THE UNIVERSITY OF HONG KONG 香港大學
faculty of architecture 建築學院

iLab @HKURBANlab the urban big data lab

Derivative-free optimization

Theory and applications in construction management

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Tongji University

Frank Xue

Dept. of REC, HKU
HKURBANlab—iLab, HKU

Outline

1. Introduction to DFO
2. DFO in construction management
3. Discussion

Section 1

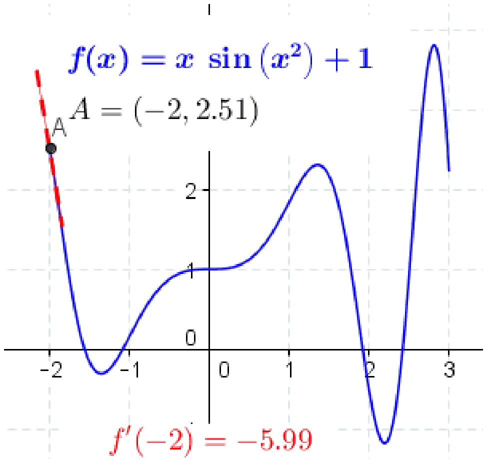
INTRODUCTION TO DFO

1.1 Fundamentals

- Optimization (a.k.a. Mathematical programming)
  - the selection of a *best* element (with regard to some criteria) from *some* set of available alternatives.
- Nonlinear optimization
  - When *objective function* or some *constraints* are nonlinear
- Optima (optimal solutions)
  - A subset of global extrema
    - Boundary of *f*
    - Non-differentiable points
    - Stationary points, where the first derivative is zero

$$\max f: \mathbb{R}^n \longmapsto \mathbb{R}$$

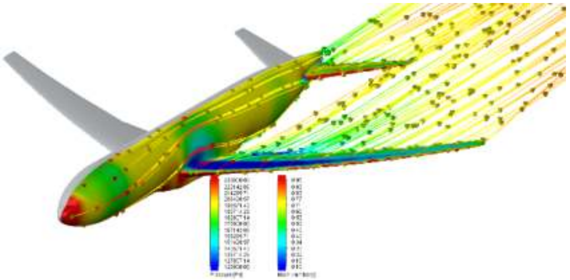
An example of optimization



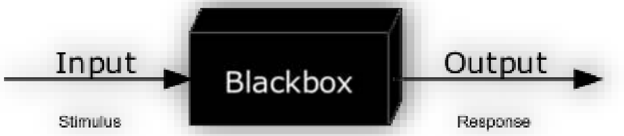
First derivative and stationary points

1.1 Derivative-free optimization

- The derivatives are often unavailable, unreliable, or impractical to obtain (Conn et al., 2009; Xue, et al., 2018a)
  - When f is too expensive or unanalyzable
    - E.g., FEM parameter tuning, aircraft wings design
  - Challenging (*NP*-hard usually) and time-consuming
- Derivative-free optimization (DFO) (Conn et al., 2009)
  - Solves problems using meta models
  - Equivalent to a black-box function regression
  - Succeeded in many science and engineering problems
    - E.g., Protein folding (Nicosia & Stracquadanio, 2008), aircraft wing design (Lee, et al., 2008), optimal adaptation of new materials (Miskin & Jaeger, 2013)



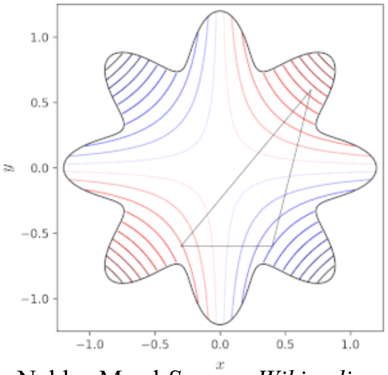
Aerodynamics simulation
Picture source: mentor.com



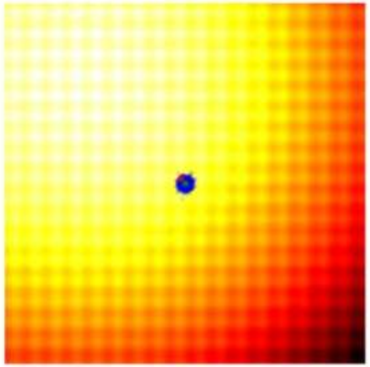
DFO: Manipulating a black-box
Picture source: Wikipedia.com

1.2 DFO algorithms

- Category by meta model
  - Heuristic
    - E.g., Monte Carlo, local search (greedy hill-climbing)
  - Meta-heuristic
    - Second-level heuristics for heuristics
    - E.g., EDA, GA, PSO, ABC, etc.
  - Quasi-derivative/ trust-region
    - Temporarily assuming regions are smooth and differentiable
    - E.g., NEWUOA, Nelder-Mead, DIRECT, etc.
  - Quasi-derivative + meta-heuristic
    - E.g., CMA-ES (covariance matrix adaptation with evolution strategy), CMA-VNS (CMA with variable neighborhood search) (Xue & Shen, 2017)

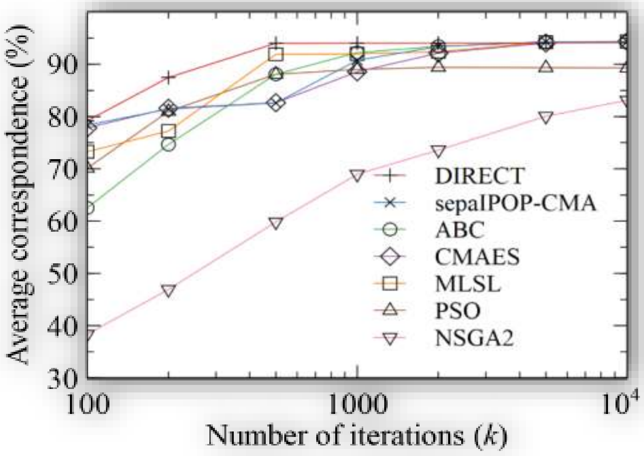


Nelder-Mead *Source: Wikipedia.org*

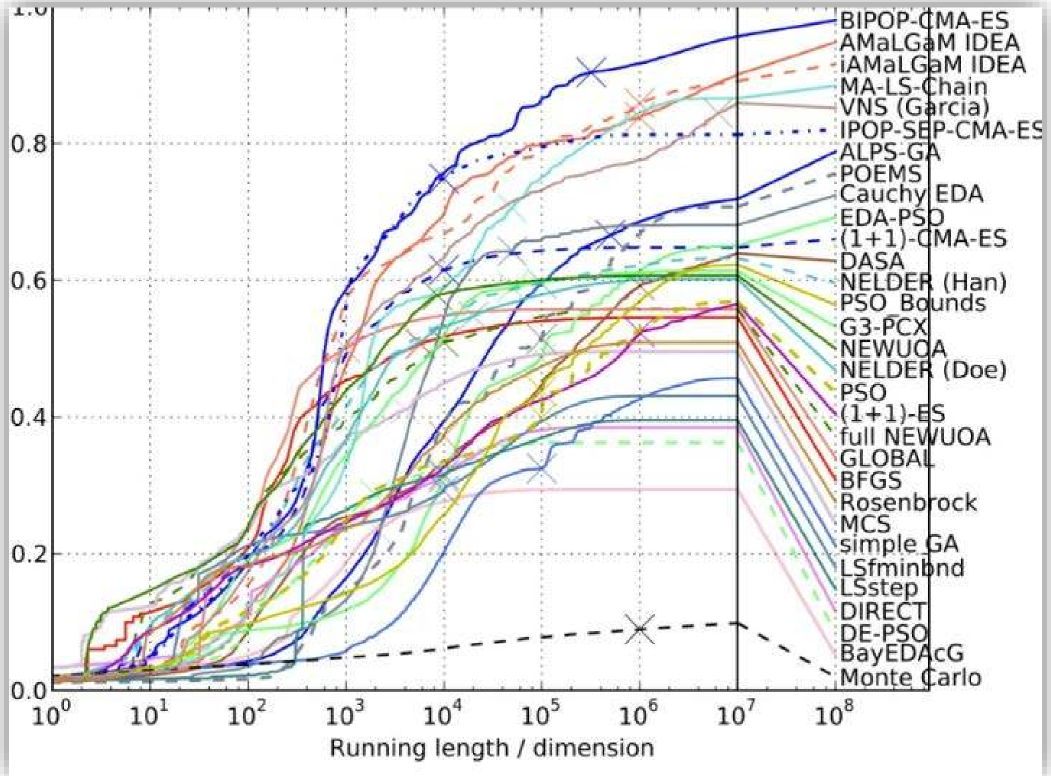

CMA-ES *Source: otoro.net*

1.2 DFO algorithms

- In general
  - 'Quasi-derivative + meta-heuristic' > Quasi-derivative > meta-heuristics
  - Due to the characteristics of real world problems



DFO for symmetry detection (Xue et al., 2018c)



Comparison of DFO algorithms for BBOB-2009 (Auger et al., 2010) *Source: Inria*

Section 2

DFO IN CONSTRUCTION MANAGEMENT

2.1 Case 1: DFO-based automatic modeling

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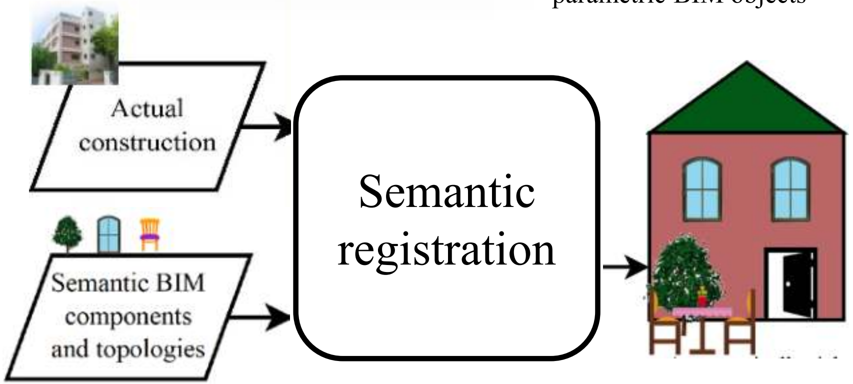
- A dilemma of urban semantics in BIM/GIS
  - *Inadequacy*: Poor semantics in the models
  - *Overload*: Rich online open BIM/GIS resources
    - With fact-nongeometric & instructional
- Semantic registration as auto-modeling
  - Registering semantics to low LOD models
  - Input 1: 2D Photo /3D point cloud
  - Input 2: Semantic components
- Performance metrics
  - Computational time
  - Precision = true positive / registered
  - Recall = true positive / actual

Google Map/Earth? ~*LOD2*

BIMobject.com has >*300,000* parametric BIM objects



Semantic registration as a process

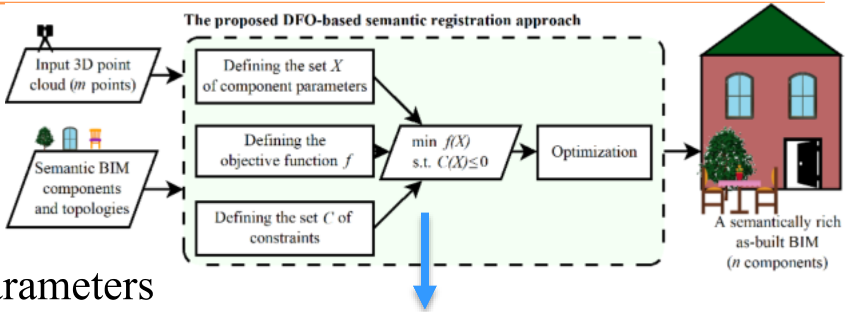
HK GRF 17201717, HK$450,000
HK GRF 17200218, HK$520,000

2.1 Problem formulation

- Semantic registration is a decision prob.
- Problem formulation (Xue et al., 2018a;b;c)
  - Input 1: E.g., 3D point cloud
  - *Variables* (*X*): component transformation parameters
  - *Objective function* (*f*):
    - Minimum geometric error (e.g., *RMSE*)

      $\left[\frac{1}{n}\sum_{p\in\mathcal{C}} d(p, T, \mathcal{C})^2\right]^{½}$
    - Dissimilarity between pictures (e.g., 1 — *SSIM*)

      $$SSIM = structure \cdot luminance \cdot contrast$$
      $$= \frac{(2\mu_{\hat{A}}\mu_A + c_1)(2\sigma_{\hat{A}A} + c_1)}{(\mu_{\hat{A}}^2 + \mu_A^2 + c_1)(\sigma_{\hat{A}}^2 + \sigma_A^2 + c_2)},$$
  - *Constraints* (*C*): Topological regularity
- DFO algorithm: CMA-ES



$$\min\ f(X)$$
$$\text{s.t. } C(X) \le 0$$

DFO-based Semantic registration (Xue et al., 2018a; 2018b)

C	Example	Example value	Notes
	scaling_max	[1.5, 1.5, 1.5]	xyz coordinates
C_I	scaling_min	[0.8, 0.8, 0.8]	Ibid.
	z_rotation_max	π/2	
	z_rotation_min	0	
	on_top_of	'Ground'	Adjacency, connectivity
C_R	contains_on	'Wall'	Containment or intersection
	min_separation	'0.5 m'	Separation

2.1 An outdoor case (Xue et al., 2018a)

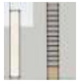
- 2D photo + free BIM objects → 3D models
  - Automatic, error tolerant, recoverable from wrong objects
  - Segmentation-free, topological relationships involved

- Time: 2.5h
- Precision: 0.92
- Recall: 0.92

(a) A photo of a demolished building

Door portico

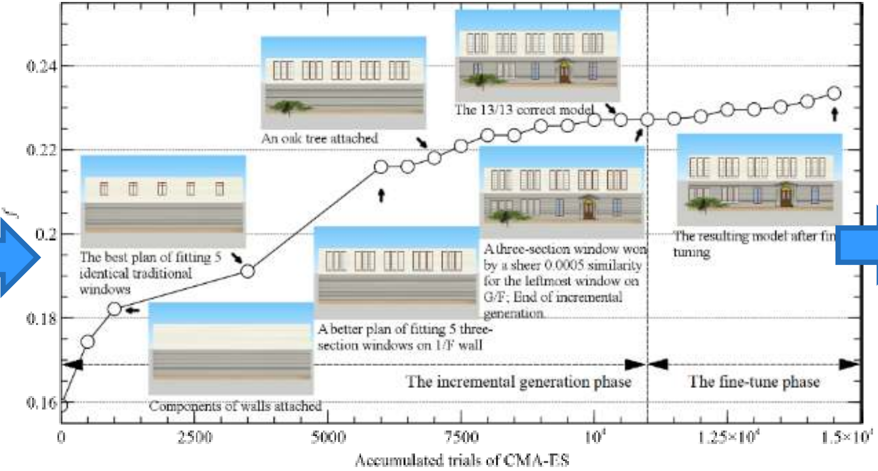
Tree × 2



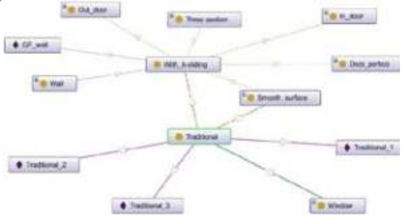
Wall × 2

Windows × 2

(b) Semantic components from web



(c) Approximate building mode



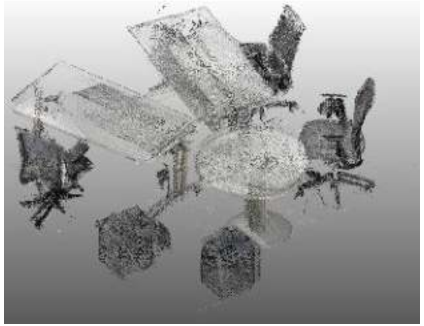
(d) Semantic/topological links

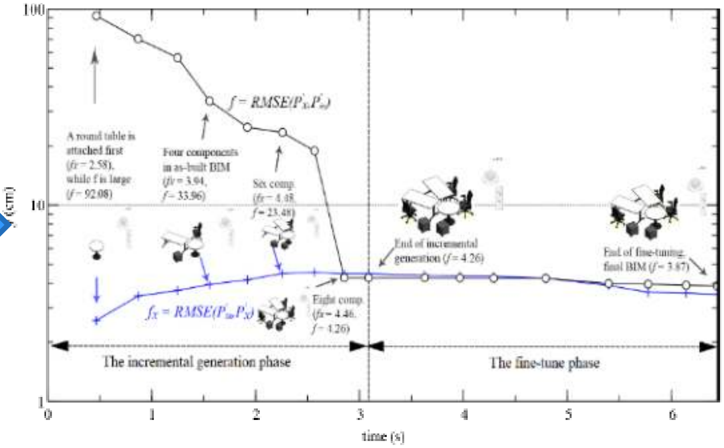
(Language: C++, Ruby; Data formats: SketchUp, Bmp, Google earth)

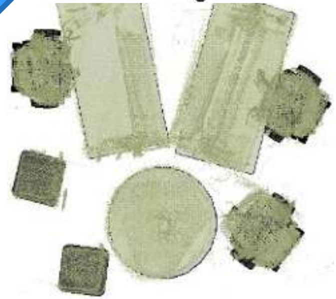
2.1 An indoor case (Xue et al., 2018b)

- ◇ Point cloud + BIM objects → indoor model
  - ▣ Automatic, saved 98% time from manual modeling
  - ▣ *RMSE* = 3.87cm, equal to experienced modelers

- ▣ Time: 6.44s
- ▣ Precision: 1.0
- ▣ Recall: 1.0







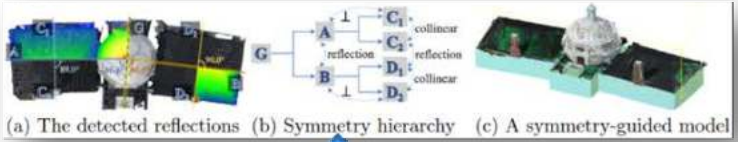
(Language: C++, CLR; Data formats: Autodesk Revit, Stanford polygon)

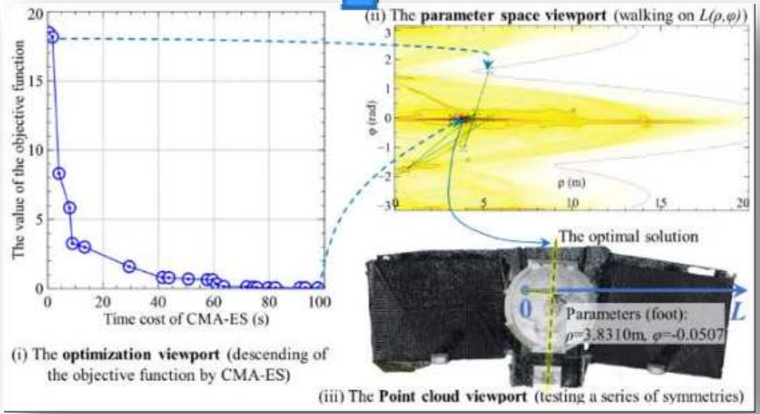
2.1 A demo video

2.1 Symmetry detection from 3D point cloud

- 3D point cloud → symmetry hierarchy (Xue et al., 2018c)
  - A knowledge discovery tool for further 3D modeling

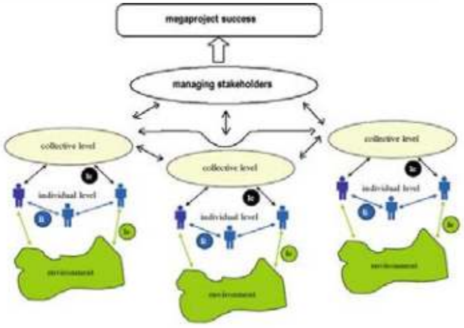
- Time = 98.6s
- PCR = 93.7%





2.2 Case 2: Megaproject stakeholder coordination

- Megaproject
  - Huge amount of investment, long project development cycle,
  - Many stakeholders, and complicated activities
- This project aims
  - 1. To identify and cluster key stakeholder network
    - Using social network analysis (SNA)
  - 2. To formulate their relationships and optimize stakeholder coordination strategy
    - Agent-based model of interests and decision preference
    - *NK* model of their coordination networks
    - DFO for mutual interests coordination
  - 3. To devise a methodology for megaproject coordination



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Section 3

DISCUSSION

3.1 Discussion

- DFO
  - Generic, cross-domain algorithms
    - Many (meta-)heuristics
    - Quasi-derivative methods
  - Proven successful in challenging science/engineering problems
  - Applied to 3D modeling processes
    - Pros: Automated, fast, accurate,
    - Cons: Still one or two parameters to tune
      - E.g., iteration, population size
      - With sensitivity analysis and recommended settings provided
  - To be applied to stakeholder network
    - For optimal collaboration

References

- Auger, A., Finck, S., Hansen, N., and Ros, R. (2010). BBOB 2009: Comparison tables of all algorithms on all noisy functions, INRIA.
- Conn, A. R., Scheinberg, K., & Vicente, L. N. (2009). Introduction to derivative-free optimization. SIAM.
- Lee, D. S., Gonzalez, L. F., Periaux, J. & Srinivas, K. (2008), Robust design optimisation using multi-objective evolutionary algorithms. Computers & Fluids, 37(5), 565-583.
- Miskin, M. Z., & Jaeger, H. M. (2013). Adapting granular materials through artificial evolution. Nature materials, 12(4), 326.
- National Institute of Building Sciences. (2015). National Building Information Modeling Standard. Version 3, Retrieved from https://www.nationalbimstandard.org/
- National Geographic Society. (2012). GIS (geographic information system). http://www.nationalgeographic.org/encyclopedia/geographic-information-system-gis/
- Nicosia, G. & Stracquadanio, G. (2008), Generalized pattern search algorithm for peptide structure prediction. Biophysical Journal, 95(10), 4988-4999.
- Niu, Y., Lu, W., **Xue, F.**, Liu D., Chen, K., Fang, D., & Anumba, C. (2018). Towards the “Third Wave”: An SCO-enabled occupational health and safety management system for construction. Safety Science. 111, 213-223.
- Rowley, J. (2007). The wisdom hierarchy: representations of the DIKW hierarchy. Journal of information science, 33(2), 163-180.
- Rowley, J., & Hartley, R. (2017). Organizing knowledge: an introduction to managing access to information. Routledge.
- Xu, J., Chen, K., **Xue, F.**, & Lu, W. (2018). 3D point clouds for architecture, engineering, construction, and operation: A SWOT analysis. Working paper
- **Xue, F.**, & Shen, G. Q. (2017). Design of an efficient hyper-heuristic algorithm CMA-VNS for combinatorial black-box optimization problems. In Proceedings of the Genetic and Evolutionary Computation Conference Companion (pp. 1157-1162). ACM.
- **Xue, F.**, Lu, W., Chen, K. (2018a). Automatic generation of semantically rich as-built building information models using 2D images: A derivative-free optimization approach. Computer-Aided Civil and Infrastructure Engineering, in press. doi: 10.1111/mice.12378
- **Xue, F.**, Lu, W., Chen, K. & Zetkulic, A. (2018b). From ‘semantic segmentation’ to ‘semantic registration’: A derivative-free optimization-based approach for automatic generation of semantically rich as-built building information models (BIMs) from 3D point clouds. Journal of Computing in Civil Engineering. Under review
- **Xue. F.**, Chen, K., Lu, W. (2018c). Architectural Symmetry Detection from 3D Urban Point Clouds: A Derivative-Free Optimization (DFO) Approach. CIB W78 2018, accepted.
- Zins, C. (2007). Conceptual approaches for defining data, information, and knowledge. Journal of the Association for Information Science and Technology, 58(4), 479-493.

THANK YOU !