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A surrogate-based evolutionary algorithm for highly constrained design problems

SAEOpt – Surrogate-Assisted Evolutionary Optimisation Workshop
@Gecco 2017
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Cenaero : Mission & Competencies

- **Private research center (Gosselies, Belgium)**

> To develop and provide methodologies
> and simulation tools to innovative companies
> in their design of more competitive products

- **Multi-scale and multi-physics modeling and design optimization niche capabilities**

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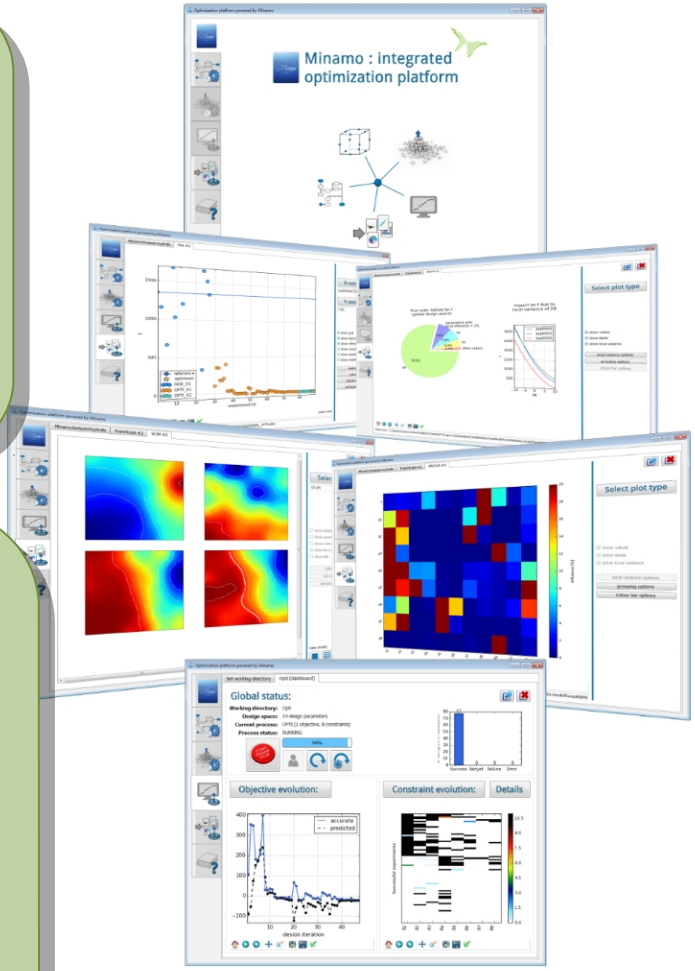
Design Competencies

- **Context : Optimization based on computationally intensive analysis**

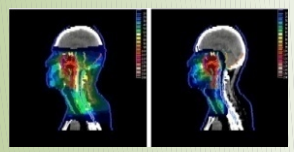
  ⇨ **Surrogate-assisted space exploration and data-mining**

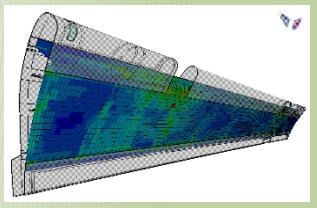
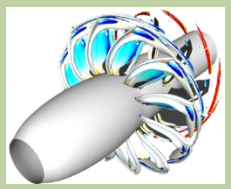
  ⇨ **Development of Minamo toolbox**



- **The optimization specification lies at the heart of the success of the design methodology**

  ⇨ **Development of tailored optimization methodologies**



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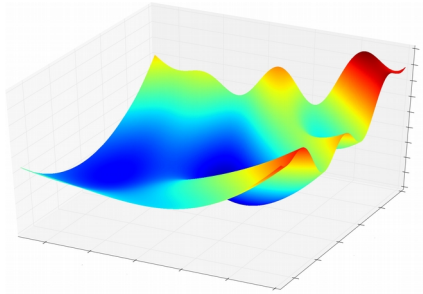
What is Minamo ?

- Minamo is the multi-disciplinary design optimization tool of Cenaero, strongly based on « fast » surrogate models, for
  - Design space exploration
  - Optimization
  - Sensitivity analysis and Parametric studies
  - Data analysis and Visualization
  - Robust design and Reliability



- Minamo is a generic and transverse tool.

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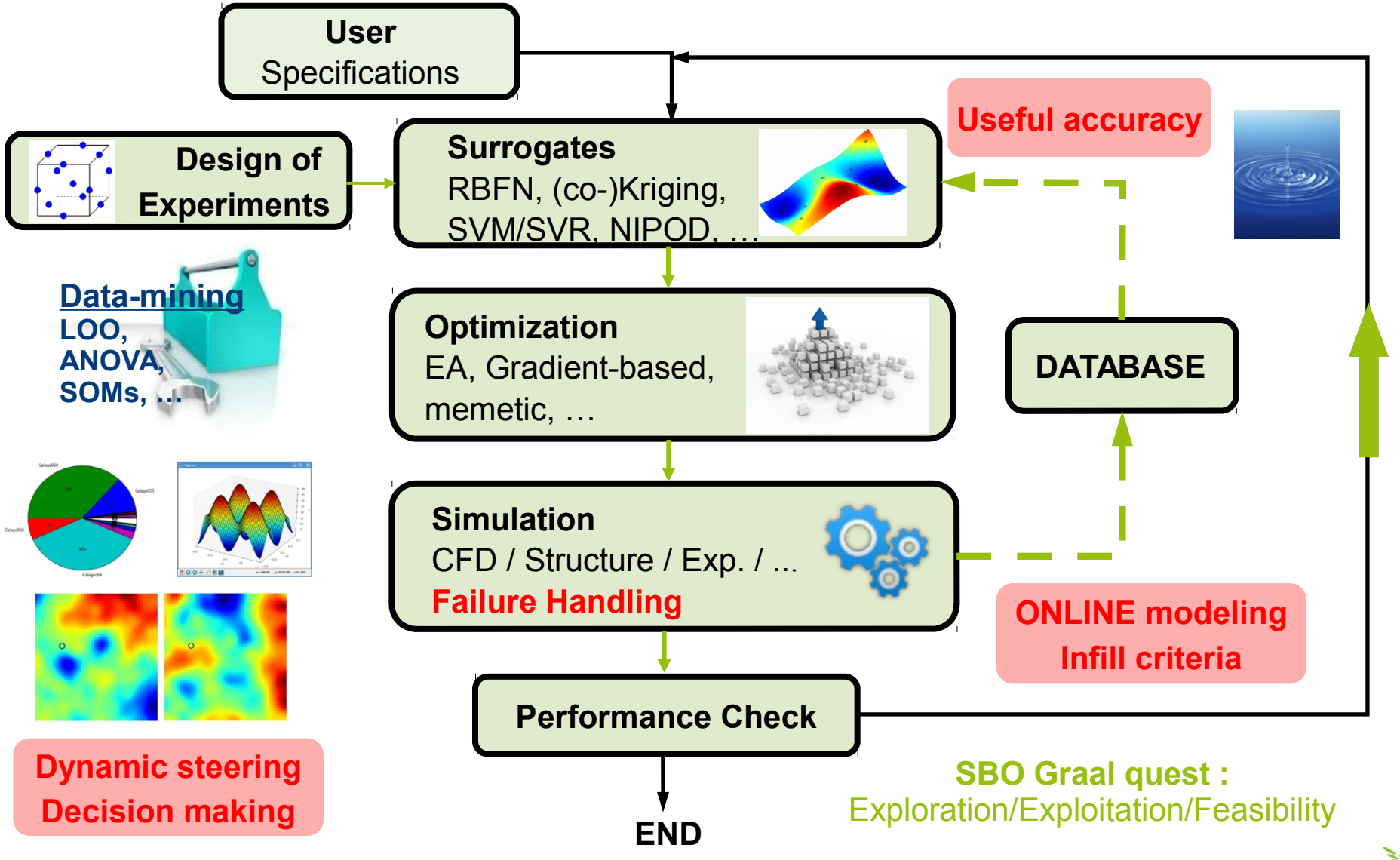
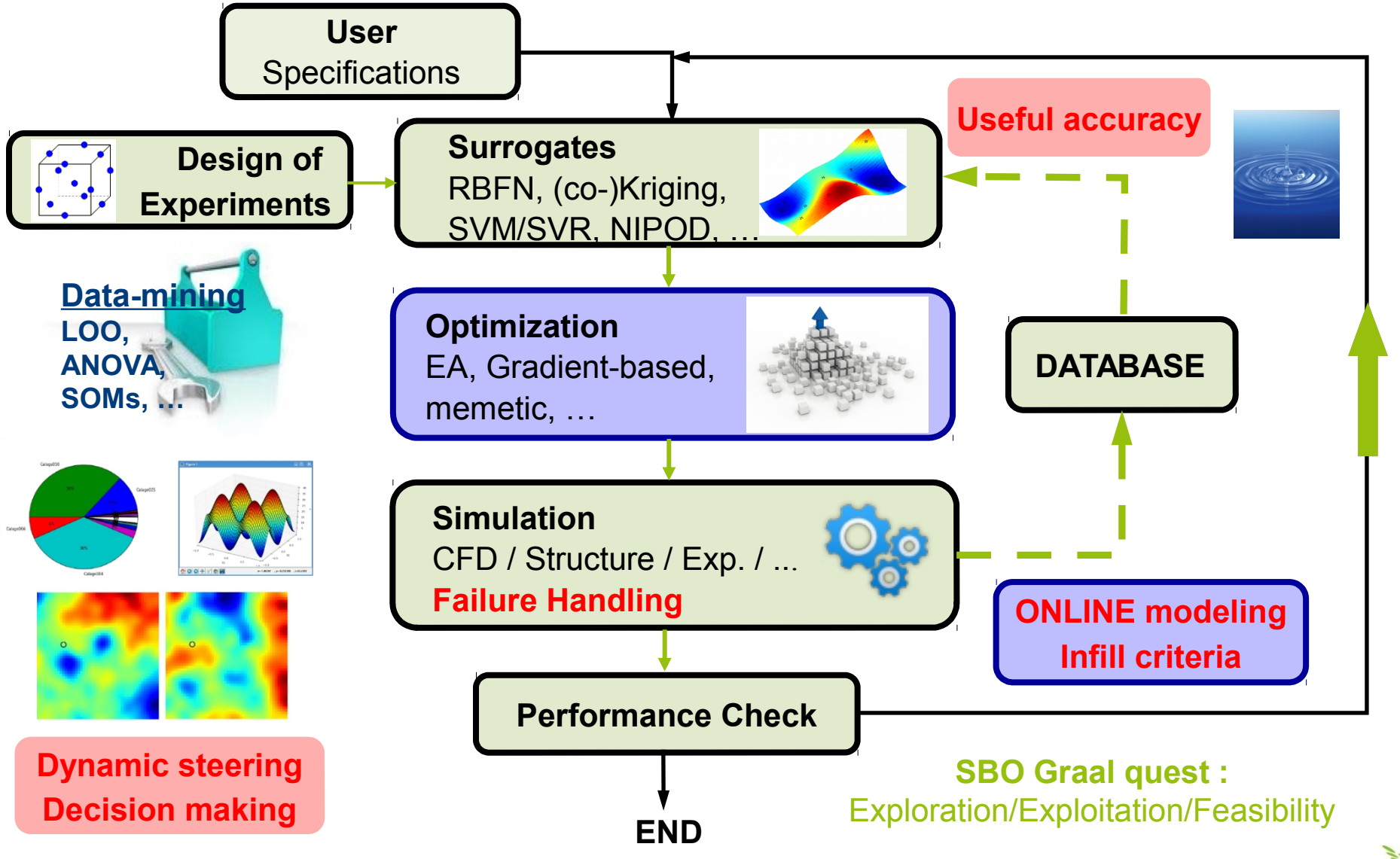
Surrogate-Assisted Approach



Surrogate-Assisted Approach



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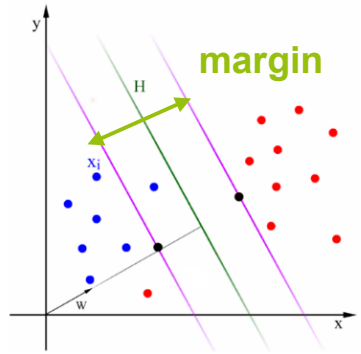
Efficient SBO – dealing with feasibility

- **A feasibility criterion imposes a classification process**
- **Classification of binary data : Support Vector Machines**
  - Supervised learning models
  - Non-probabilistic linear classifier
  - Separating hyperplane with margin maximization
  - Classification/Regression in a high-dimensional space



- **Classification of continuous data:**
  - Define the probability of classification (pf) based on the SVM model
  - Sigmoid model proposed by Platt

$$\mathrm{pf} = \mathrm{Prob}\left(+1|x\right) = \frac{1}{1+e^{\left(As(x)+B\left(\frac{d_0}{d_1}-\frac{d_1}{d_0}\right)\right)}}$$

J. Platt. *Probabilistic outputs for support vector machines and comparisons to regularized likelihood methods*, Advances in large margin classifiers, 10(3): 61-74, 1999.

Probabilistic Support Vector Machines (PSVM)

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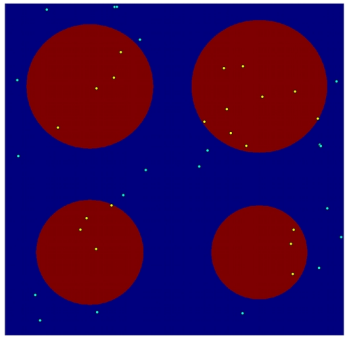
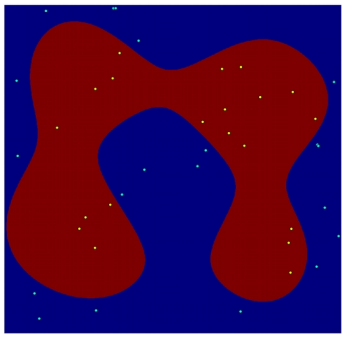
Probabilistic Support Vector Machines (PSVM)

Feasible zones in red



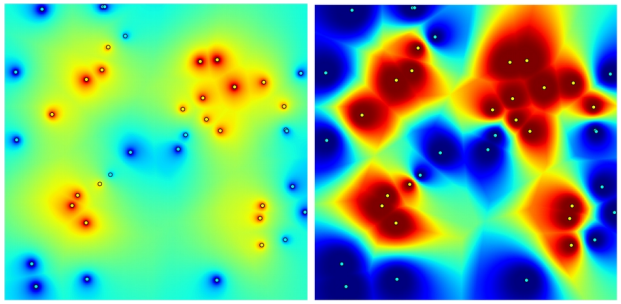
Original zones

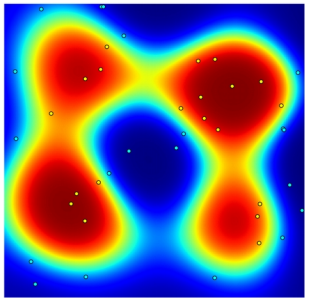


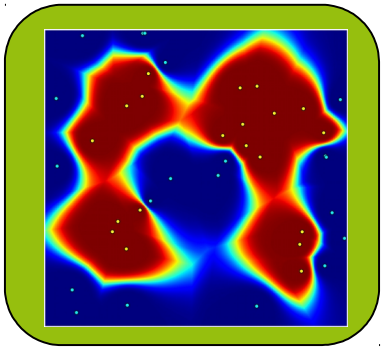
SVM model

$$\text{Prob}(+1|x) = \frac{1}{1+e^{\left(As(x)+B\left(\frac{d_n}{d_p}-\frac{d_p}{d_n}\right)\right)}}$$

PSVM feasibility probability (pf)







Trade-off between points distances and SVM output determined thanks to parameters A and B

Efficient SBO – dealing with feasibility

- **Enhanced capturing of the feasible zones in Minamo :**
  - **Auto-adaptive surrogate models in an online framework**
  - **Constraint handling : blend of interpolation/regression and classification :**
    - Combining constraint tournament selection methods with PSVM-enabled feasibility probability to improve its ability to quickly reach feasible zones
- **Mono-point : Complexity of combining exploitation, exploration and feasibility in one single additional point.**
- **⇨ A multi-point strategy** ***(can be parallelized)***
  - **First point : default ISC based on Deb constrained tournament selection**
  - **Second point : criterion exploiting the PSVM-enabled feasibility probability → Determination of feasible boundary**

⇨ Innovative mono and multi-point infill sampling criteria

Numerical results

- **Results on analytical constrained optimization problems (see e.g. [1] and [2])**
- **Objective function and constraint violation evolutions (mean of 500 independent runs, started from an initial database without any feasible point)**
  - **Minamo default mono-point : based on RBFN interpolation surrogates**
  - **Minamo feasibility mono-point : based on PSVM feasibility probability**
  - **Minamo feasibility multi-point : based on RBFN and PSVM**
  - **Compared to the best known solution**

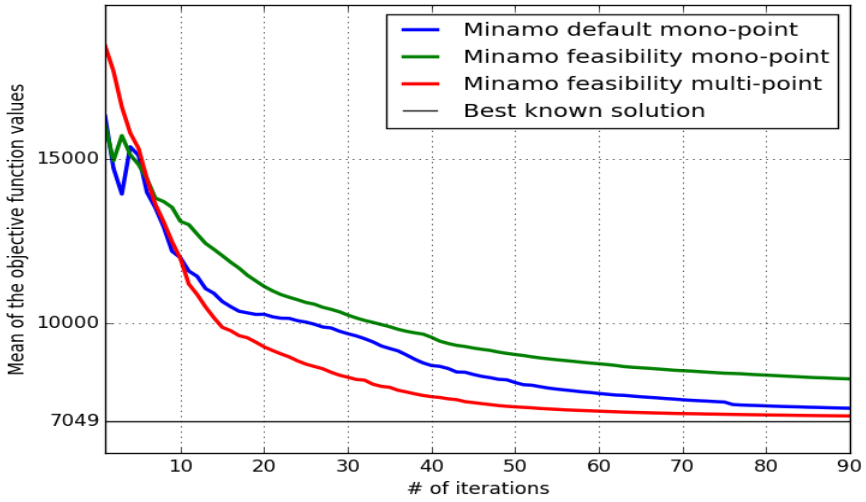
[1] Michalewicz, Z. and Schoenauer, M. Evolutionary algorithms for constrained parameter optimization problems. Evolutionary Computation 4(1), 1–32 (1996)
[2] Regis, R. G. Evolutionnary programming for high-dimensional constrained expensive black-box optimization using radial basis functions. IEEE Transactions on Evolutionary Computation 18(3),326–347 (2014).

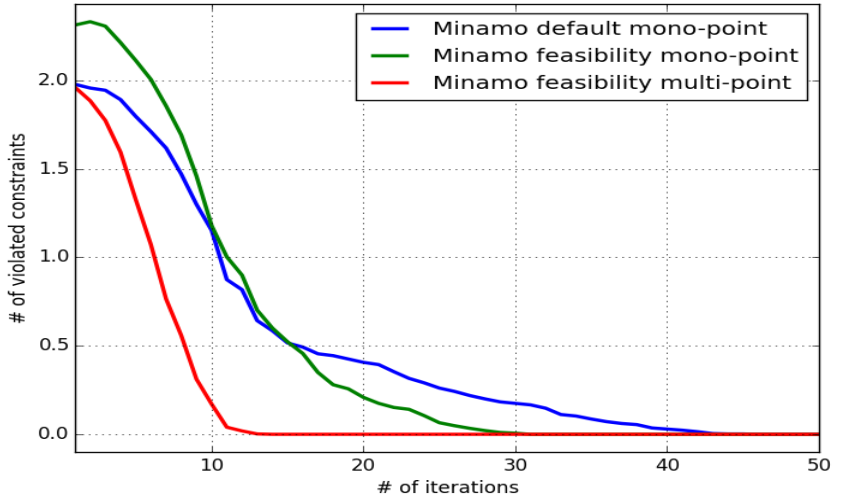
Results on constrained optimization problems

Mean of the objective

# of violated constraints

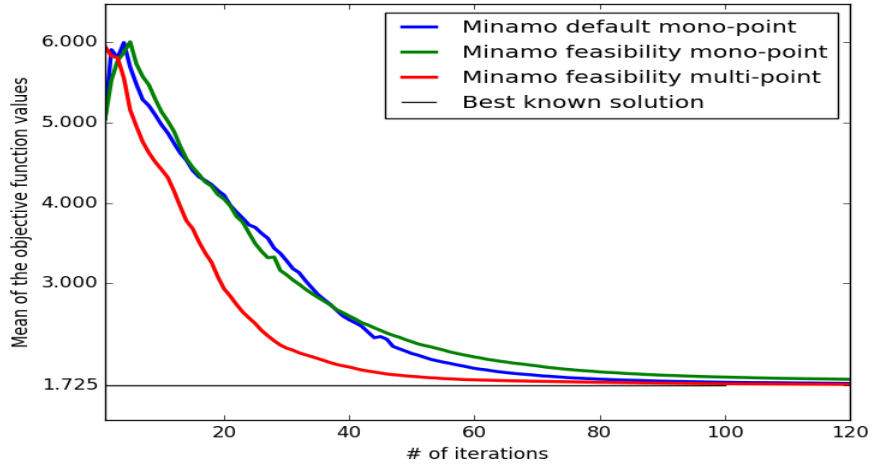
G10

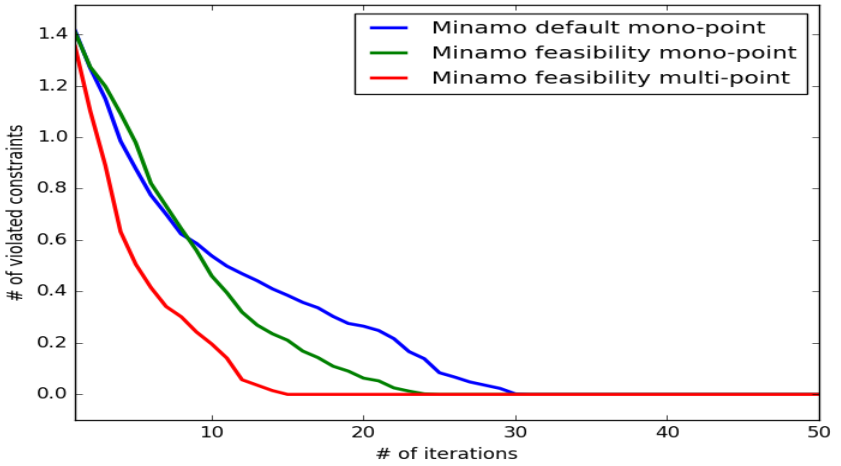




PSVM-based strategies reach faster feasible zones
(but to the detriment of the objective convergence (for mono-point))

WB4



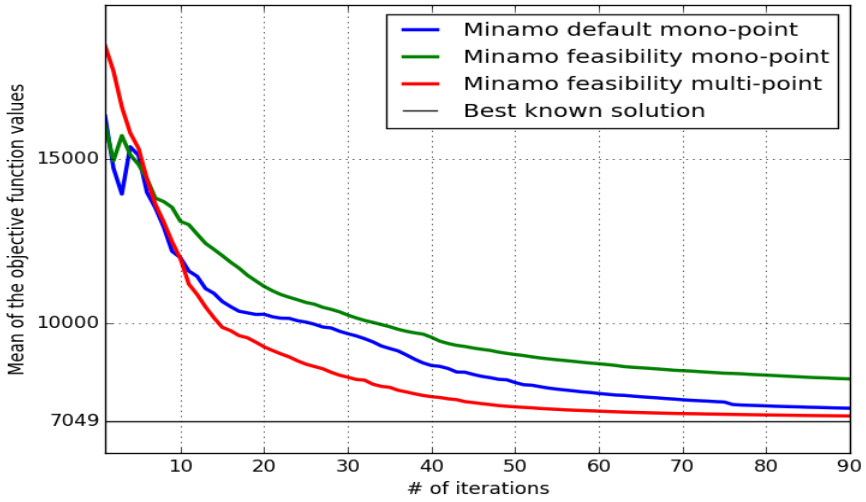


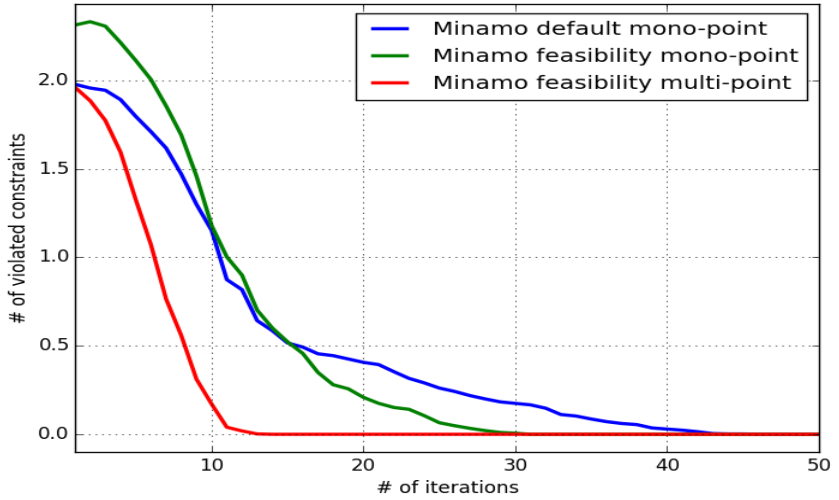
Results on constrained optimization problems

Mean of the objective

# of violated constraints

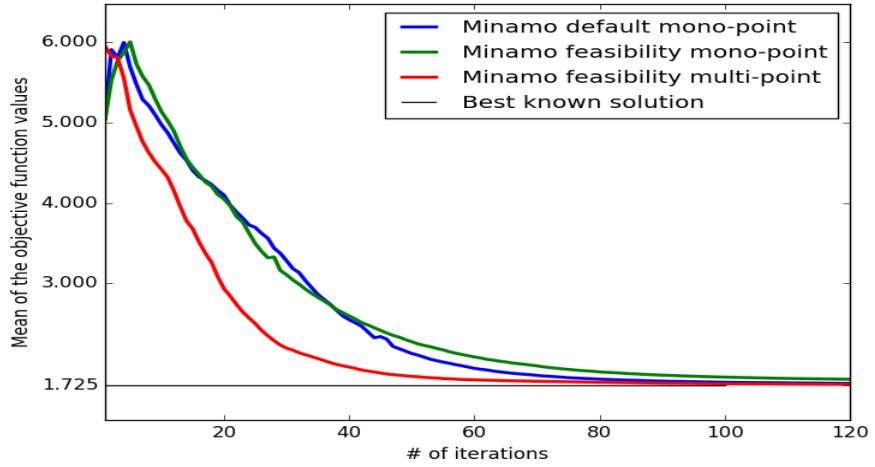
G10

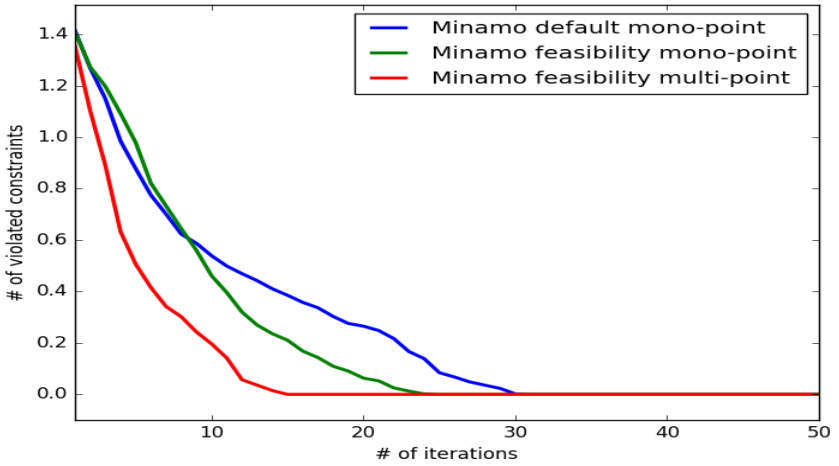




The multi-point strategy allows to quickly identify the feasible zone with a good convergence

WB4

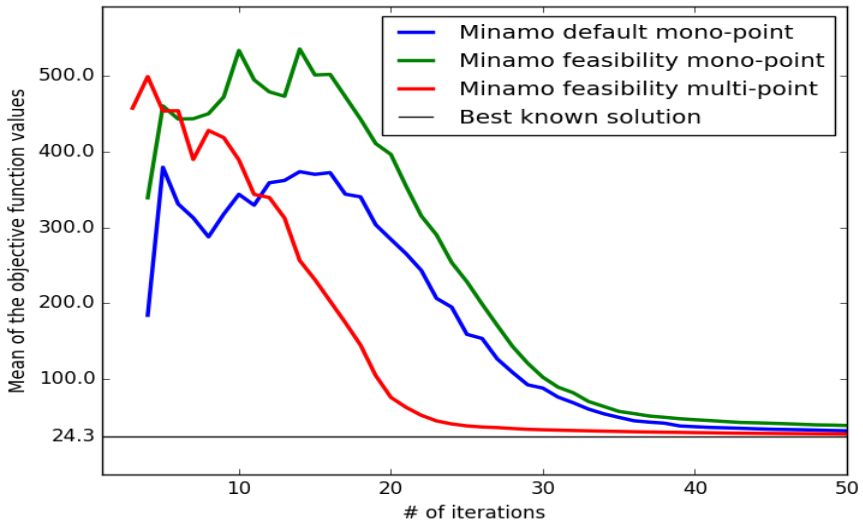




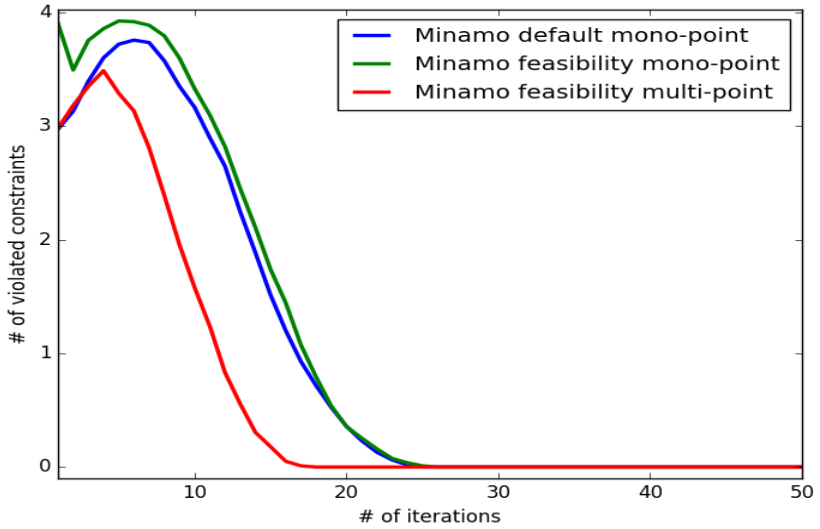
Results on constrained optimization problems

G7

Mean of the objective



# of violated constraints



- **The multi-point strategy :**
  - **Allows to quickly identify the feasible zone with a good convergence**
  - **Is more powerful (# of iterations, CPU time)**

Conclusions and perspectives

- **Innovative SBO framework, combining interpolation/regression and classification surrogates**
- **Perspectives for further improvement of the SBO methodology to tackle high-dimensional highly constrained multi-disciplinary optimization problems :**
  - **Multi-point strategies with multiple zones of research**
  - **Surrogate-models : dimensionality reduction / multi-fidelity / multi-level**
  - **Cooperative Co-evolutionary algorithm**

    (see Julien Blanchard's talk, ENUM2 session on Tuesday *"A Cooperative Co-evolutionary Algorithm for solving Large-Scale Constrained Problems with Interaction Detection"*)

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Towards multi-disciplinary, techno-economical, integrated process / product conception

Thank you for your attention !