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Project-Team Metalau

Méthodes, algorithmes et logiciels pour l'automatique

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THEME NUM

Activity Report

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2. Overall Objectives

2.1. Overall Objectives

Keywords: *DAE*, *DEDS*, *Scicos*, *Scilab*, *active failure detection*, *code generation*, *diagnosis*, *discrete event systems*, *dynamical systems modeling and simulation*, *hybrid systems*, *implicit systems*, *linear system theory and control*, *max-plus linear systems*, *modeling and simulation software*, *passive failure detection*, *plant growth modeling and simulation*, *robust control*, *robust estimation*, *robust filtering*, *scientific software*, *stochastic control*, *transportation systems*.

2.1.1. Research fields

The project-team is particularly active in the following areas:

- classical theory of dynamical systems
- optimal deterministic, stochastic and robust control
- failure detection in dynamical systems (both passive and active)
- network control and monitoring for transportation systems
- hybrid systems, in particular the development of Scicos
- maxplus linear systems: applications to transportation systems
- numerical matrix algebra and its implementation in Scilab

2.1.2. Objectives

The objectives of the project-team are the design, analysis and development of new methods and algorithms for detection, identification, simulation and control of dynamical systems and their software implementations.

These methods and algorithms are usually implemented in Scilab which is an open-source scientific software package originally developed in the project-team.

The project-team 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 developed 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-team. A lot of effort is put into the development of Scicos within the project-team.

As theory and applications enrich mutually, many of the objectives of the project-team 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
- using robust control theory, and finite element models for identification purposes in the framework of failure detection and default localization for space systems, civil structures and other dynamical systems.

3. Scientific Foundations

3.1. Classical system theory

3.1.1. Systems, Control and Signal Processing

Systems, control and signal processing constitute the main foundations of the research work of the project-team. 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-team 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, we have developed the robust control tools in Scilab in collaboration with industrial users. Similarly for Scilab's LMI toolbox, which we have developed with the help of other research groups. It should also be noted that most of the basic systems and control functions in Scilab are based on algorithms developed in the European research project Slicot in which METALAU has taken part.

3.1.2. Implicit Systems

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, residual generation 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. For example nonlinear implicit system theory has been used to develop a predictive control system 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.

3.2. Failure detection in dynamical systems

3.2.1. Active failure detection

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 for 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*.

In the active failure detection method considered an 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

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

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 the case 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 main results of our research can be found in a book published in 2004. We have developed many extension since, which have been published in various journals and presented at conferences.

3.2.2. Passive failure detection

3.2.2.1. Modal analysis and diagnosis

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:

$$\left\{\begin{array}{rcl} M\ddot{\mathcal{Z}}(t)+C\dot{\mathcal{Z}}(t)+K\mathcal{Z}(t) & = & \nu(t) \\ Y(t) & = & L\mathcal{Z}(t) \end{array}\right.$$

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:

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

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

$$X_k=\left[\begin{array}{c} \mathcal{Z}(k\delta) \\ \dot{\mathcal{Z}}(k\delta) \end{array}\right] \ , \ Y_k=Y(k\delta)$$

we get the following equivalent state-space model:

$$\left\{\begin{array}{rcl} X_{k+1} & = & FX_k+V_k \\ Y_k & = & HX_k \end{array}\right.$$

with

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

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-team SISTHEM (a spin-off of the project-team SIGMA2) (see the web-site of this project-team for a complete presentation and bibliography) and with the project-team MACS for the physical diagnosis (on civil structures).

3.2.2.2. Robust failure detection and control

Failure detection problems are formulated in such a way that mathematical techniques in robust control can be used to formulate and solve the problem of robust detection. Concepts developed for H_∞ control can be used in particular to formulate the notion of robustness and provide numerically tractable solutions.

This system approach can also be used to formulate both the detection and the control in a single framework. The Simultaneous Fault Detection and Control problem is formulated as a mixed $\mathcal{H}_2/\mathcal{H}_\infty$ optimization problem and its solution is given in terms of Riccati equations. It is shown that controllers/detectors resulting from this approach have reasonable complexity and can be used for practical applications.

3.3. Exotic systems

3.3.1. Hybrid dynamical systems

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-team 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-team.

It turns out that the Scicos formalism and the Modelica language share many common features, and are in many respects complementary. Scicos formalism provides a solid ground for modeling discrete-time and event dynamics, in a hybrid framework, based on the theory of synchronous languages, and Modelica is a powerful language for the construction of continuous-time models. We work closely with Modelica association and other actors in the Modelica community to make sure Modelica remains consistent with Scicos. We do this in particular by proposing new discrete-time extensions to Modelica inspired by Scicos formalism.

3.3.2. Maxplus Algebra, Discrete Event Systems and Dynamic Programming

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 counterpart 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. Similarly, 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:

$$y = h \Box u \stackrel{def}{=} \inf_s [h(s) + u(\cdot - s)]$$

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 $h_n = CA^n B$, 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 apply because the class of linear systems is not large enough for realistic applications. Generalization to nonlinear maxplus systems 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 the 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 counterpart 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 ($\mathcal{C} \stackrel{def}{=} \mathcal{F} \circ \log \circ \mathcal{L}$), where $\mathcal{L}$ denotes the Laplace transform, maps probability measures to convex functions and transform convolutions into inf-convolutions:

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

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-team. In the METALAU project-team we are more concerned with applications to traffic systems of this theory.

4. Application Domains

4.1. Transport

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

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 $10 \rightarrow 01$ 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 other hand 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

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

The fundamental traffic law linking the density of vehicles and the flow of vehicles 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.

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.

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 counterpart of the shortest path computation (of the case 1) up to the substitution of the minplus semiring by the Gibbs-Maslov semiring, where we call Gibbs-Maslov semiring the set of real numbers endowed with the following two operations :

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

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.

Based on this classification, a toolbox dedicated to traffic assignment is available and maintained in Scilab.

4.2. Modal analysis and diagnosis

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.

5. Software

5.1. Scicos

Scicos, a tool for modeling, simulation and code generation included in Scilab (www.scicos.org)

5.2. Scilab toolboxes and functions

- Scilab's control and signal processing toolboxes (included in Scilab)
- CiudadSim Scilab Traffic Assignment toolboxes
- COSMAD Output modal analysis and diagnosis
- Greenlab plant growth simulation
- MAXPLUS Maxplus arithmetic and linear systems toolbox by the Maxplus Working Group
- LMITOOL optimization for robust control applications (included in Scilab)
- FFTW interface for Scilab, contribution to Scilab software

6. New Results

6.1. Computer aided control system design

6.1.1. Scicos

Participants: R. Nikoukhah, S. Steer, M. Najafi, Fady Nassif, A. Layec, J. Ph. Chancelier, S. Mannori, B. Bayol.

The development of Scicos continues. Our development strategy consists of actively participating in R& D projects (ANR, European). We choose the projects to support long term development of Scicos.

A survey made early in the year among industrial users of Scicos had shown an overall satisfaction with the formalism, the compiler and the simulator, but the editor had been qualified as inadequate and online help and documentation not complete. That is why we have devoted a considerable effort to develop a new editor. This new editor, along with major improvements in the compiler, simulator and code generator, have been released with Scicos 4.2 last October.

Scicos 4.2 has been a major release. It included in particular

- A fully redesigned editor with many functionalities
- Extended data types: integers, matrices, complex
- New blocks (two new palettes and more)
- Improved compiler algorithm
- New numerical solvers
- New code generator
- Better documentation and online help
- Improved Modelica integration

The most important new features of the editor are

- Windows-style editing
- Multi-window (diagram) editor
- Active Scilab command shell
- Masking operation

The compiler has been extended to support general data types: signed/unsigned integers, real and complex matrices. An extension has been introduced to support synchronized Sample clocks (clock computation à la Simulink). The main compilation algorithm has also been partially rewritten to be more efficient and for fixing a subtle bug.

The simulator, which now uses Sundials routines, and code generator have also been extended to be able to take advantage of the extended data types. There is currently work being done on qualified embedded critical real-time code generation in collaboration with Siemens VDO Automotive, Airbus,..., in the framework of the GeneAuto project.

The next version of the code generator should be completely modular to allow easier extension for use on specific platforms (for example for applications such as “Scilab/Scicos code generator for ERIKA Enterprise and the FLEX board” made by Evidence in Italy, or “Scicos-RTAI : Scicos code generation for hard real time Linux” made by R. Bucher at SUPSI in Switzerland.

Many new blocks operating on new data types have been introduced. The blocks devoted to integer data types are of great importance for code generation applications, whereas the blocks manipulating matrices are particularly useful for coding control and signal processing algorithms. For example in Scicos 4.2, it is possible to code the evolution of a Riccati equation using only basic Scicos blocks.

The ability to code control and signal processing algorithms in Scicos should open the door to improved implementation of failure detection algorithms in Scicos, which has been the original motivation for the development of this modeling and simulation software.

This year, the reference book on Scicos: Modeling and simulation with Scilab/Scicos by S. L. Campbell, J. Ph. Chancelier and R. Nikoukhah, has been translated into Chinese. We hope that this will open the door to new users and contributors for Scicos.

6.1.2. Hybrid system modeling and simulation

Participants: R. Nikoukhah, M. Najafi, A. Layec, D. Chapon.

The research work on hybrid system modeling and simulation provides the backbone of the modeling and simulation software Scicos. Modeling hybrid systems in a rigorous fashion is the objective of the Scicos formalism.

Currently the major axes of research and development on Scicos formalism are:

- **Modelica.** Modelica is a programming language primarily devoted to continuous-time system modeling. We consider that the extension of the Modelica language to discrete time dynamics consistently with the Scicos formalism would lead to a very powerful and broad modeling paradigm. We have thus been involved in close collaboration with Modelica Association for the specification of the language in the spirit of Scicos formalisme. We develop an open-source Modelica compiler with LMS-Imagine (to be included in Scicos). We work closely with EDF and IFP (benchmarks,...) and we are in close contact with the OpenModelica project (U. Linkoping). We also participate in the development of Modelica libraries for hybrid components in Modelica (collaboration with Dassault Systems).

  This activity is developed under the following contracts: RNTL Simpa2 project, and the European projects Eurosyslib and OpenControl (submitted).

- **Code generation.** The work on code generation in the asynchronuous framework continues. It is particularly important for Modelica integration to find a solution that allows separate compilation of subsystems in Scicos even if the subsystem is not fully synchronous.

- **Co-simulation.** The ability to perform co-simulation is an important feature of a simulation environment. We study various approaches such as wavefrom relaxation and QSS. For the moment Scicos is used as a platform for testing the research work on the subject. We expect that this research produces concrete co-simulation techniques to be integrated in Scicos. This work is being done in the framework of the RNTL project Parade.

- **Numerical solvers.** Even though we do not develop nermerical solvers for ODE and DAE systems, we use them quite extensively in Scicos. Standard solvers are not directly usable in the hyrid environment; their usage requires a good underestanding of how they function. Proper handling of these solvers is essential for efficient simulation in the hybrid context. D. Chapon has started a Ph.D. thesis financed by a EADS Cifre fellowship to study some of the problems encountered.
- **Applications.** A modeling paradigm must respond to real needs. That is why we continue our close collaboration with industrial partners to better underestand their problems. We have been involved in the development of a number of applications in the past few years with PSA, EDF, IFP and others. New collaborations with EADS and DGA have recently been initiated.

6.1.3. Communication systems

Participant: A. Layec.

Scicos-ModNum ("MODulations NUMériques") is an open and free Scilab/Scicos toolbox for the modeling and the simulation of communication systems. It proposes blocks, schematics and in-line functions of base-band PSK/QAM modulations in order to build communication chains in the Scilab/Scicos environment. Components used to build spread-spectrum communication systems, such Pseudo Noise sequence generators (Quasi-Chaotic, PN and Gold sequence generators) are also included. Scicos-ModNum also includes miscellaneous scopes for Scicos, such as a 3D trajectory Scope and other scopes used for analysis of digital transmissions (e.g. Eye Diagram Scope, Scattered Diagram). Schematics and blocks of integer and fractional frequency synthesizer components (e.g. Phase/Frequency Detector, VCO, Delta-Sigma modulators,...) are provided. Scicos-ModNum also focuses on the simulation of chaotic systems and gives schematics of simulation of Chua's, Rössler's, Van Der Pol's systems (and others). More information on ModNum is available on ModNum web site.

The development of the Scicos Toolbox MODNUM continues. MODNUM has been updated to take advantage of the new features available in Scicos. MODNUM will be used as a basis for developing a simulation tool for HF transmitter/receiver system for the DGA (Scerne project).

6.1.4. Scilab

Participants: J. Ph. Chancelier, F. Delebecque, J.P. Quadrat.

Scilab and its predecessor Basile have been developed in the Metalau (formerly Meta2) project. This work has been carried out in close collaboration with J. Ph. Chancelier of ENPC who has made major contributions to Scilab such as the development of the graphics and the port to the Windows platform.

The development of Scilab has been taken over by the Scilab team since the creation of the Scilab consortium. Metalau team however continues to provide support for a version of Scilab: ScilabGtk, in cooperation with ENPC. ScilabGtk is a GTK version of Scilab, based on the Scilab BUILD4 distribution. This version of Scilab includes, in addition to the Gtk2 GUI, the maxplus built-in toolbox. ScilabGtk can be downloaded from http://cermics.enpc.fr/ jpc/scilab/site/Scilab-Gtk.

6.2. Signal processing

6.2.1. Active failure detection

Participants: R. Nikoukhah, S. L. Campbell, A. Esna Ashari.

We develop a novel theory of robust active failure detection based on multi-model formulation of failures. The results of years of research have been published in a book in 2004.

We have continued also to work on the extension of our approach to more general situations. In 2007, we have mainly worked on the problem of incipient failure detection. The multi-model approach is still used to model the normal and the failed systems however the two models are supposed to be “close”. A situation that occurs when the (incipient) fault manifests itself through small variations in system parameters. We have developed an efficient solution for this problem. The result appears in a journal paper and will appear in the European Journal of Control.

We continue the work on active failure detection by considering feedback for generating auxiliary inputs. This work is carried out as part of the thesis work of A. Esna-Ashari who has joined the team as a Ph.D. student.

6.2.2. Modal analysis and diagnosis

Participant: M. Goursat.

The new results concern mainly modifications of the identification procedure to improve the robustness and the quality of the results. The domain where theoretical results are still under consideration are for more general models with influence of exogeneous phenomema (noise, temperature, fluids...).

For the diagnosis the studies are focused on fast on-line detection (e.g. for flutter) and improvment of the physical diagnosis.

6.3. Current Profile Control of Tokamak

Participants: F. Delebecque, J.P. Quadrat.

The collaboration with CEA/DSM/DRFC (Pilotage Group) at Cadarache has continued on the control of the plasma profile for the ITER fusion project. Several work meetings at Cadarache with the Pilote group took place this year.

A simplification of transport plasma model proposed by the CEA has been studied and implemented in Scilab/Scicos. The simulation results were compared with experimental data obtained by the CEA Software Cronos. A feedback improving the security factor profile has been proposed and implemented numerically. We are currently in the phase of the validation of this feedback control law.

It has been observed that some particular profiles are more efficient to produce fusion reactions. It is an important issue to obtain and stabilize these profiles by controlling the set of eating antennas. A paper describing these results is in the final stage of preparation.

6.4. Application of Maxplus algebra to traffic modeling and control

Participants: N. Farhi, M. Goursat, J.P. Quadrat.

The thesis of N. Farhi is dedicated to maxplus modeling of traffic. The fundamental traffic law giving the relationship between the average flow and the density of vehicles is studied in different cases. This year, cases of complete regular towns have been considered. It has been shown that the corresponding diagrams are very similar to the one obtained with two roads and only one crossing.

We have continued to study the mathematical justification of the existence of an average flow. It is a difficult problem since these systems are homogeneous of degree one in minplus algebra but are not monotonous and therefore chaotic behaviors may occur. For some particular cases, the existence of the average flow has been shown: for example systems of roads with crossings but without turning possibilities. In the general case we can show only the existence of upper and lower bounds on an average flow.

Nadir's thesis is in the final stages of preparation. Four articles have been written on this subject this year.

7. Contracts and Grants with Industry

7.1. Grants with Industry

7.1.1. RNTL Project Simpa2

Objective: continue the work in Simpa project, i.e., extending Scicos capabilities to allow the usage of "implicit blocks". This is done by developing a Modelica compiler in collaboration with LMS-Imagine and interfacing it with Scicos. Examples will be provided by EDF and IFP.

7.1.2. RNTL Project Parade

The objective of this project is the development of parallel numerical algorithms for real time simulation of systems of algebraic differential Equations. Imagine, Siemens, Lagep are other partners of the project.

7.2. European Research Contracts

7.2.1. European project GeneAuto

The participant are Airbus Industries, Barco, EADS Astrium, FERIA, B Krates, INRIA, Israel Aircraft Industries, Siemens VDO Automotive (leader), allinn Technical University.

In this project, both industries and universities will seek to develop, use and make better tools and methods for design, development, integration and validation of embedded software-intensive systems. The overall goal of the development project is to create a proper prototype for industrial code generation starting from a diverse set of desktop system development tools in particular Matlab/Simulink/Stateflow and Scilab/scicos. Additional efforts will be necessary after the end of the project to make an industrial product out of this prototype, as well as certification activities for the respective industrial domains.

This ITEA European project started in 2006. Metalau experience in hybrid system modeling, simulation, and Code generation is an important factor in the success of this project. This year we publish the first version of the Scilab/Scicos front end of this code generator. This work required extensions of the Scicos semantic and the definition of an XML grammar used as intermediate language between Scicos and the GeneAuto code generator.

7.2.2. European project EuroSysLib

The objective is to develop Modelica libraries to make the Modelica language a standard powerful modeling environmnet. Metalau participates in this project to help shape the hybrid formalisme in Modelica and develop associated library components, which can then be used in the Implicit Scicos environment.

8. Other Grants and Activities

8.1. International Actions

- R. Nikoukhah. Member of the International Program Committee of the Meditteranean Control and Automation Conference.
- R. Nikoukhah. Member of IFAC Technical Committee on Fault Detection, Supervision and Safety in Technical Processes (SAFEPROCESS TC).
- R. Nikoukhah. Member of International Program Committee for SAFEPROCESS.
- R. Nikoukhah. Senior Member of IEEE.
- E. Rofman. Nomination as ”Ad-Honorem“ adviser for Productive Science, Technology and Innovation by the Government of the Province of Santa Fe in Argentina.

8.2. Cooperations

- North Carolina State University (USA): on failure detection and numerical solution of hybrid DAEs under the coordination of R. Nikoukhah.
- OCSID (Optimisation et Contrôle des Systèmes Dynamiques) - Argentinian institute of Mathematics IAM-CONICET under the coordination of E. Rofman

9. Dissemination

9.1. Short Courses and Exhibitions

- Ramine Nikoukhah. Organization of the the IliaTech meeting on Modeling, simulation and real-time embedded code generation, Dec. 17 2007 INRIA-Rocquencourt.
- Ramine Nikoukhah, Simone Mannori. Scilab/Scicos exhibition at IEEE-CCA Sept. 2007, Singapore.
- Ramine Nikoukhah, Maurice Goursat, Serge Steer. This workshop sponsored by CEFIPRA, consisted of introductory and advanced level talks on the use of Scilab and Scicos. Strategies to promote their use in India and the ways to organize the contribution of Indian researchers to the development of Scilab/Scicos were discussed.
- Maurice Goursat, Serge Steer, Francois Delebecque. This Scilab/Scicos course organized by the "Gaston Berger" University gathered researchers from Mauritania, Burkina-Faso, Mali and the Ivory Coast.
- Simone Mannori, Serge Steer. Ecole JD-JN-MACS organized by the MACS GDR for young researchers, 11-12 July 2007, in Reims. We presented Scilab and Scicos tools for modeling and real time applications, as well as the prospects and model of development of these two open source software.

9.2. Conference and workshop participations, invited conferences

- A. Layec
  - MTT-S IMS'07 workshop : Pratical Analysis, Stabilization, and Exploitation of Nonlinear Dynamics in RF, Microwave, and Optical Circuits, Honolulu, USA, June 2007
- M. Goursat
  - 2006 SEM Annual Conference, Saint-Louis, Missouri, USA, June 06.
  - MESM 2006, Alexandria, Egypt, Aug. 06.
  - Scilab Workshop, Hangzhou, China, Sep. 06.
- S. Mannori
  - IEEE-CCA 2007, Singapore, Sept-Oct. 2007.
- R. Nikoukhah
  - ECC 2007, Kos, Grece, July 2007.
  - ICMSAO-07 Int Conf Modeling, Simulation and Applied Optimization, Abu-Dhabi, March 2007.
  - ICMOSPS'07, Durban, South-Africa, Jan 2007.
  - ECOOP 2007, European Conference on Object-Oriented Programming, Berlin, Germany, July-August 2007.
  - IEEE-CCA 2007, Singapore, Sept-Oct. 2007.

9.3. Teaching

- F. Delebecque

  - Ensta, Systems and Control, 2nd year.

  - DEA MMMEF, University of Paris 1. Systems Theory course.

  - Agrégation Mathématique, committee member.

- 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.

9.4. Ph.D. Thesis supervision

- Nadir Farhi, supervised by M. Goursat and J.-P. Quadrat.
- Alireza Esna Ashari, supervised by Ramine Nikoukhah.
- Damien Chapon, supervised by Ramine Nikoukhah.

9.5. Intern supervision

- B. Bayol, supervised by Ramine Nikoukhah, 2007.
- F. Nassif, supervised by Ramine Nikoukhah, 2007.

9.6. Extern supervision

- R. Katz supervised by E. Rofman,
- P. Lotito and E. Mancinelli supervised by E. Rofman and J.P. Quadrat

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