Ph. D. Proposal for 2012

Constraints for Packing Curved Objects

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Possible Funding : ANR NetWMS2
Abstract. The thesis deals with the study and development of a new class of geometrical constraints. These constraints enforce the fact that a set of objects do not overlap. These objects belong to families of shapes that can be described as polygons, as algebraic manifold or parametric curves and surfaces like NURBS (Non-uniform rational basis splines). These constraints will be first used in the context of the ANR project NETWMS2, and, beyond this context, spreaded towards others applications in CAD. The thesis embraces different fields and will contribute to the area of discrete on continuous constraints.

Keywords. Constraint programming, numerical analysis, computational geometry, hybrid optimization, packing problems, warehouse management, CAD.
Introduction

Context and Problem Description

The topic is linked to the ANR project NETWMS2 that focuses on the placement of complex shapes in a restricted area, with as the main motivation the problem of container packing with curved objects. Beside the INRIA TASC team where the thesis will take place, there are two other partners:

– An academic partner which is the INRIA Contraintes team from Rocquencourt.
– An industrial partner which is the company KLS specialized in logistics.

The thesis is located at the frontier of constraint programming, computational geometry and numerical analysis.

The goal of the thesis is to contribute to the design of a constraint programming based tool for addressing problems that mix combinatorial and geometric aspects. The concrete case study is a tool for packing a set of curved objects into the smallest number of containers, where containers have to be selected from a predefined set (see Figure 1). The practical goal is to minimize the travel cost as well as the impact.

Figure 1: Example of curved objects packing problem. Eight bottles are packed in a constrained space (a rectangle).

The central problem is to design new geometrical constraints for enforcing non overlapping between curved objects. The goal is to directly express these constraints in term of geometrical conditions which seems the appropriate level of abstraction. This stems from the fact that a reformulation in term of algebraic constraints is not always straightforward and may be not efficient at all.

The application problem consists in addition to non overlapping to deals with business constraints such as the minimum distance between certain types of objects or accessibility constraints arising in the context of pick up delivery. This is an hybrid problem where we both have continuous variables (position and orientation of an object) and discrete
variables (container assigned to an object). This problem will be handled by extending the geost kernel developed in the NetWMS project.

To summarize the goal of the thesis is the creation of new geometrical constraints and their integration in the geometrical kernel that both handle continuous and discrete variables.

**Problems et opportunities**

The core of the thesis is the study and development of non-overlapping constraints. The first case of study will be simple polygons. The second case will be algebraic curves and surfaces (conics and more generally, manifolds). The last and more important case in this these will be objects delineated by parametric curves and surfaces (like Bezier curves, splines, NURBS) that are extensively used in computer-aided design (see Figure 2).

![Figure 2: Non-overlapping constraints. (a). Between two polygons. (b). Between two manifolds (here, ellipsis) defined by algebraic equations. (c). Between two Bézier curves (tangents and control points are painted in red).](image)

Each constraint involves a theoretical aspect (assimilation of underlying mathematical formalisms and tools, computational complexity analysis), an algorithmic aspect (design of efficient propagators) and an applicative aspect (development and validation within the software suite of the TASC team and, in a first step, independently of the GEOST kernel).

In all cases, we will resort to generic methods and avoid the introduction of specific geometrical properties related to a given shape. For instance, the non-intersection of curves will be addressed using general-purpose existence theorems based on interval analysis.

The applicative part of the thesis includes the integration of the constraints in the GEOST kernel and the solving of real packing instances. In this context, a study will also have to be conducted concerning the convergence issue and the numerical validation. Indeed, by minimizing the occupied space, the GEOST algorithm creates many tangency between objects, leading to a bad numerical conditionning (hindering the validation of
solutions) and slow convergence phenomenon (making the last placement tasks very time consuming).

The thesis will resort to various fields: discrete mathematics, interval analysis, linear algebra, computational geometry, differential geometry, convex analysis, CAD,... Of course, it is not required to be competent in all these fields but rather to get a global knowledge. Experts of the different fields will be consulted for the advanced technical issues.

The main challenge is to develop an interdisciplinary approach. A solid knowledge of the fundations of constraint programming will have to be, however, acquired.

So the main opportunities offered by this thesis are:
– An academic research of increasing difficulty
– The connections with different scientific fields
– An industrial application

This thesis will also contribute to the convergence of discrete and continuous constraints.

Previsional Work Plan

**Year 1**

1. State of the art: continuous constraints [BG06, Neu04],
2. Placement: linear case [BGT01, JKDW01, DBCvK08]
3. Getting familiar with the Ibex library [Cha07, CJL09] and creation of a constraint
4. Study of the Geost kernel [BC01, BCT06, BCP07, CBM08]
5. Experimental validation in Geost

**Year 2**

1. Publication of the first results
2. State of the art: interval analysis [Neu90, JKDW01, Han92]
3. Non-overlapping: algebraic case [CB10]
4. Integration in Geost
5. Questions of convergence and correctness in Geost

**Year 3**

1. State of the art of different representation in CAO
2. Non-overlapping: parametrized curves and surfaces
3. Integration in Geost and publication
4. Dissemination within the CAD community
Advisors

The follow up of the PhD thesis will be mainly done by Gilles Chabert. He will take care of bringing the candidate at the required level with respect to numerical constraints. He will also initiate the candidate to the other topics and guide the research on a regular basis.

Nicolas Beldiceanu will be in charge of the questions related to the geometrical kernel GEOST. In the continuous case different questions are still open, regardless the type of considered object: problems of convergence, validation of a solution, search heuristics, scalability, . . . . Such questions will be considered. He will manage the integration phase.

Applicant

Requirements

While this thesis is located across different topics we do not require the applicant to be expert on any specific domain. However it is expected that the applicant has a good programming skill, and that the applicant is familiar with applied mathematics or geometry, while being open to other topics such as constraint programming.
Bibliography


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CV of the PhD advisor (N. Beldiceanu)

University Education

– PhD thesis of University Paris 6 (1988)
– HDR from University Paris 6 (2003)

Employment

– Researcher at MASI laboratory, CNRS and University Paris 6 (1988)
– Researcher at ECRC (European Computer Research Centre, research centre from BULL, SIEMENS and ICL) Munich, Germany (1988-1990)
– Full professor at Ecole des Mines de Nantes (since 2003)
CV of the co-advisor of the PhD thesis (G. Chabert)

University Education

– Engineer degree from Polytech’Nice (2001)
– PhD thesis in Computer Science from Nice University (2003)

Employment

– PostDoc at ENSIETA, Brest (2007)
– Associate Professor at Ecole des Mines de Nantes (2008)
– Associate Professor (permanent position) at Ecole des Mines de Nantes (since Sep 2009)

Publications

– 7 papers in international journals (scientific computing and robotic)
– 11 papers at international conferences