrary if the density is larger than $1/2$ all the free places are separated after a finite amount of time and go backward freely. Then we have $p - n$ car which can go forward. Then the relation between flow and density becomes

$$f(t) = (p - n)/p = 1 - d \ .$$

This can be stated formally: it exists a time T such that for all $t \geq T$ $f(t)$ stays equal to a constant that we call f with

$$f = \begin{cases} d & \text{si } \ d \leq 1/2 \ , \\ 1 - d & \text{si } \ d \geq 1/2 \ . \end{cases}$$

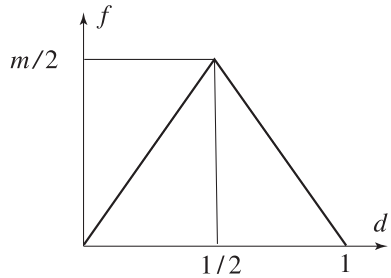

Figure 2. Fundamental traffic law

The fundamental traffic law linking the density of vehicle and the flow of vehicle can be also derived easily from maxplus modeling : – in the deterministic case by computing the eigenvalue of a maxplus matrix, – in the stochastic case by computing a Lyapounov exponent of stochastic maxplus matrices see [8].

The main research consists in developing extensions to systems of roads with crossings. In this case, we leave maxplus linear modeling and have to study more general dynamical systems. Nevertheless these systems can still be defined in matrix form using standard and maxplus linear algebra simultaneously.

With this point of view efficient microscopic traffic simulator can be developed in Scilab.

4.1.2. Traffic Assignment

Given a transportation network $\mathcal{G} = (\mathcal{N}, \mathcal{A})$ and a set $\mathcal{D}$ of transportation demands from an origin $o \in \mathcal{N}$ to a destination $d \in \mathcal{N}$ the *traffic assignment* problem consists in determining the flows f_a on the arcs $a \in \mathcal{A}$ of the network when the times t_a spent on the arcs a are given functions of the flows f_a.

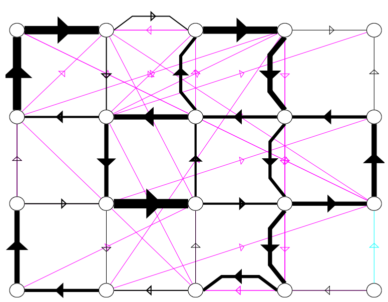

Figure 3. A Regular Small Town

We can distinguish the deterministic case — when all the travel times are known by the users — from the stochastic cases — when the users perceive travel times different from the actual ones.

1. When the travel times are deterministic and do not depend on the link flows, the assignment can be reduced to compute the routes with shortest travel times for each origin-destination pair.
2. When the travel times are deterministic and depend on the link flows, Wardrop equilibriums are defined and computed by iterative methods based on the previous case.
3. When the perceived travel times do not depend on the link flows but are stochastic with error distribution — between the perceived time and the actual time — satisfying a Gumbel distribution, the probability that a user choose a particular route can be computed explicitly. This probability has a Gibbs distribution called logit in transportation literature. From this distribution the arc flows

— supposed to be deterministic — can be computed using a matrix calculus which can be seen as the analogue of the shortest path computation (of the case 1) up to the substitution of the minplus semiring by the Gibbs-Maslov semiring [66][67], where we call Gibbs-Maslov semiring the set of real numbers endowed with the following two operations :

$$x \oplus^{\mu} y = -\frac{1}{\mu}\log(e^{-\mu x} + e^{-\mu y})\ ,\quad x \otimes y = x + y\ .$$

4. When the perceived travel times are stochastic and depend on the link flows — supposed to be deterministic quantities — stochastic equilibriums are defined and can be computed using iterative methods based on the logit assignments discussed in the case 3.

The purpose of this research is double :

1. To study an engineering example of quantization. By quantization we mean the application of a morphism changing a deterministic optimization problem into a linear system of equations for modeling improvement by analogy with the way we obtain the Quantum Mechanics Equation from the Hamilton-Jacobi Equation of a system. This quantization can be seen as an application of what we have called previously "the duality between probability and optimization" introduced in the section 4.1.2.
2. To develop a toolbox in Scilab dedicated to traffic assignment (see [60][62][71][68]) indeed it does not exist any free toolbox for this kind of application.

4.2. Modal analysis and diagnosis

Participant: M. Goursat.

We have used the techniques developed for modal analysis and diagnosis in many different applications: rotating machines, aircrafts, parts of cars, space launcher, civil structures. The most recent examples are:

- Eureka (FLITE) project: exploitation of flight test data under natural excitation conditions.
- Ariane 5 launcher: application to a ground experiment (contract with CNES and EADS Space Transportation)
- Steelquake: a European benchmark for a civil structure.

4.3. Plant Modeling

Participants: Ph. de Reffye, M. Goursat, J.P. Quadrat.

Mathematical models on tree architecture principally concern the step by step algorithms depending on a genetic program, that insure the organ production during the growth process. Adding geometrical rules, one can obtain nice shapes of trees that are used mainly in the world of computer graphics. This pure morphogenetic approach has given more particularly a formalism based on grammar called L-System [70] or on Automata [17].

In Agronomy, the vegetable matter production is the main goal. Simulation of the photosynthesis (biomass production and biomass allocation) is then performed, thank to crude plant models mainly divided in compartments (leaves, branches, roots,...). No specific formalism has been developed in these last cases [63][72].

Recently new kind of tree models arouse, named "structural functional tree" [69], [16][6]. These models endeavor to combine both aspects: organogenesis and photosynthesis. The L-System approach has, then, also incorporated interactions with environment [64][65]. In all the cases the principle of the growth starting from seed and the parallel simulation of numerous buds can make the computing time of a big tree quite long.

Figure 4. The geometry of a tree with 5 physiological ages.

A new approach of tree computation has been done in the dynamical model GreenLab. Thanks to the Physiological Ages notion and the botanical description, it is possible to divide a tree according to substructures that can be retrieved frequently inside the main architecture. Computing only one time these substructures improves dramatically the speed of the computation [7][9][10].

5. Software

5.1. Scilab Research Core Team

Participants: F. Delebecque, S. Steer, R. Nikoukhah, M. Goursat, J.-Ph. Chancelier.

SRCT (Scilab Research Core Team) is currently made up of original Scilab developers but in terms will include other researchers, from Inria and elsewhere. The team has developed Scilab Core and most of the applications available in it and has expertise in scientific areas of interest to Scilab users. As such, the team provides scientific support for the development team which is in charge of developing Scilab since the creation of the Scilab Consortium. For example, the team responds to user inquiries about scientific questions related to various tools available in Scilab, and in particular those developed by the project members.

The team also continues to develop and improve most fundamental tools in Scilab such as control, simulation and optimization functions. For doing this, it tries to establish contact with other research groups who may be interested in contributing to Scilab.

Finally, the team studies various solutions to improve the kernel of Scilab, something which cannot be done without the experience and expertise in systems and control applications. The team implements different solutions, tests them and proposes them to the Consortium for possible integration in Scilab.

5.2. Scilab

Participants: F. Delebecque, S. Steer, R. Nikoukhah, M. Goursat, C. Gomez, J.-Ph. Chancelier.

Scilab is a general purpose numerical scientific software package. Scilab has been developed by the Metalau project with major contributions from J.-Ph.Chancelier of ENPC. The development of Scilab dates back to the 80's and it originated as a simple interpreter manipulating matrices using routines from standard linear algebra libraries. From the beginning, Scilab has been used for systems control and signal processing applications for which it is particularly well adapted.

Over the years, many functionalities have been added to Scilab including sophisticated data structures, powerful graphics and many application oriented toolboxes developed within the project or contributed by other research teams.

Since 1994, Scilab is distributed freely over the Internet with all of its source code. Today, it is being widely used all over the world both in the academia and in the industry. To be able to propose professional support and maintenance to the users, a Consortium, financed by industrial and academic partners, has been created along with a development Inria project-team in 2003. The development project-team Scilab has the responsibility of new releases; it takes care of testing, porting and validating the code, and other similar tasks. See the Activity Report of Scilab project-team for more details. The Consortium is a place for industrial users to express their needs and their wishes with regards to the development of new functionalities in Scilab. Some of these developments can be done within the Scilab project-team.

The evolution of Scilab is based on research activities in automatic control and computer science. These activities remain the responsibility of the Metalau project-team which either does the research itself or manages outside scientific contributions. The transfer of these research activities to the development of Scilab is in part assured by two Metalau researchers who participate on a part time basis in the development of Scilab within the Scilab project. Other scientific activities such as organizing conferences, workshops, training and international contacts are assured by the Metalau project.

Since most Scilab built-in basic functions and toolboxes are developed and maintained by Metalau project, only software engineering issues and the first level maintenance such as porting to and testing on new platforms

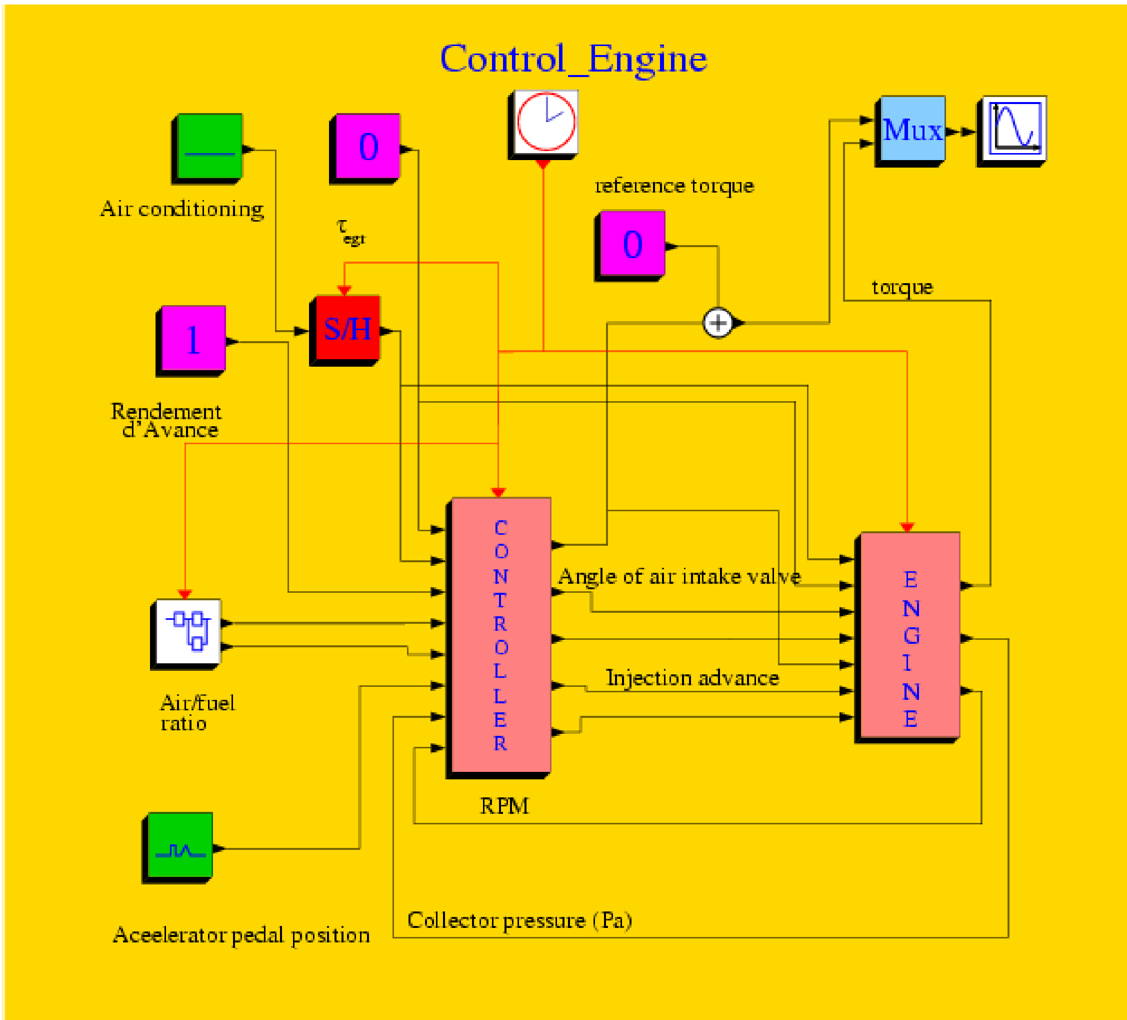

Figure 5. Scicos used in automotive applications

are handled by the Scilab project; scientific issues and future developments are the responsibility of the Metalau project.

5.2.1. Specialized Toolboxes

Based on long tradition of research in automatic control and optimization in the Metalau project, a number of specialized toolboxes have been developed during the past two decades. Control, Robust control, Signal Processing Polynomial, LMI optimization, maxplus arithmetic, Traffic assignment, Modal analysis, Scicos and Metanet toolboxes but also basic Scilab functionalities for simulation and optimization have been developed and continue to be developed within our project.

5.2.2. Academic contacts

Academic contacts nourish the development of Scilab through the open-source model. The usage of Scilab in the academic world is crucial both for Scilab and its development and for the research in Metalau project. That is why the project is actively seeking national and international research cooperations. For example many contacts have been established with West African, Chinese and Indian Universities in the past few years. The project has also been involved in national (RNTL,..) and European projects (Slicot,..). The project also encourages the use of Scilab in academia both directly and indirectly. Thanks to our efforts, today Scilab is used for teaching purposes at ENSTA, ENPC, Ecole des Mines, Ecole Polytechnique and many others in France and elsewhere in the world.

5.3. Scicos

Participants: R. Nikoukhah, S. Steer.

Scicos (http://www.scicos.org) is a dynamic systems modeler and simulator. It is a Scilab toolbox included in the Scilab package. Written in C and Scilab language, it comes with complete source code.

Scicos provides many functionalities available in commercial products such as Simulink and MatrixX and can replace these products in many applications. In particular, Scicos includes:

- Graphical Editor: Scicos provides a hierarchical graphical editor for the construction of models of dynamical systems using block diagrams. A number of predefined blocks are also provided in various palettes. New blocks can be defined by the user in C, Fortran or Scilab.
- Compiler: Scicos compiler uses the model description, usually compiled by the Scicos editor, to construct scheduling tables which can then be used by the simulator and the code generation function.
- Simulator: Scicos simulator uses the scheduling tables and other information provided by the compiler to run simulations. The simulator is of hybrid nature in that it has to deal with discrete and continuous time systems, and events. For the continuous time part, it uses the ODE solver LSODAR or the DAE solver DASKR depending on the nature of the continuous time system considered.
- Code generator: Scicos can generate C code for realizing the behavior of some subsystems. These subsystems should not include continuous time components.

The development of Scicos is done in close collaboration with industrial partners, in particular in the framework of RNTL projects.

5.4. CiudadSim

Participants: P. Lotito, E. Mancinelli, J.P. Quadrat.

This toolbox is dedicated to traffic assignment. A first version supported by DTT (Direction des transports terrestres) has been achieved this year. It is available, on the Web, as a Scilab contribution.

5.5. Greenlab

Participant: P. De Reffye.

There are different parts of software (at Liama, Inria, Cirad) for plants modeling, growth simulation and visualization. This work was initiated in LIAMA. The goal is to obtain a fully integrated software as a toolbox of Scilab. A preliminary version is under development and can be used for simple trees. A released version should be available in 2004.

6. New Results

6.1. Plant growth modeling

6.1.1. Greenlab revisited

Participants: P. De Reffye, M. Goursat, J.-P. Quadrat.

We make explicit the dynamic equations that follow a tree during its growth according to the Greenlab model (Organogenesis, Photosynthesis and Morphogenesis). Some of these dynamic equations were still implicit inside the Greenlab software. This work was an attempt to write completely the equations at least in the simplest case where there the Organogenesis does not depend for of the Morphogenesis. The result has been published in [57]. This work and the introduction of the feedback between photosynthesis and organogenesis is developed in cooperation with ECP.

6.2. Computer aided control system design (CACSD)

6.2.1. Scicos

Participants: R. Nikoukhah, S. Steer, A. Azil, M. Najafi, J. Agrawal, R. Djenidi.

Major effort has been invested in the development of Scicos this past year. This development is now supported by outside research and development teams through RNTL projects Simpa, Eclipse and Metisse.

A number of issues concerning Scicos formalism have been resolved allowing for major improvement of the compiler and the simulator. In particular, by introducing improvements in the ODE (Ordinary Differential Equation) and DAE (Differential Algebraic Equation) solvers used in Scicos, Lsodar and Daskr, Scicos simulator has been greatly simplified resulting in more efficient simulations. Some of these improvements proposed by M. Najafi, in particular concerning the handling of zero-crossings, have been included in Daskr by the authors of the code.

The compiler has also been revisited and improved. But some inefficiency problems remain which in some cases result in very long compilation times. These problems have been identified and are currently under investigation by A. Azil.

The extension of Scicos to allow for “implicit blocks” in the framework of the RNTL Simpa project has been pursued. New block types have been introduced facilitating the development of new blocks in general. Implicit blocks pose however new problems because the continuous time behaviors of the model can now be of DAE type. This has lead in particular to problems with the computation of consistent initial condition, a difficult problem in the hybrid context. This problem is studied in particular by M. Najafi in his doctoral work. Our new Post-Doc J. Agrawal, specialized in discontinuous DAE’s, will be working on these issues as well.

Finally work is under way to upgrade the Code Generation facility to work with new block types. In terms, the Code Generation facility will be extended to allow for continuous time blocks through the usage of fixed step numerical solvers. This work is undertaken by A. Azil and should be useful for the two RNTL projects Eclipse and Metisse.

On the more practical side, the work on the extension of Scicos editor to accept non-oriented links and blocks has continued. R. Djenidi has developed automatic testing routines for various editor functionalities and basic blocks. Overall, the robustness of the editor has been greatly improved. The user interface has also been improved, in particular under the Windows environment. This has been done through the usage of tcl-tk for block and editor GUI. But also by fixing two major limitations of Scilab graphics with the help of J.Ph.

Chancelier of ENPC: the absence of backing store under Windows and fixed size postscript export of graphical window contents.

6.2.2. Scilab activities

Participants: F. Delebecque, S. Steer, R. Nikoukhah, J.-Ph. Chancelier, B. Pinçon.

- Mex files for Scilab
  To facilitate interoperability with Matlab, an interface has been developed to emulate Matlab Mex function mechanism.
- Integration of new built-in functions: the least square optimizer LSQR based on Levenberg-Marquardt algorithm of MINPACK, sparse eigenproblem solver from ARPACK
- Port of the Matlab toolbox CUTEr (http://hsl.rl.ac.uk/cuter-www) for testing linear solvers and optimization routines
- Addition of backing store for graphical windows under Windows environment and the improvement of the postscript generation mechanism in Scilab
- Hard coding of hypermatrix operations to improve speed.
- Some extensions of Scilab language

6.2.3. Labostat

Participants: C. Klimann, Y. Lechevallier.

We have continued the development of the new "spreadsheet" environment for statistics in Scilab. Some problems have been fixed and the Partial Least Squares algorithm has been thoroughly tested although its implementation requires further improvements. A number of routines in Exploratory Data Analysis, sampling and non parametric statistics were also added.

6.3. Control and signal processing

6.3.1. Auxiliary signal design for active failure detection

Participants: R. Nikoukhah, S.L. Campbell.

The active approach to failure detection consists in acting upon the system using a test signal called an *auxiliary signal* in order to detect abnormal behaviors which would otherwise remain undetected during normal operation. This year we have spent a lot of time compiling our research works on active failure detection into a book to be published in 2004 ([21]). We have also extended our auxiliary signal design methodology to the sampled-data case, a case which has many practical applications.

We have studied in particular the problem of active failure detection in continuous-time dynamical systems with sampled observations. This work follows previous works where we have considered multiple models to represent the behaviors of normal and failed systems and used a deterministic set membership approach to seek guaranteed detectability. Many of the ideas we use here come from these studies. What is new in is the hybrid nature of the model (continuous-time dynamics with discrete-time observations). These models which are called sampled-data systems are often encountered in practice where a physical process is connected to a digital controller/detector. This work has been presented at the European Control Conference [53].

6.3.2. Control and failure detection: an integrated design approach

Participants: R. Nikoukhah, J. Khosrowjerdi.

Failure detection mechanism is usually designed separately from the control mechanism even though they both process the same information obtained via the sensors placed on the controlled system. Indeed both mechanisms use sensor outputs to estimate the state of the system using observers. So it is only natural to consider the integrated design of failure detection and control mechanisms in order to reduce controller/detector complexity.

The difficulty however is that control and failure detection don't use the same performance objectives: for robustness purposes, control uses the H_∞ norm whereas failure detection uses the H_2 norm. This means that the observers needed for the two mechanisms are not identical.

M. Khosrowjerdi in his thesis has addressed this problem and has developed an integrated approach using a mixed H_2/H_∞ methodology. He has obtained solutions based on coupled Riccati equations and LMI techniques. M. Khosrowjerdi defended his thesis in October and some of his results appeared in [47].

6.3.3. Robust estimation

Participants: R. Nikoukhah, S. Campbell.

We have examined the problem of robust least-square estimation with relative entropy constraint [30]. Given a nominal statistical model, we consider the minimax estimation problem consisting of finding the best least-squares estimator for the least-favorable statistical model within a neighborhood of the nominal model. The neighborhood is formed by placing a bound on the Kullback-Leibler divergence between the actual and nominal models. For a Gaussian nominal model and a finite observations interval, or for a stationary Gaussian process over an infinite interval, the usual noncausal Wiener filter remains optimal. However the worst-case performance of the filter is affected by the size of the neighborhood representing the model uncertainty. On the other hand, standard causal least-squares estimators are not optimal, and a characterization is provided for the causal estimator and the corresponding least-favorable model. The causal estimator takes the form of a risk-sensitive estimator with an appropriately selected risk sensitivity coefficient. We are currently examining the links with H_∞ filters.

6.4. Discrete Event Systems, Maxplus Algebra and Dynamic programming

6.4.1. Maxplus Convex Analysis

Participants: G. Cohen, S. Gaubert, J.P. Quadrat.

The previous work on separation theorems of convex sets in maxplus algebra is accepted for publication [26].

Another work showing that maxplus convex functions are envelope of maxplus affine functions has been presented at the Workshop on Idempotent Mathematics and Mathematical Physics at ESI (International Erwin Schrödinger Institute for Mathematical Physics) Vienna, February, 2003. It is also available at [25].

6.4.2. Idempotent SemiModules

Participants: G. Cohen, S. Gaubert, J.P. Quadrat.

In studying projectors on semimodules we have shown in previous works that the projector on a semimodule parallel to another semimodule is sometimes maxplus linear, sometimes nonlinear, depending on the semimodules. In this work we try to characterize the semimodules called regular or projective on which it is possible to make linear projection. Some results have been presented at the International Workshop on Max-algebra, Birmingham university, June 2003. We are currently writing a paper giving all the known characterizations of these regular semimodules.

6.4.3. Dynamic linear system theory

Participant: E. Rofman.

Participation at the supervision of the thesis of R. Katz directed by S. Gaubert, see MAXPLUS project report.

6.5. Transport

6.5.1. Fundamental Traffic Law in Regular Town and Optimal Control of Traffic lights

Participants: P. Lotito, E. Mancinelli, J.P. Quadrat, Tao Zhenyu.

In this work we continue two previous works. The first one, with P. Ndong, was on determining the fundamental traffic law for a road system with crossings. The fundamental traffic law gives the relation between the average flow and the density of vehicles in the system. We have continued this work by improving the modeling in terms of Petri Nets of such kind of systems. This year we have obtained a way to determine the equations for a general Petri Net and we have applied it to a crossing with or without traffic lights. Previously, we were able to write the equations only for simplified models.

The second work, done with E. Mancinelli some years ago, was to determine the traffic light control using maxplus algebra techniques. This year, following Papageorgiou, we use standard LQG technique to determine the light cycles. Then, we evaluate the results on the Petri Nets models of the first part. In particular, we show the improvement of the feedback traffic light control on the fundamental traffic law. Preliminary results are given in the Industrial Master Thesis of Tao Zhenyu.

Moreover, a previous work with P. Lotito and E. Mancinelli on the derivation by maxplus methods of the fundamental traffic law, in the case of a unique circular road, has been improved and submitted to IEEE-AC journal. A survey on this point of view will be soon available in [31].

6.5.2. CiudadSim the Traffic Toolbox of Scilab

Participants: G. Cohen, P. Lotito, E. Mancinelli, J.P. Quadrat, L. Wynter.

Key words: *transport*, *trafic*.

The traffic Assignment Toolbox started previously has been finished this year. It is able to edit and visualize transport networks, to compute Wardrop equilibriums, stochastic traffic assignment and equilibriums. Some Network examples are given. It is freely available on the Web as a contribution to Scilab. A report [56] explains the functionality and gives the complete documentation of the toolbox.

Moreover, explicit formula for stochastic logit assignments have been obtained. The duality between deterministic and stochastic assignments seen as the same problem up to a change of algebra has been understood. In [55] these formula and this duality are explained. This work has been presented also at the Workshop on Idempotent Mathematics and Mathematical Physics ESI (International Erwin Schrödinger Institute for Mathematical Physics), Vienna, February, 2003.

6.5.3. Optimal pricing of traffic network resources

Participants: P. Lotito, E. Mancinelli, J.P. Quadrat.

This work is concerned with the bi-level optimization problem where we want, at the upper level, optimize the prices of some resources of a traffic network taking into account the impact of this pricing on the traffic assignment defined by an optimization problem (the lower level). This kind of problem is non concave. In previous work we have given heuristics to solve this non concave problem. In this new work, we try to define a concave problem solving the bi-level problem by restricting the domain of the optimization variables. Indeed these bi-level problems can be reduced to supremum of a finite number of concave functions. If we are able to determine the function which achieves the optimum, we can reduce the problem to the optimization of a pure concave function. Some preliminary work gives us hope to be able to achieve this goal.

7. Contracts and Grants with Industry

7.1. Modal identification and monitoring

Participant: M. Goursat.

7.1.1. Ariane 5 launcher

This is the continuation of a previous study on a real flight of Ariane 5. In this case the main problem is due to the fact that the structure is far to be stationary; the structure is fast varying and there is a sliding effect on the eigenfrequencies. The conclusion of the study was positive for the capabilities of the method and a second case has been examined in a more simple situation compared with previous result. The case is a ground test for a part of the launcher: the bench firing of one stage of Ariane. The experiment has been done in Germany and we had to compare the results obtained with the output only measurements with the previous results obtained by the German company in the input-output situation. In this case we still have the non stationarity of the structure but the structure is simpler than the complete launcher and we have certified results for the comparison.

7.1.2. FLITE Eureka project

Aircrafts are the application domain for this project. There are different interesting problems for airplanes. The first one is the design, certification and flight domain definition. These steps are done by finite element modelization and simulation and then ground test and identification phases and flight testing. In some cases it is possible to add a controlled and measured input but these experiments are very expensive. We are in a real example for the use of input-only techniques.

The second problem is to follow the evolution of the modes during the flight, in particular to monitor the damping values for some specific modes to avoid the flutter phenomena.

In case of different configurations of aircrafts (for business jets with equipments depending on customer demand and for military aircrafts) it is of paramount interest to have a technique which can be used at any time during tests and flights. The main industrial partners are Airbus France and Dassault Aviation.

(See the SIGMA2 website for the comprehensive description of FLITE).

7.2. RNTL Project SIMPA

Participants: R. Nikoukhah, S. Steer, R. Djenidi, A. Azil, M. Najafi.

We have achieved most of the objectives of the project. The main objective has been to extend Scicos capabilities to allow the usage of “implicit blocks”. These are modeling blocks representing system components which are not connected to the rest of the system through explicitely defined inputs and outputs. Most physical components are naturally modeled as implicit blocks. For example a capacitor in an electrical circuit imposes constraints on currents and voltages but has no explicit input or output. Same holds for a spring in a mechanical system or a pipe in a hydraulic system.

The main difference between implicit blocks and standard blocks is that the dynamics of implicit blocks are defined symbolically. Standard blocks in Scicos are black boxes as far as the compiler and the simulator are concerned; they know some of their properties but not the actual dynamics. Implicit blocks on the other hand are defined symbolically using (a subset of) the Modelica language. The additional information available to Scicos during the compilation phase can be used to simplify the system and improve simulation efficiency.

Implicit blocks can now be used in Scicos diagrams and simulated. This extension of Scicos will be integrated into the official version and released along the next release of Scilab in June 2004. In the mean time, some points remain that needs to be worked on. Currently the symbolic simplification phase is not totally satisfactory. For small models for which we have tested it, there is no problem because the simulator can deal with fairly large DAE systems. However we think that for larger systems, having a high performance simplification routine is of capital importance. Work is currently under way to improve the simplification routine.

Another problem has to do with finding consistent states at initialization and re-initialization. This is a classical problem with DAE’s but it is particularly difficult in our case because of the hybrid nature of the models considered. This research problem is being investigated.

7.3. RNTL Project ECLIPSE

Participants: R. Nikoukhah, Y. Sorel.

The objective of this project which has started in November 2003 is to provide Scicos with real-time multiprocessor code generation capabilities through an interface with the SynDEx software. Real world applications for testing and validating the complete system will be provided by PSA Company.

7.4. RNTL Project METISSE

Participants: R. Nikoukhah, J. Agrawal.

This project which starts at the end of the year 2003 should provide Scicos with the capability to import models constructed using the software AmeSim. AmeSim is a specialized modeling tool developed by the company Imagine.

7.5. Traffic

7.5.1. RAPL: Trucks automated traffic

Participants: C. Gomez, M. Goursat.

The truck traffic work is done under contract with the ministry of transportation.

7.5.2. PREDIT: project transportation pricing

Participants: E. Mancinelli, L. Wynter.

We have finished the PREDIT contract concerning the optimal pricing of transportations systems seen as bilevel optimization problems.

8. Other Grants and Activities

8.1. National Actions

8.1.1. Scicos Course (INRIA, 11/20/2003)

Participants: R. Nikoukhah, A. Azil, M. Najafi.

This one day course has been organized to present Scicos and in particular its new features which will be available in the next release. The course was primarily destined to our industrial partners of various RNTL projects.

8.1.2. Journée Scilab et Enseignement (ENPC, 10/15/2003)

Participants: F. Delebecque, J.-Ph. Chancelier.

This one day workshop has been organized for academic users of Scilab so that they can exchange their teaching experiences. About 15 papers were presented at the workshop.

8.2. International Actions

Participants: F. Delebecque, C. Gomez, M. Goursat, S. Steer.

Organization of a Scilab Workshop with the Cheik Anta Diop Dakar University.

This workshop has been held (3-7 march 2003) at the faculty of Sciences and Techniques with the support of the Dakar University and Agence pour la Francophonie. The attendees of this workshop were teachers and Ph D. Students from different French-speaking countries of West Africa.

8.3. Working group

Participant: R. Nikoukhah.

Participation in the 6th Framework Program Network of Excellence in Embedded Systems.

JRA: From hybrid systems models to implementation.

8.4. Post-Doc

- J. Agrawal: Post-Doc financed by the RNTL project ECLIPSE

8.5. Cooperations

- University of Rosario (Argentina): on optimal control problems and application with the research team of R. Gonzales under the coordination of E. Rofman.
- North Carolina State University (USA): on detection under the coordination of R. Nikoukhah.
- LIAMA (Equipe associée): on plant modeling under the coordination of Ph. de Reffye.
- CIRAD: on plant modeling under the coordination of Ph. de Reffye.
- ECP: on plant modeling under the coordination of Ph. de Reffye.
- ENPC Cermics: on maxplus algebra under the coordination of G. Cohen.

9. Dissemination

9.1. Scientific Committees

- R. Nikoukhah.
  - Member of the International Program Committee of the Meditteranean Control and Automation Conference 2003 and 2004.
  - Member of IFAC Technical Committee on Fault Detection, Supervision and Safety in Technical Processes (SAFEPROCESS TC).
  - Member of International Program Committee for SAFEPROCESS 2006.
  - Senior Member of IEEE.
- F. Delebecque
  - Member of the French national board of “Agrégation de Mathématique”.

9.2. University Teaching

- R. Nikoukhah
  - Ensta: Systems and Control, 2nd year, Dynamic Programming, 3rd year.
  - Pulv: Systems and Control, fifth year, Stochastic processes, forth year.
- J.P. Quadrat
  - Paris 1 : Introduction to optimal stochastic control: DEA.
- F. Delebecque
  - Ensta: Systems and Control, 2nd year.
  - Essi: Financial Math, DESS.
- Ph. de Reffye
  - ECP: Plant growths modeling.

9.3. Ph.D. Thesis supervision

- M. J. Khosrowjerdi. Co-supervision by R. Nikoukhah and N. Safari-Shad. Thesis successfully defended in Oct. 2003 at K.N. University of Technology in Tehran, Iran.
- M. Najafi supervised by R. Nikoukhah.
- A. Azil supervised by R. Nikoukhah.
- G. Desilles. Supervisors are: J.P. Quadrat, F. Delebecque, R. Nikoukhah.
- A. Mathieu, A.L. Vastelier. Supervised by Ph. de Reffye.

9.4. Member of thesis committee

- R. Nikoukhah - for thesis defense of M. J. Khosrowjerdi.
- J.P. Quadrat - for thesis defense of Ricardo Katz (Rosario University - Argentina).
- E. Rofman - for thesis defense of Ricardo Katz (Rosario University - Argentina).

9.5. Workshop and Conferences

- A. Azil
  - Journées Nationales du RNTL, Grenoble, October 2003.
- M. Goursat
  - IMAC Conference Kissimmee - USA - February 2003.
  - Scilab workshop Dakar - Senegal - March 2003.
  - GRETSI Conference - Paris - September 2003.
  - PMA03 Conference - Beijing - China - October 2003.
  - Scilab workshop Xi'An - China - December 2003.
- M. Najafi
  - 15TH European Simulation Symposium and Exhibition, Delft, The Netherlands, October 2003
- C. Klimman was invited to present the toolbox at the "Journée Logiciels Libres" organized by "Société Française de Statistique", Institut H. Poincaré, Paris, October 16, 2003.
- R. Nikoukhah
  - European Control Conference in Cambridge, UK, September 2003.
  - Scilab Workshop in Xi'an China, December 2003.
  - Journées Scilab Scicos organized by CNES in Toulouse, October 2003.
  - Presentation of Scicos at the "Jounée Scilab et l'enseignement" at ENPC.
  - Invited presentation of Scicos at MBDA and EADS.
- J.P. Quadrat
  - Workshop on Idempotent Mathematics - ESI Vienna - Feburary 2003.
- Ph. de Reffye
  - PMA03 Conference - Beijing - China - October 2003.
  - The 11th International Conference in Central Europe on Computer Graphics, Visuations and Computer Vision. Plezen, Czech Republic. 3-7 February 2003.
- S. Steer
  - Scilab workshop in Dakar - Senegal - March 2003.
  - Scilab workshop in Xi'an - China - December 2003.
  - "Journées Scilab/Scicos" organized by CNES in Touoouse - October 2003.

9.6. Web sites

Participants: R. Nikoukhah, J.P. Quadrat.

- http://www.maxplus.org: this web site is dedicated to maxplus linear algebra (J.P. Quadrat).
- http://www.scicos.org: this web site is the home of the software Scicos (R. Nikoukhah).

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