Mini-Ker-2, un logiciel d'Analyse et Modélisation des Systèmes Dynamiques Non-Linéaires

Motivation
Whenever modelling is needed, either in industrial or research projects, simulation is not the end of the story; it is a beginning.

Simple models are thought as "model for understanding" because their structure and analytical aspects give fecund insight on real systems. However, in industrial problems and applied research fields, a model seldom exhibits obvious properties,
and a numerical analysis is necessary to grab some understanding.

The purpose of this project is to numerically exhibit the properties and characteristics of nonlinear dynamical models.

Objectives

The kernel of the present project has been to develop a simulation and modelling tool able to enrich the analysis of a problem using available numerical methods. Such a software is believed to advance the state-of-the-art of modelling physical systems, offering facilities to give quantitative answers to qualitative questions.

Specifications and methods

An pertinent modelling environment should be able to carry out, in addition to numerical simulation:

- sensitivity analyses in terms of initial conditions (stability, asymptotic instability), perturbation (contextual stability to canonical perturbations),
- uncertainty on parameters, mechanisms and experimental aspects, response to noise sources;

- and, in particular cases:

- - investigation of the propagation of uncertainties within a model;

- - optimal control of dynamic systems;
- - sensitivity of cost functions or summarising functions to changes in parameters;
- - stability to stochastic sources;
- - parametric studies (optimality in design analyses);
- - parametric identification (in experimental context);

The present project proposes a consistent and unique methodology to do so, based on the systematic use of the Tangent Linear System (and Circulating TLS) of the system. The present Collaboration has shown in various contexts how the *Transfer Evolution Formalism* (TEF), developed by the Collaboration, allows to conduct automatically all these functionalities.

A TEF model consists of a set of connected elementary objects (sub-models) that correspond to well-posed problems. As a consequence, the question of the inter-nfluence between objects is meaningful and directly accessible. As a consequence, the *objects* of the model are not defined as computer science ``oriented objects'', but physicaly oriented elements of a system.

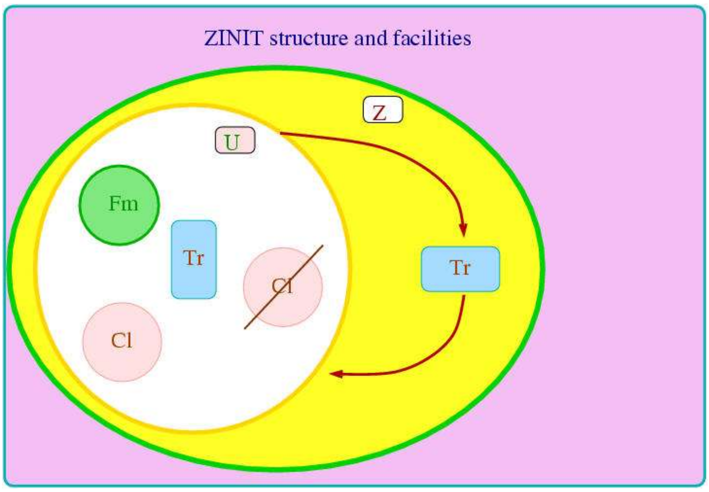
A tree-structure of elementary objects gathered in famillies allows to explicit the interaction between sub-parts in a hierarchical manner. An additional benefit of this structure is that the systematic partitioning of systems under TEF gives immediate access to massive parallelisation of the simulation code.

The TEF approach of modelling is rich of of experience in various scientific fields, from theoretical research to industrial applications, among which engineering, fluid mechanics, chemistry, physics, economy, molecular biology, climatology, etc. This work has lead to numerous peer-reviewed publications in international journals (e.g., Journal of Economic Behavior and Organization, Euro.Phys.Lett., J.Atmos.Sci., Electrophoresis, Q.J.R.M.S., Energy Policy,etc.).

The TEF and Mini-Ker Collaboration

Twenty years of methodological development and numerical implementation have paralleled the development of the ZOOM code. More recently, a simplified version, named Mini-ker -which is currently in its version 102 see http://www.lmd.jussieu.fr/doc/mini_ker_102.pdf - have been developed, starting in August 2003;

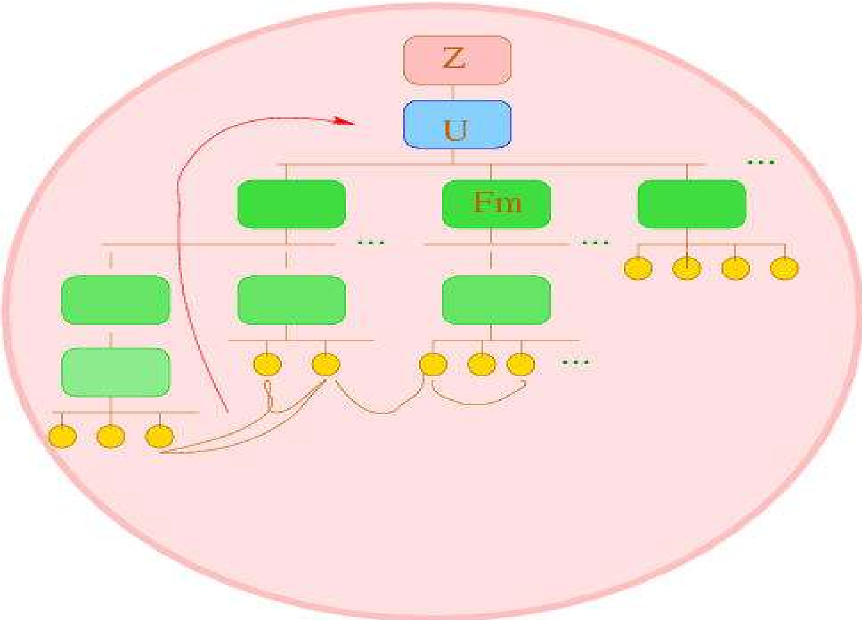
Mini-ker is a research tool which is so far limited to a few tens of equations (a few hundreds for 1D models). The basis of this software is a symbolic partial differential technique that gives access to all Jacobian matrices of the system at every point along the trajectory. In other words, the Tangent Linear System is computed together with the model trajectory, allowing a variety of analyses: systematic forward sensitivity analyses, calculation of the adjoint system and gradient computing, extended-Kalman filtering, linear and non-linear feedback studies, etc.



Research Application

The **TEF-ZOOM** collaboration is involved in research and engineering studies, with systematic use of modelling of dynamical systems along with experimental or observational analyses.
To quote some results related to the present project, let here mention the modelling of non autonomous feedback dynamics in Climate Sciences, which is an important issue to understand and predict Global Climate Change. The CTLS methodology developed in the Collaboration allowed some breakthrough in this domain.
Climate-economy interactions is another very active field where the interaction dynamics is of primary importance to study and anticipate impacts of global warming and to propose mitigation actions. Many problems involving the analysis of nonlinear dynamical systems are the every-day plate of the authors of this project.

Closer to industrial applications, the modelling of electrophoresis, well known for posing stiff numerical problems, a thermal heat pump and a liquid heat pump developed for space-craft, for which their model is the only one to retrieve the important oscillations.



List of Participants

The Mini-Ker development is based on the TEF-ZOOM collaboration:

- at Centre International de Recherche sur l'Environnement et le Développement (CIRED, UMR CNRS-EHESS-ENPC-ENGREF, Paris, France) Stéphane Hallegatte, principal investigator; Fran\,cois Gusdorf, consultant;
- at Laboratoire de Météorologie Dynamique (CNRS-UPMC-INSU-IPSL, Paris, France), Alain Lahellec as principal investigator and leader of the Mini-ker project, Jean-Yves Grandpeix (former leader of the ZOOM project), and Robert Franchisseur, consultants;
- at Plateforme Environnement (ENS, Paris, France) Patrice Dumas, consultant;
- at Laboratoire d'Energétique (UPS, Toulouse, France) Stéphane Blanco, as principal investigator, Richard Fournier and Sébastien Dufour;
- at I.U.T. Tarbes (France), Vincent Platel;

- RESEARCH FIELDS:
-

. Urban policy and macro-economy (CIRED, François Gusdorf and Stephane Hallegatte : Development paths of urban systems involve elements (agents, infrastructures, ...) and mechanisms that are characterized by different timescales. Focusing on dynamic transitions of cities, we identify several variables that we intend to analyse. The explicit representation of the behaviors and the physical mechanisms that explain their evolutions, allow for:

- a better understanding of the functioning of the whole system;
- the implementation of an efficient programmation tool that can simulate the evolutions of the variables that have been identified ex-ante as crucial for the analysis.

. **Two-phase closed heat transfer systems – Laplace,Toulouse**: In the field of the electronic industry, components development is motivated by the increase of the level of integration and/or the performance of the device. That results in both an increase and an intensification of the heat dissipation so that the thermal management is now a major challenge in power electronics and microelectronics. Two-phase closed systems using the liquid-vapour phase change heat transfer efficiency and the fluid transport properties can provide a passive cooling solution for transferring large level of heat fluxes and heat flux densities from confined spaces to the heat sink. Among them, loop heat pipes (LHP) are specific capillary-driven two-phase heat transport devices which have proved their reliability and flexibility for space applications. Their use is now in development for ground applications in particular in miniature size. However, there are still many unexplained behaviours (i) in microgravity vs ground performances for space applications (sensitivity to the phase distribution) (ii) in the condenser section (bubble/annular flows transition regime) (iii) during LHP start-up and/or consecutive to transient operations.

- **Dynamic Feedback gain in a simple model of Global Climate (ClimSI) at LMD-CIRED:** The model has already been coded in ZOO, but recoding itin Mini-ker will allow to develop new types of anlyses of important dynamical aspects of the Global Climate. In particular, sensitivity to different bands of radiative exchanges will be analyzed at equilibrium and under a cyclic forcing with Floquet theory;
-
- **Modelling during pre-designing phase of an industrial project,** Benjamin Muyl and Co. : As naval Architects and engineers designing prototype racing boat for the America' Cup, and for Round the world races "Vendée Globe" and "Trophée Jules Vernes", we need to go further in the development of existing Velocity Prediction Programs (VPP). A better understanding of the dynamics of these boat would allow to design not only to get the higher speed, but also, to get it quickly. The ability of an America's cup boat to accelerate is of first importance when racing against best teams. Next steps in the developement of theses tools are:
- - integration of structure deformation under stress in the calculus of the velocity of the boat
- - Optimisation Algorithms to help us to identify important parameters to play with, and to find right values.
- - Sensibility analysis to improve Design robustness.

- - Analysis of dynamical behaviours of the system "sailing boat" during manoeuvers or on waves.
- - Real-time fit of main model parameters from inboard measurements to make the simplified model osculate the real system.

A first draft of such an application has already be done in Mini-ker 1.00 We were expecting Mini-Ker-2 to enter in it's new developpement phase to really start working on the full version of this VPP.

- **Macro-Economy (CIRED, Stephane Hallegatte):**

NEDyM is a macro-economic model able to capture short-term disequilibrium mechanisms. It has been used in the literature to investigate the drivers of business cycles, to assess the consequences of natural disaster, and to assess the potential cost of climate change. In a new phase, the model needs to be upgraded to take into account new processes of the greatest importance (international trade, central bank policy...). Then, its potential to forecast economic evolution and to identify policies able to improve the economic resilience will be investigated. This research theme is important, as it fills a major gap of the other widely-used approaches, namely econometric models used for forecasting and long-term equilibrium models used for policy assessments.

Publications of the TEF Collaboration:

A.Lahellec, S.Hallegatte, J-Y.Grandpeix, P. Dumas, and S.Blanco, 2008:
Feedback gain in nonlinear dynamical systems, Euro. Phys. Lett.,(81), 6001-6006 .

F.Gusdorf , S.Hallegatte and A.Lahellec, 2007:
Time and space matter: how urban transitions create inequality, Global Environmental Change, prix spécial du Jury pour ``Innovative Thinking'' par le Joint Transport Research Center international dans la catégorie Young Researchers Award;

Hallegatte S., A. Lahellec, J.Y. Grandpeix, 2006, An elicitation of the dynamic nature of water vapor feedback using a 1D model, Journal of Atmospheric Science 63(7), 1878-1894

A. Mathieu and A. Lahellec, 2005, Comments on a DYCOMS-II Analysis of Stratocumulus Stability, Quart. J. R. Met. Soc. (607),1293-1299.

A. Mathieu, A. Lahellec and A. Weill, 2004,
Evaluation of a numerical weather forecast model using boundary layer cloud top temperature retrieved from AVHRR, Mon. Wea. Rev. (132),915-928.

A. Mathieu, G. Sèze, A. Lahellec and C. Guerin and A. Weill, 2003 :
Characterization of the Cloud Topped Boundary Layer at the Synoptic Scale Using AVHRR Observations during the SEMAPHORE Experiment}, J. Appl. Meteor. (42),1720-1730.

Mini-Ker,: Nonlinear Dynamical Systems Analysis and Modelling. A ZOOM-TEF collaboration.

Hallegatte S., 2005 : The time scales of the climate-economy feedback and the climatic cost of growth, Environmental Modelling and Assessment, 10 (4), pp. 277-289

Hallegatte S., A. Lahellec, J.Y. Grandpeix, 2006: An elicitation of the dynamic nature of water vapor feedback using a 1D model, J. Atmos. Sc. 63(7), 1878-1894.

Hallegatte S., Hourcade J.-C., Dumas, P., 2006:
Why economic dynamics matters in the assessment of climate change damages: illustration on extreme events, Ecological Economics, in press

Hallegatte S., Ghil M., Dumas P., Hourcade, J.-C., 2006,:
Business cycles, bifurcation and chaos in a neo-classical model with investment dynamics, Journal of Economic Behavior and Organization, in press

Gusdorf S., S. Hallegatte, 2006, Behaviors and housing inertia are key factors in determining the consequences of a shock in transportation costs, Energy Policy, in press

Jost C, Verret J, Casellas E, et al. The interplay between a self-organized process and an environmental template: corpse clustering under the influence of air currents in ants JOURNAL OF THE ROYAL SOCIETY INTERFACE 4 (12): 107-116 FEB 22 2007

B.Piaud, S.Blanco, R.Fournier, et al. Energy-conserving lattice Boltzmann thermal model in two dimensions JOURNAL OF STATISTICAL PHYSICS 121 (1-2): 119-131 OCT 2005

M.Roger, S. Blanco, M.El Hafi, et al. Monte Carlo estimates of domain-deformation sensitivities Phys.Rev. Lett. 95 (18): Art. No. 180601 OCT 28 2005

S. Blanco and R. Fournier, 2006:
Short-Path Statistics and the Diffusion Approximation Phys. Rev. Lett. (97), 230604

S. Blanco and R. Fournier An invariance property of diffusive random walks , 2003 : Europhys. Lett. (61) 168-173.

Pouzet E., J.L. Joly, V. Platel, J.Y. Grandpeix, C. Butto, 2004: Dynamic response of a Capillary pumped loop subjected to various heat load transients,
Int. J. Heat Mass Tansfer (47), 2293-2316.