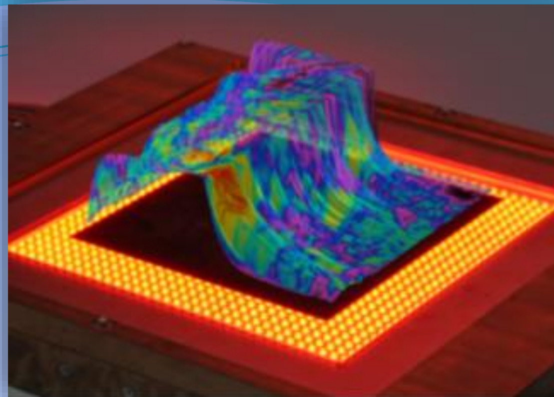
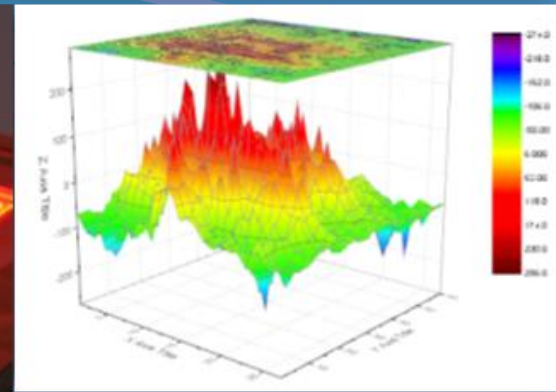




Advanced Optimization

Lecture 1

Shahryar Rahnamayan, PhD, PEng, SMIEEE
Department Chair and Associate Professor

NICI
Nature-Inspired Computational Intelligence

SIRC 3330
11:10 AM - 2:00 PM
Fri., Sept. 6, 2019

About the course instructor

- B.Sc. (First Class Honour): Software Eng. (1994-1998)
- M.Sc. (First Class Honour): Software Eng. (1999-2001)
- PhD (Nominated to PhD Alumni Gold Medal): Systems Design Eng., University of Waterloo (2003-2007)
- CIHR Training Fellow: Medical Image Processing, Robarts Research Center (2002-2004)
- Postdoctoral Fellow: Simon Fraser University (2008), Canada
- Faculty member: UOIT, Sept. 2008
- Registered Professional Engineer: PEng (2009), ON, Canada
- Visiting Researcher: Michigan State University (2014-2016), BEACON Research Center, MI, USA

About the course instructor (Cont.)

- Publications: More than 170 papers (2005-present)
- The highest impact paper: 33^{th} (in term of number of citations) out of 254,000 papers published in IEEE with keyword of optimization (2008-present) [inspired more than 500 papers]
- Awards: OGS, OGSST, CIHR, JSPS, IRDF, … (more than 40 awards and recognitions)
- Current positions: Department Chair and Associate professor at UOIT, Adjunct professor at University of Waterloo, Faculty member in BEACON, Michigan State University (MSU)
- Professional Memberships: SMIEEE, PMACM, PEng, ASSE, COIN, INFORMS, Mitacs, CEEA, CORS, reviewer for more than 35 journal papers
- Research fields: Evolutionary Computation, Machine Learning, Image Processing, and Metaheuristics
- Received UOIT Research Excellence Award, 2017
- Nominated by FEAS for the UOIT Teaching Excellence Award, 2018

My research homes (2003- present)

2003-2007 (PhD),
2009-present (Adjunct)

2003-2005 (CIHR Strategic Training Fellow)

May 2007- Feb. 2008 Researcher

March-Aug., 2008 (PDF)

2008- present (Faculty Member)

2009-2014 (Adjunct)

1999-2001 (MSc)

2014-2016 (Visiting Researcher)

2014-present (Faculty member)

Let me say first!

(what I know/what I don't know) approaches to zero fast when we talk about my expertise.

Summary of Course Outline

Course Description

This course can be helpful for Master and PhD students in all fields of Engineering, Computer Science, Applied Mathematics, and Operations Research. All steps of an optimization process, including, modeling the problems, designing and implementation of optimization algorithms, solving the optimization problems, and results comparison and analysis will be covered in this course.

Prerequisites: A moderate level of knowledge about mathematics, algorithms design, implementation, and analysis is required for this course.

Course Expectations (completing a comprehensive chain)

- Understanding of the given problem
- Converting it to an optimization problem
- Finding out the type of the problem to solve
- Utilizing/designing the algorithm to solve the problem
- Implementing the problem and algorithm
- Reporting and comparison of the results
- Visualization of the optimization process and solution(s)
- Results analysis
- Technical reporting as a paper

Course Design

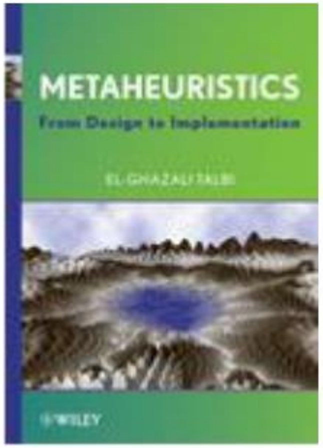
Teaching mode for this course is mainly lecture-based; during the lectures all required learning tools, including clips, Java applets, simulation software, open source codes and toolboxes will be utilized properly. Lectures attendance is mandatory. All teaching materials and assignments will be posted on the Blackboard. All commutations should be conducted via the Blackboard.

Outline of Topics in the Course

The following topics will be covered in this course:
- Introduction to Optimization (optimization in research and research in optimization)
- Fundamental Concepts in Optimization (e.g., multi-modal, convex, concave, linear, nonlinear, constraint, unconstraint, NP-complete, large scale, combinatorial, mixed-type, expensive, noisy, dynamic, multi-objective problems)
- Single-Solution Based Methods
- Linear Programming
- Continuous, discrete and combinatorial optimization
- Steepest descent and Newton methods for unconstrained optimization
- Population-Based Methods (e.g., Differential Evolution, Genetic Algorithms, Genetic Programming, Particle Swarm Optimization, Ant Colony Optimization)
- Multi-objective Optimizations
- Many-objective optimization
- Hybrid Metaheuristics
- Parallelizing optimization algorithms
- Visualization techniques utilized in optimization (RadViz, Parallel Coordinates, Heatmap, ...)

- Deb, Kalyanmoy. Multi-objective optimization using evolutionary algorithms. Vol. 16. John Wiley & Sons, 2001.

- EL-GHAZALI TALBI, Metaheuristics From Design to Implementation, John Wiley and Sons, 2009, ISBN: 978-0-470-27858-1.



Components	Percent of Final Mark	Remarks
Assignments and Quizzes*	40%	*Including algorithms implementation, experiments, and results analysis* *Submission deadline will be indicated in each assignment.*
Project Paper*	30% [Source code: 0% (but mandatory), Topic difficulty: 5%, **paper**: 25%] {**paper**: Organization - 3% Comprehensive Background review - 7% Novelty - 3% Technical soundness - 4% Results - 8%}	*Page number: 8-12 pages* *Submission Deadline**:* *Dec. 4, 2019, before 11:59 PM* *Note: MEng students can submit their project in a report style (which should include: Title, abstract, introduction, proposed method, results, result analysis, conclusion, future work, and references).*
In-class Presentation*	10%	*A comprehensive journal papers' set will be shared with students to select for their presentation.* *Date: Friday, Nov. 29, 2019, Lecture time*
In-class Bonus questions	0.5% (per question)	*I'll be mentioned which question is a bonus one during the lecture.*
Midterm Exam	20%	*Date: Friday, Nov. 22, 2019* *The exam would be **Individual based.***
TOTAL: 100% + (in-class bonus questions' mark, if any)		

* Groups: No more than three students in each group.

** The mentioned deadlines are hard ones (i.e., no extension).

Course Project

- Please start to work on it ASAP
- First consult with your supervisor(s)
- Find/define a complex optimization problem in your research direction
- Try to make your course project a chapter of your thesis and/or a paper

Finalizing project topic:	Friday, Oct. 4, 2019, lecture time
Finalizing presentation topic:	Friday, Nov. 15, 2019, lecture time
Assignment submission:	Will be announced for each assignment
In-class presentation:	Friday, Nov. 29, 2019, Lecture time
Midterm Exam:	Friday, Nov. 22, 2019, Lecture time
Project submission:	Friday, Dec. 4, 2019, before 11:59 PM

Accessibility

Students with disabilities may request to be considered for formal academic accommodation in accordance with the Ontario Human Rights Code. Students seeking accommodation must make their requests through Student Accessibility Services. Requests must be made in a timely manner, and students must provide relevant and recent documentation to verify the effect of their disability and to allow the university to determine appropriate accommodations.

Accommodation decisions will be made in accordance with the Ontario Human Rights Code. Accommodations will be consistent with and supportive of the essential requirements of courses and programs, and provided in a way that respects the dignity of students with disabilities and encourages integration and equality of opportunity. Reasonable academic accommodation may require instructors to exercise creativity and flexibility in responding to the needs of students with disabilities while maintaining academic integrity.

Academic Integrity

Students and faculty at UOIT share an important responsibility to maintain the integrity of the teaching and learning relationship. This relationship is characterized by honesty, fairness and mutual respect for the aim and principles of the pursuit of education. Academic misconduct impedes the activities of the university community and is punishable by appropriate disciplinary action.

Students are expected to be familiar with and abide by UOIT's regulations on Academic Conduct (Section 5.15 of the Academic Calendar) which sets out the kinds of actions that constitute academic misconduct, including plagiarism, copying or allowing one's own work to copied, use of unauthorized aids in examinations and tests, submitting work prepared in collaboration with another student when such collaboration has not been authorized, among other academic offences. The regulations also describe the procedures for dealing with allegations, and the sanctions for any finding of academic misconduct, which can range from a resubmission of work to a failing grade to permanent expulsion from the university. A lack of familiarity with UOIT's regulations on academic conduct does not constitute a defense against its application.

Asking for recommendation letter

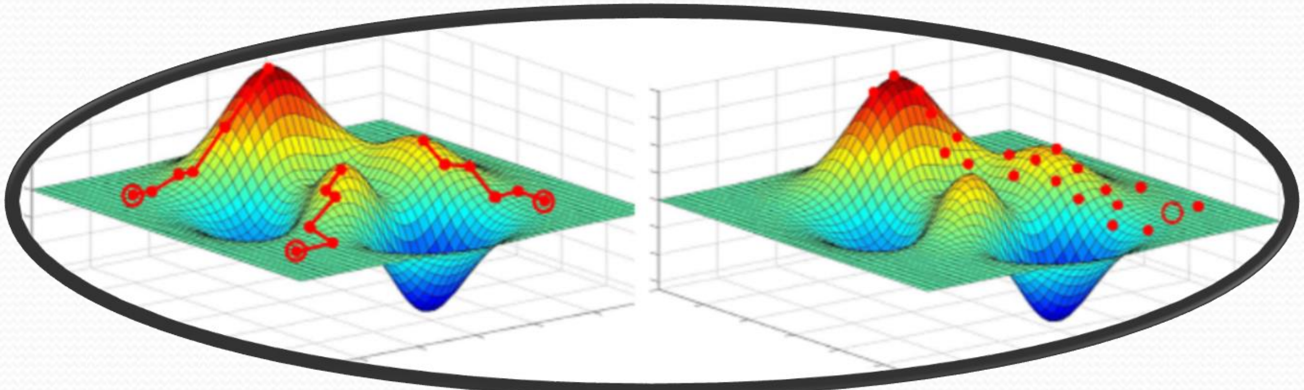
Any student who gets 90%+ (A+) in this course can ask for and expect a very good letter of recommendation/reference when he or she is looking for a job or applying to a graduate program or for a scholarship.

To the best of my knowledge, this course is the most productive course at UOIT in term of resulted published papers

What is Optimization?

An act, process, or methodology of making something (as a design, system, or decision) as fully perfect, functional, or effective as possible.

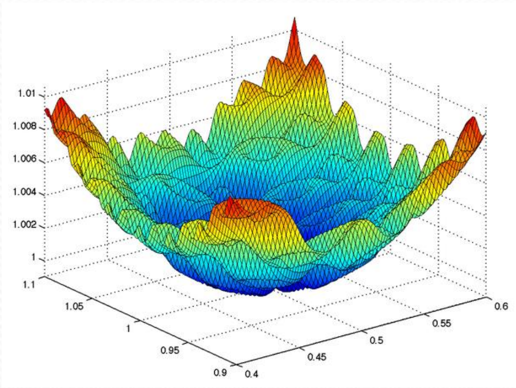
Merriam-Webster Online Dictionary



Examples for Optimization

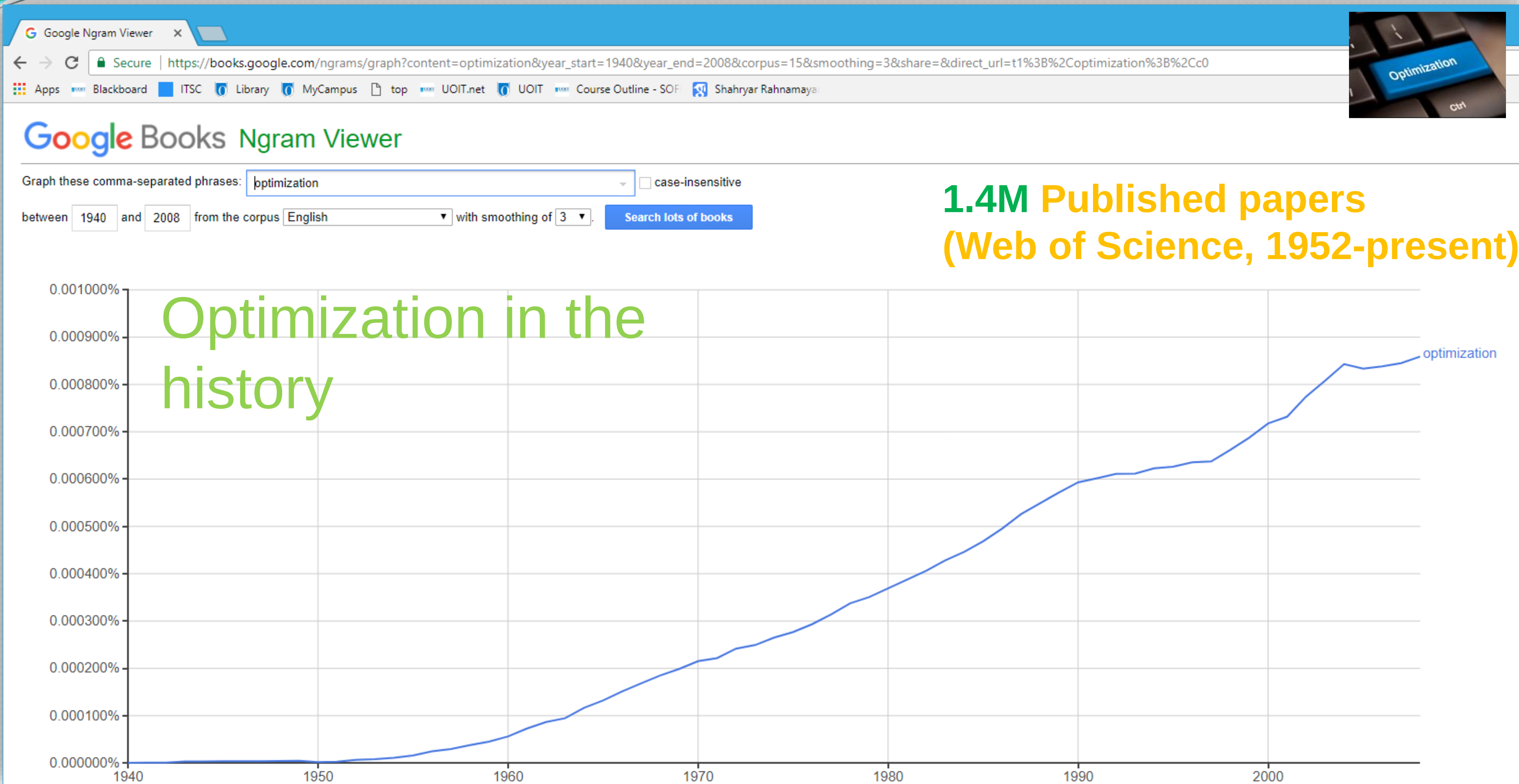
- Maximization of performance, accuracy, efficiency, benefit, stability, durability, life span, …….

- Minimization of development/maintenance cost, manufacturing cost, risk factor, error rate, wasting energy, utilized materials, negative environmental impact, response time, weight, …..



Optimization in the history

1.4M Published papers (Web of Science, 1952-present)



An Optimization Problem

- *Given:*

a function $f : A \rightarrow R$ from some set A to the real numbers

- *Looking for:*

  an element x_0 in A such that $f(x_0) \leq f(x)$ for all x in A ("minimization") or such that $f(x_0) \geq f(x)$ for all x in A ("maximization").

Horse Racing

The slowest horse is the winner!

Q. How can you run this competition?

Horse Racing

By Switching the horses to convert a minimization problem to the maximization one!

A formal definition of a continuous optimization problem

$$\begin{aligned} &\underset{x}{\operatorname{minimize}} && f(x) \\ &\operatorname{subject\ to} && g_i(x) \leq 0, \quad i = 1, \dots, m \\ &&& h_i(x) = 0, \quad i = 1, \dots, p \end{aligned}$$

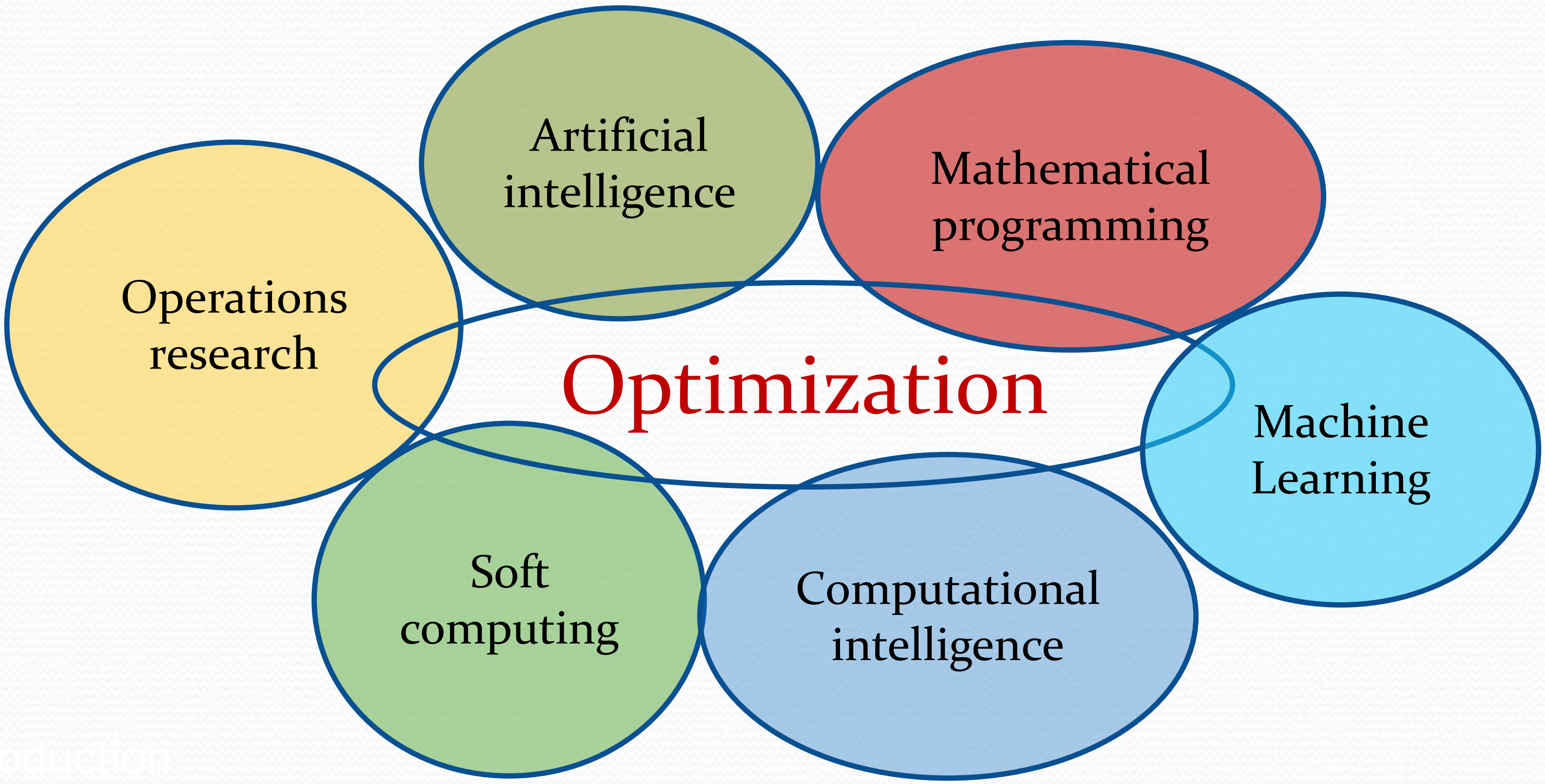
where

- $f(x) : \mathbb{R}^n \to \mathbb{R}$ is the **objective function** to be minimized over the variable x,
- $g_i(x) \leq 0$ are called **inequality constraints**, and
- $h_i(x) = 0$ are called **equality constraints**.

Let us first make our simple intuitive mini-dictionary about type of optimization problems

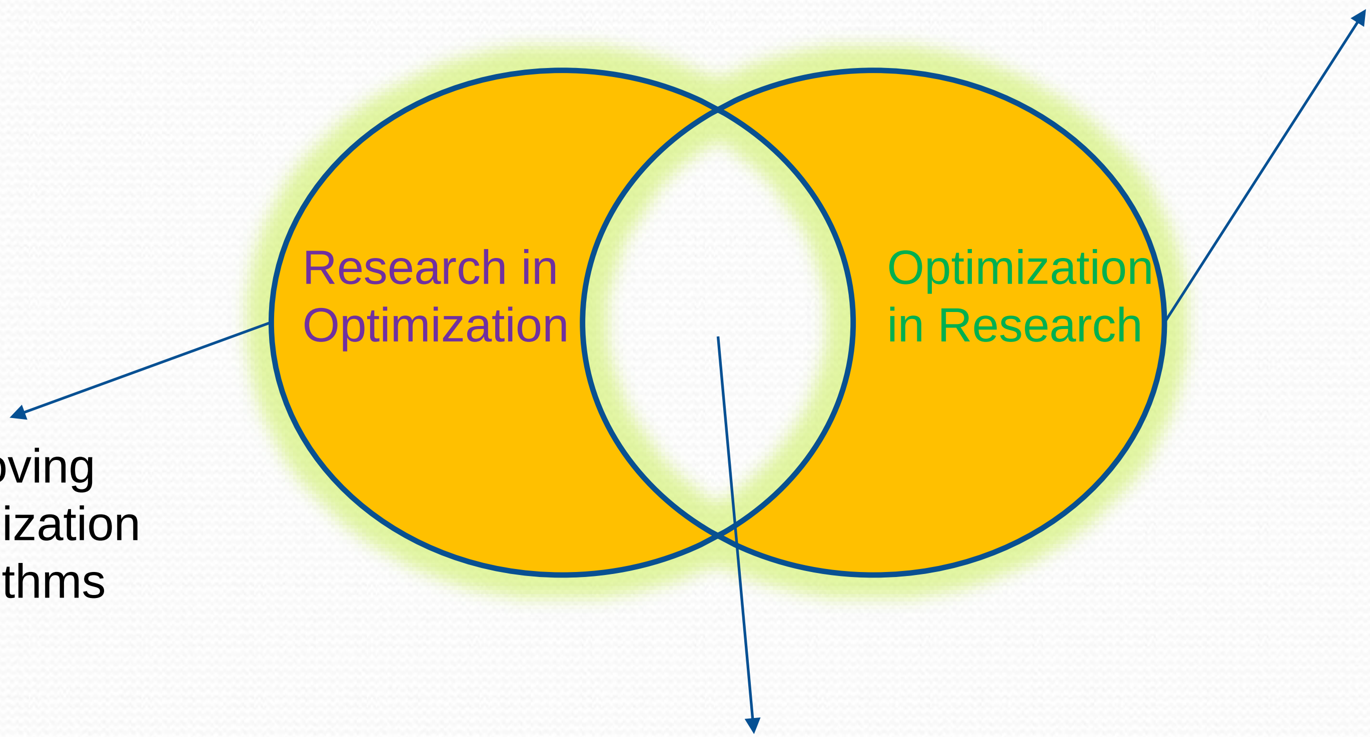
1) Objective function
2) Mathematical/Simulator/Experimental
3) Minimization/maximization
4) Dimension
5) Large-scale
6) Landscape
7) Discrete/continuous/mixed-type
8) Unimodal/multi-modal
9) One solution/many solutions
10) With know/ unknown solution
11) Design/control
12) Exact/approximate solution
13) Single/multi/many objectives
14) Black-box/grey-box problem
15) Constraint, box-constraint
16) Static/Dynamic
17) Noisy
18) Single- or Multi-level
19) Deceptive
20) Combinatorial
21) Expensive
22) Variable dimension size
23) Linear/nonlinear
24) Convex/concave
25) Interactive (single- or multi – objective)
26) Separable/non separable

Where is the home of optimization?



Research and Optimization

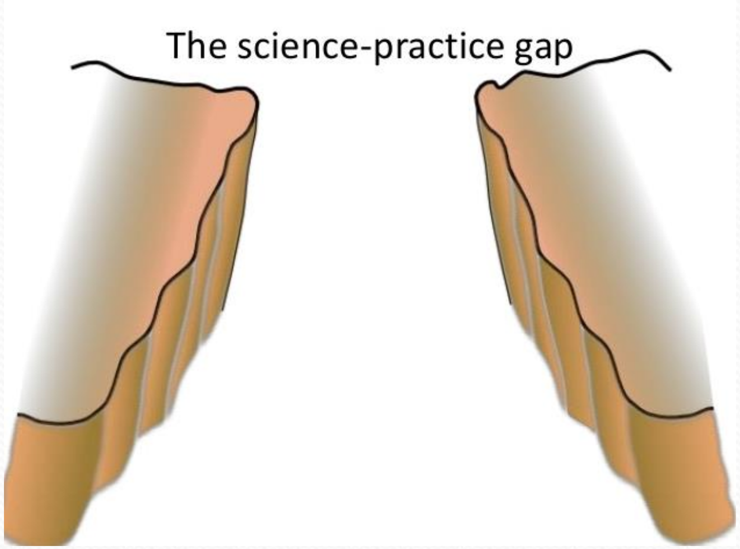
Solving real-world
optimization problems
using existence algorithms



Improving
optimization
algorithms

Tailoring optimization algorithm
to solve specific real-world problems

Theory and Practice!



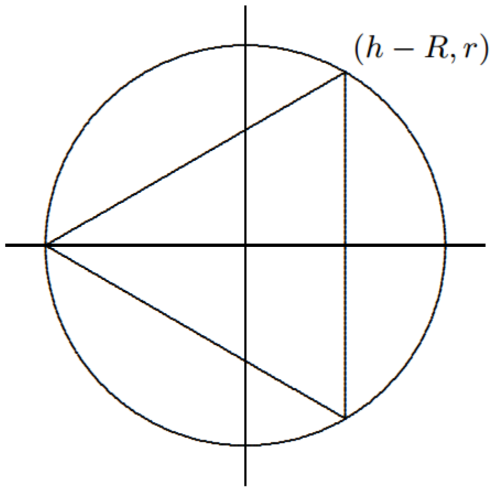
Theory is when one knows everything but nothing works. Practice is when everything works but nobody knows why.

If theory and practice go hand in hand: nothing works and nobody knows why!

A joke, but can happen!

A simple optimization problem (Application of the Derivative)

If you fit the largest possible cone inside a sphere, what fraction of the volume of the sphere is occupied by the cone? (Here by "cone" we mean a right circular cone, i.e., a cone for which the base is perpendicular to the axis of symmetry, and for which the cross-section cut perpendicular to the axis of symmetry at any point is a circle.)



Cone in a sphere.

https://www.whitman.edu/mathematics/calculus/calculus_06_Applications_of_the_Derivative.pdf

A simple optimization problem (Application of the Derivative)[Cont.]

Notice that the function we want to maximize, $\pi r^2 h/3$, depends on *two* variables. This is frequently the case, but often the two variables are related in some way so that "really" there is only one variable. So our next step is to find the relationship and use it to solve for one of the variables in terms of the other, so as to have a function of only one variable to maximize. In this problem, the condition is apparent in the figure: the upper corner of the triangle, whose coordinates are $(h - R, r)$, must be on the circle of radius R. That is,

$$(h - R)^2 + r^2 = R^2.$$

We can solve for h in terms of r or for r in terms of h. Either involves taking a square root, but we notice that the volume function contains r^2, not r by itself, so it is easiest to solve for r^2 directly: $r^2 = R^2 - (h - R)^2$. Then we substitute the result into $\pi r^2 h/3$:

$$\begin{aligned} V(h) &= \pi(R^2 - (h - R)^2)h/3 \\ &= -\frac{\pi}{3}h^3 + \frac{2}{3}\pi h^2 R \end{aligned}$$

https://www.whitman.edu/mathematics/calculus/calculus_06_Applications_of_the_Derivative.pdf

A simple optimization problem (Application of the Derivative)[Cont.]

We want to maximize $V(h)$ when h is between 0 and $2R$. Now we solve $0 = f'(h) = -\pi h^2 + (4/3)\pi h R$, getting $h = 0$ or $h = 4R/3$. We compute $V(0) = V(2R) = 0$ and $V(4R/3) = (32/81)\pi R^3$. The maximum is the latter; since the volume of the sphere is $(4/3)\pi R^3$, the fraction of the sphere occupied by the cone is

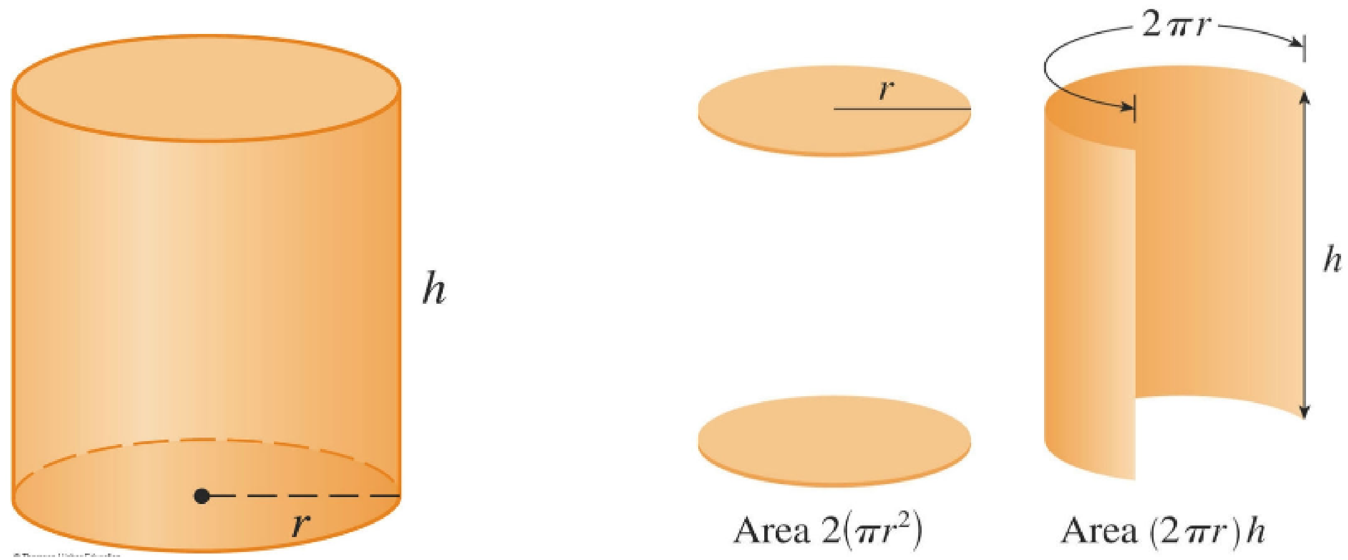
$$\frac{(32/81)\pi R^3}{(4/3)\pi R^3} = \frac{8}{27} \approx 30\%.$$

□

https://www.whitman.edu/mathematics/calculus/calculus_06_Applications_of_the_Derivative.pdf

EXAMPLE : A manufacturer needs to make a cylindrical can that will hold 1.5 liters of liquid. Determine the dimensions of the can that will minimize the amount of material used in its construction.

Solution: We first draw a picture:



The next step is to create a corresponding mathematical model:

$$\text{Minimize: } A = 2\pi r^2 + 2\pi r h$$

$$\text{Constraint: } V = \pi r^2 h = 1500$$

Analytical Vs. Algorithmic Optimization

Demonstration: Benchmark Function

Five types of problems to solve

- Type 1: Problems with known global solution(s)
- Type 2: Problems with best known solution(s)
- Type 3: Problems with unknown solution but with known optimal value for objective function
- Type 4: Problems with unknown solution and unknown optimal value for objective function
- Type 5: Problem with no objective function!

Name a science or engineering field with no fingerprint of optimization there?

Applications of Optimization

- Countless
- Many challenging applications in science and industry can be formulated as optimization problems.
- Minimization of time, cost, and risk
- Maximization of profit, quality, and efficiency

Applications I

- Mobile communications infrastructure optimization
- Composite material design and multi-objective design of automotive components, weight savings, and other characteristics
- Molecular Structure Optimization
- Learning Robot behavior
- Designing of water and electricity distributions
- RNA structure prediction
- Solving the machine-component grouping problem required for cellular manufacturing systems
- Automated drug design

Applications II

- Designing data compression systems
- Job-shop scheduling
- Finding hardware bugs
- Wireless Sensor/Ad-hoc Networks
- Proposing economic models
- Linguistic analysis, including Grammar Induction and other aspects of Natural Language Processing
- Designing of sophisticated trading systems in the financial sector
- Designing heat transfer systems

Applications III

- Medical image processing
- Aircraft Design
- VLSI and electronic circuit design
- Marketing mix Analysis
- Designing healthcare systems
- Mathematical modeling for biological systems
- Non-conflicting class/exam timetabling for universities
- Data Mining
- Assembly line design
- Architectural design
- Art and music design
- .... (open-ended)

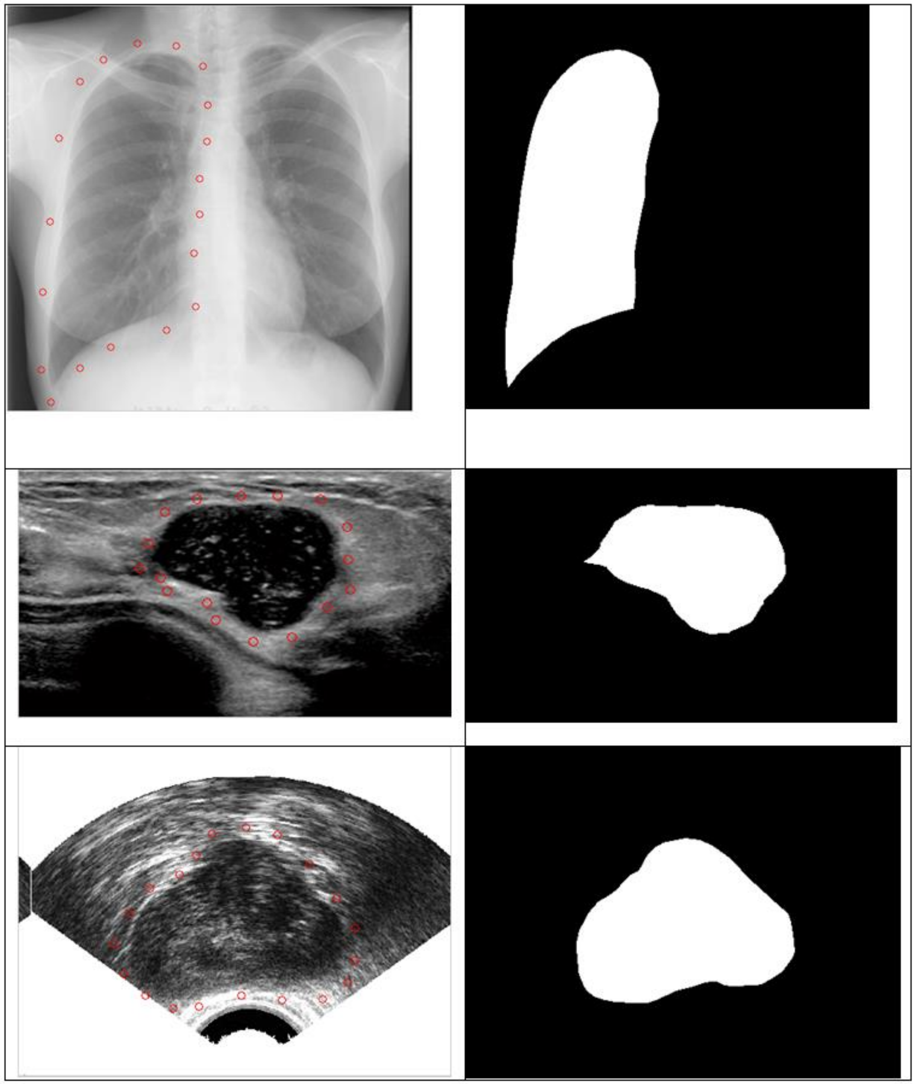
Our Some Sample Application-oriented Contributions

(helpful to get an idea about your course project)

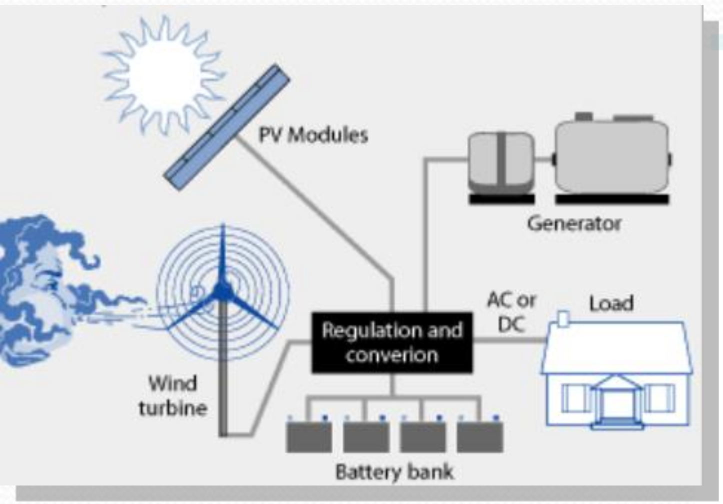
Class activity (time: 3 mins)

- Find a journal paper in your field (or any field which you are interested in) which has utilized an optimization method to solve a problem?

Optimal Parameter Setting of Active-Contours Using Differential Evolution and Expert-Segmented Sample Image



Optimal Design Methods for Hybrid Renewable Energy Systems



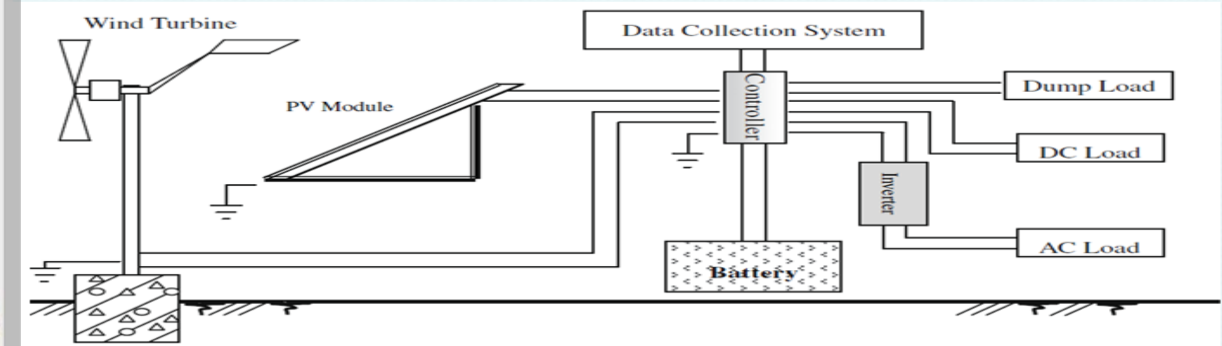


Figure 1: Example of a hybrid PV-wind energy system

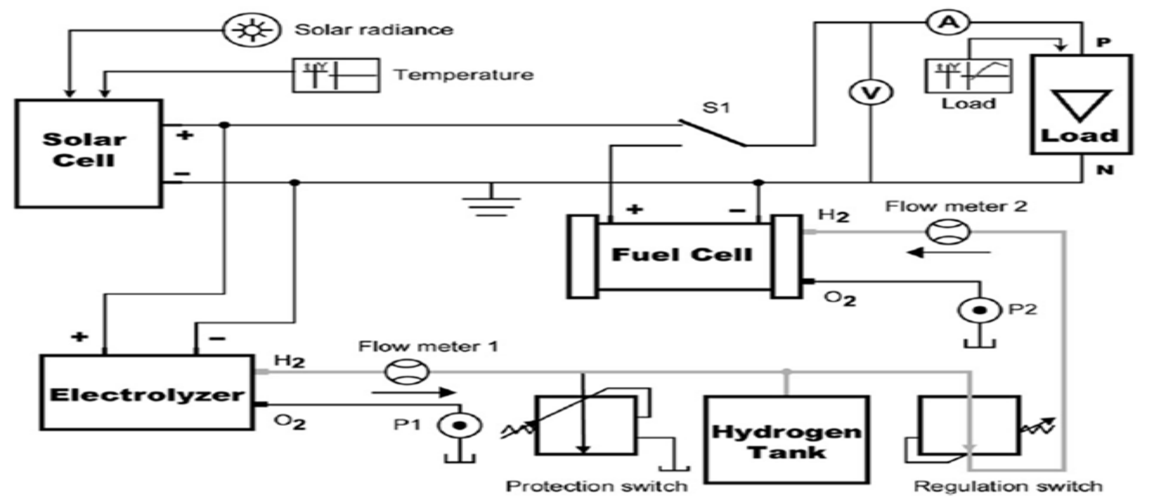
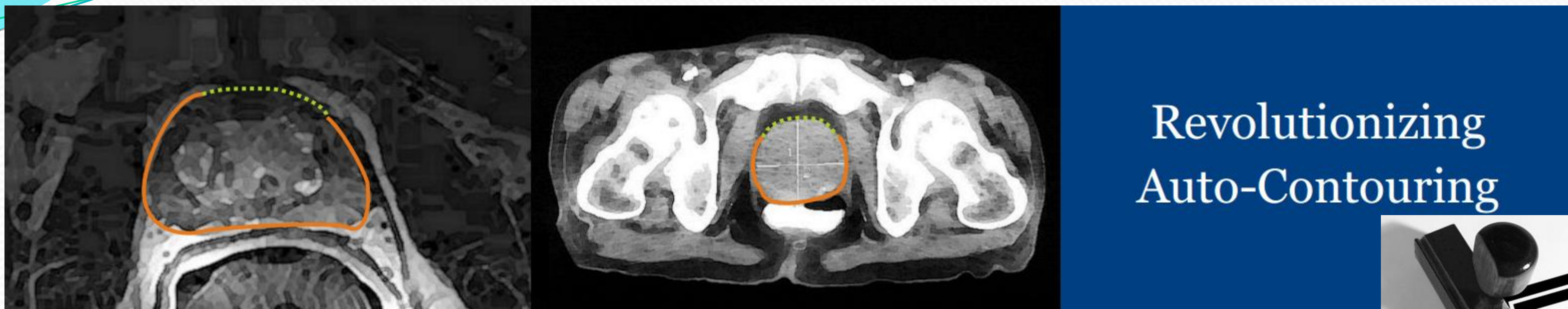
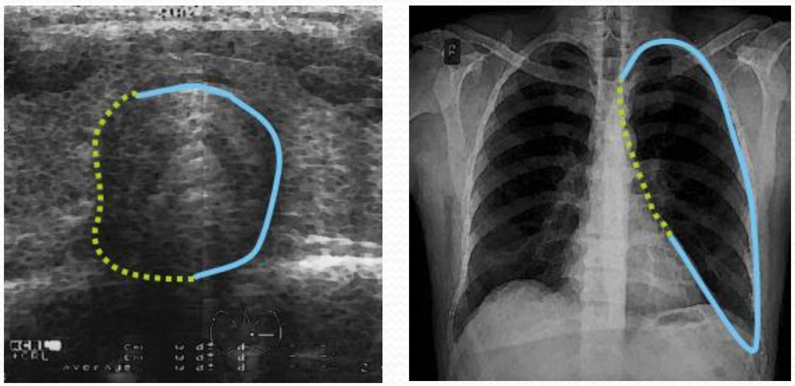
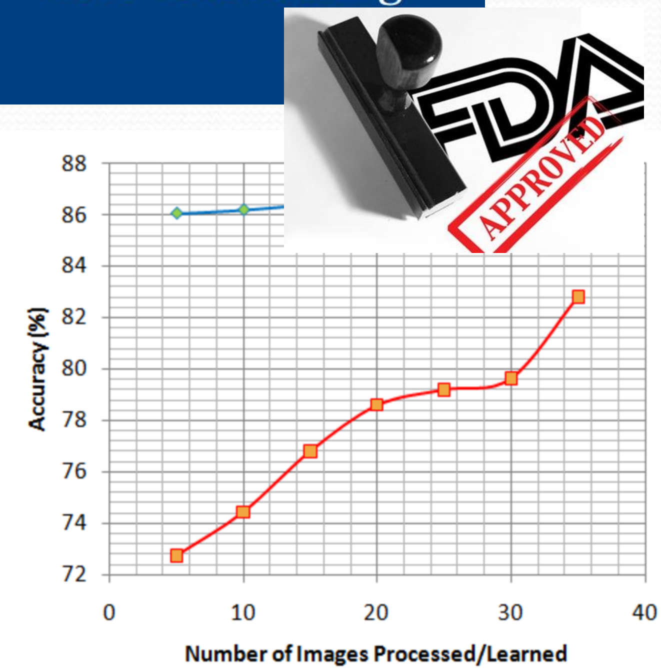


Figure 2: Example of modeling of a PV-hydrogen FC energy system







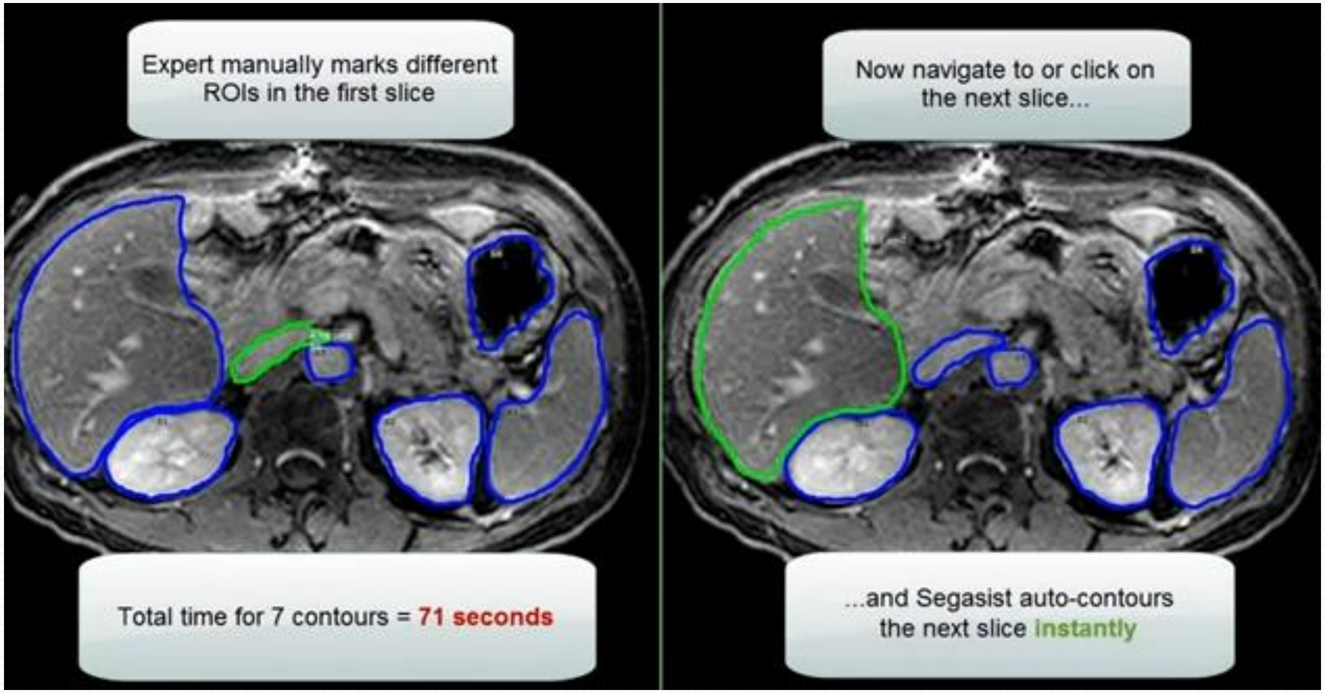
Segasist can auto-contour lesions/organs in any modality (CT, MR, Ultrasound etc.)

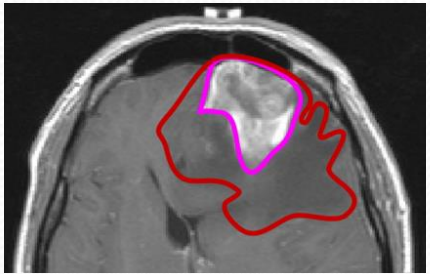
Learning through calibration with gold standard images: The software generates more accurate contours the more images are processed (red curve). In addition, if the information of the same patient is used (volume data of the same patient being segmented), the accuracy can be maintained at a very high level (blue curve).

Current Products: Prostate CT, Prostate MRI, Prostate Ultrasound, Breast MRI

Under Development: Lung CT, Liver CT, Thyroid Ultrasound, Cardiac MRI

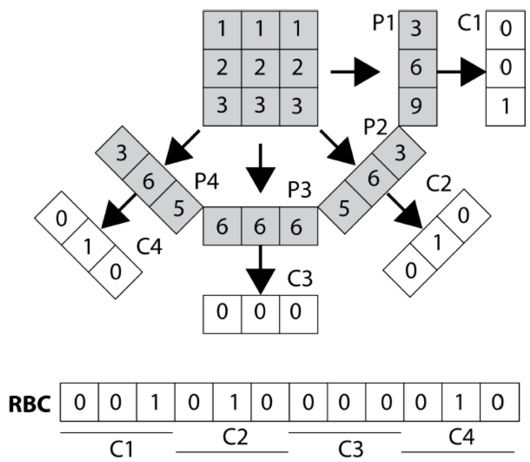
Auto-Contouring of Multiple Regions in Medical Images: Segasist's Fast Multi-Contouring



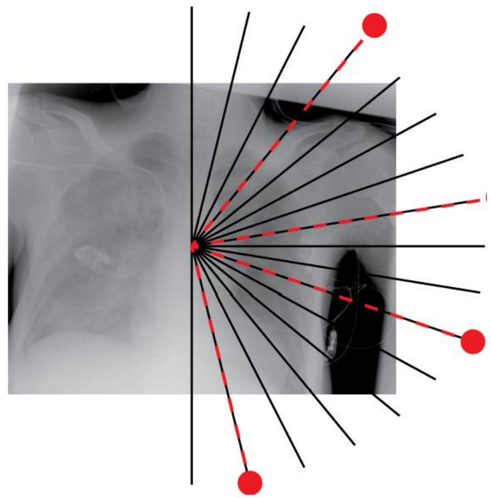


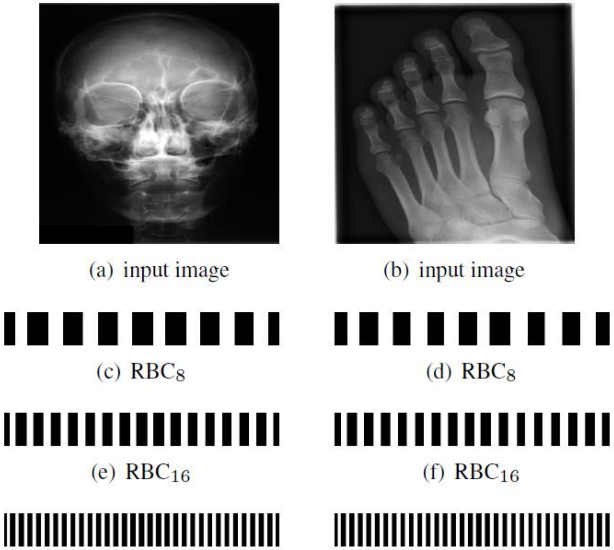
- Raised almost $2 million
- Developed two software packages: Prostate Auto-Contouring, and Brain Cancer Contouring in MRI images
- Filed 4 patents (two granted, two pending)
- Received FDA clearance for the prostate software
- Sold licenses to multiple hospitals

Optimal Projection Selection For Radon Barcodes



Radon Barcode (RBC) [12] – Projections (P1,P2,P3,P4) are binarized to generate code fragments C1,C2,C3,C4. Putting all code fragments together delivers the barcode **RBC**.





(a) input image (b) input image

(c) RBC_8 (d) RBC_8

(e) RBC_{16} (f) RBC_{16}

(g) RBC_{32} (h) RBC_{32}

Examples for Radon Barcodes with 8, 16 and 32 projection angles [12].

Optimal Projection Selection For Radon Barcodes (Cont.)

Test set: 12,000 medical images (ten types), success rate: 83%

Table 2. Results for five breast images from Figure 4.

image	BF (4/16)	$C_{\max}$	MDE (4/180)	$C_{\max}$	MDE (8/180)	$C_{\max}$
b1	[22,67,123,157]	0.83	[30,50,120,160]	0.83	[70,130,30,120,100,150,170,50]	0.89
b2	[33,67,123,169]	0.83	[30,70,120,160]	0.83	[170,140,150,60,40,80,20,110]	0.89
b3	[22,67,123,157]	0.81	[30,50,120,160]	0.81	[150,170,10,70,40,130,110,50]	0.85
b4	[11,56,146,169]	0.81	[20,60,120,160]	0.80	[160,20,120,170,40,30,130,70]	0.86
b5	[11,56,112,157]	0.81	[20,60,120,160]	0.81	[80,20,120,60,160,90,10,140]	0.86

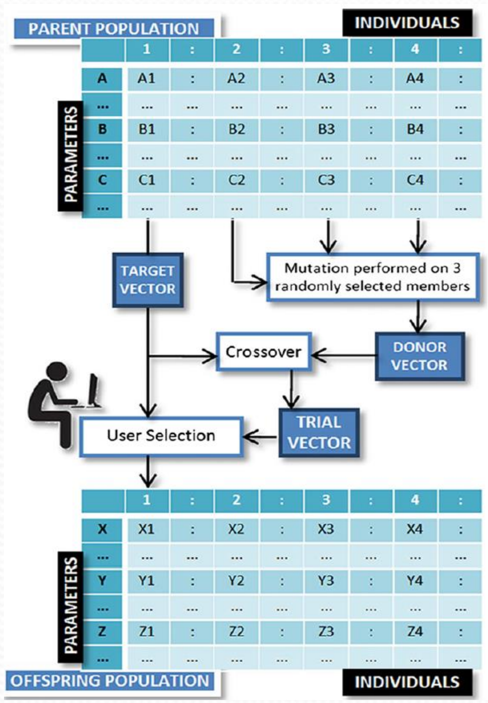
Table 3. Results for five foot images from Figure 5.

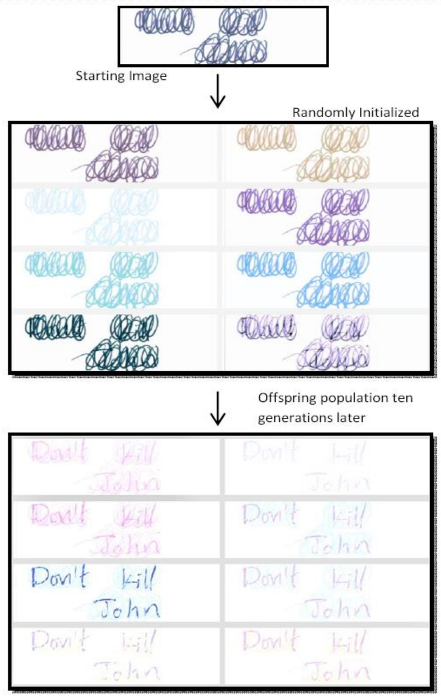
image	BF (4/16)	$C_{\max}$	MDE (4/180)	$C_{\max}$	MDE (8/180)	$C_{\max}$
f1	[34,67,112,157]	0.79	[30,80,110,150]	0.80	[80,160,30,130,30,100,140,60]	0.85
f2	[79,101,135,169]	0.73	[80,110,140,170]	0.73	[70,20,160,0,120,80,130,100]	0.80
f3	[11,56,112,158]	0.64	[20,60,100,170]	0.65	[40,130,160,70,10,170,110,60]	0.70
f4	[11,79,101,169]	0.77	[0,30,80,100]	0.77	[20,180,50,60,80,110,170,120]	0.84
f5	[22,67,112,157]	0.85	[80,30,120,160]	0.86	[120,60,80,10,150,100,170,40]	0.89

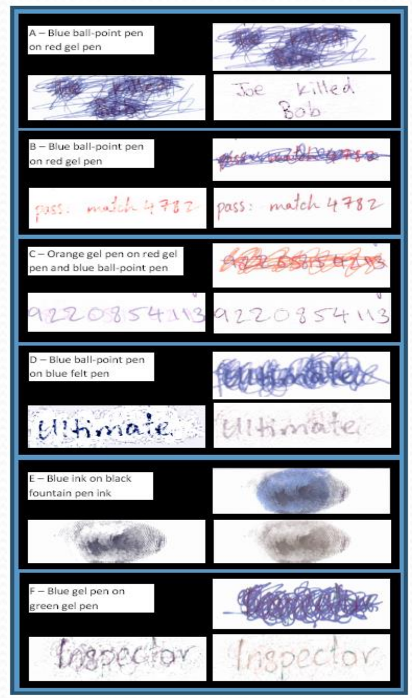
Table 4. Results for five lung images from Figure 6.

image	BF (4/16)	$C_{\max}$	MDE (4/180)	$C_{\max}$	MDE (8/180)	$C_{\max}$
f1	[11,45,135,169]	0.61	[20,40,140,170]	0.59	[180,170,30,90,10,90,40,120]	0.65
f2	[11,67,112,169]	0.66	[30,170,70,110]	0.66	[70,70,100,140,20,20,160,170]	0.70
f3	[11,67,112,169]	0.69	[10,30,120,170]	0.68	[30,50,100,110,80,10,150,180]	0.72
f4	[22,78,112,157]	0.59	[20,80,120,160]	0.60	[70,40,10,150,180,90,50,130]	0.66
f5	[22,78,101,169]	0.58	[20,90,130,170]	0.61	[110,140,40,20,90,80,170,10]	0.65

Color Separation in Forensic Image Processing Using Interactive Differential Evolution



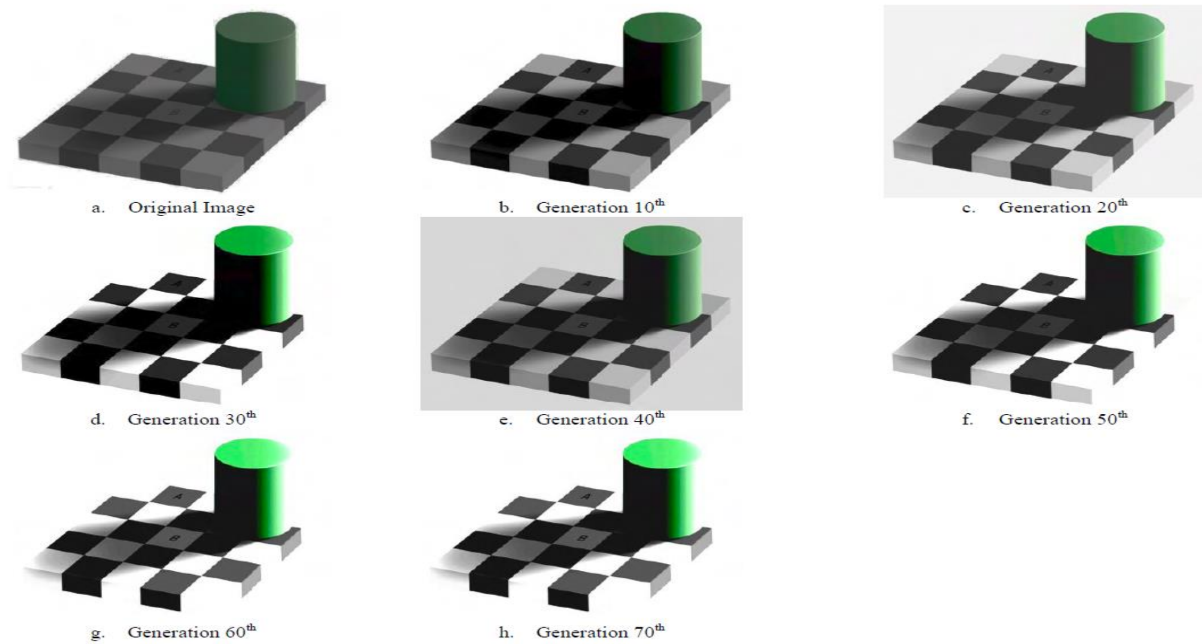




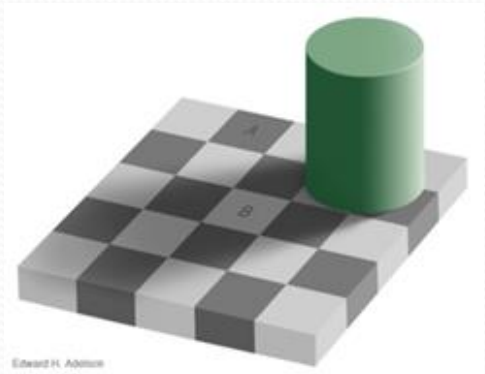
Invited Speaker in the 73rd Annual General Meeting of the American Society of Questioned Document Examiners, Aug. 2015

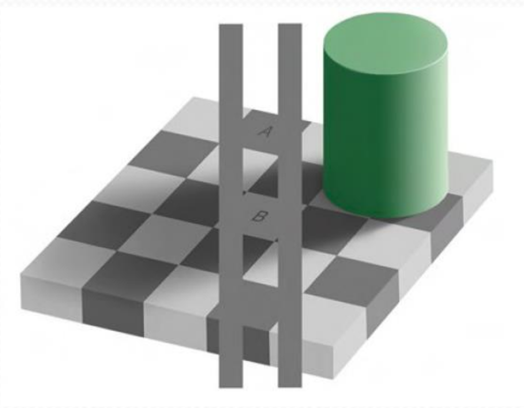
Mushtaq, Harris, Shahryar Rahnamayan, and Areeb Siddiqi. "Color Separation in Forensic Image Processing Using Interactive Differential Evolution." *Journal of forensic sciences* 60.1 (2015): 212-218.

Eye Illusion Enhancement Using Interactive Differential Evolution



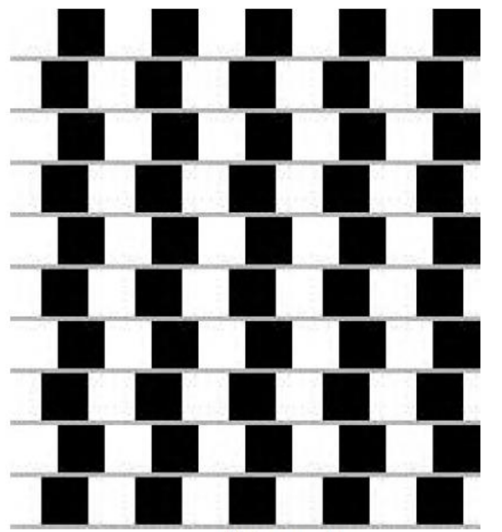
The third experiment, input image and the best results after 10, 20, 30, 40, 50, 60, and 70 generations.



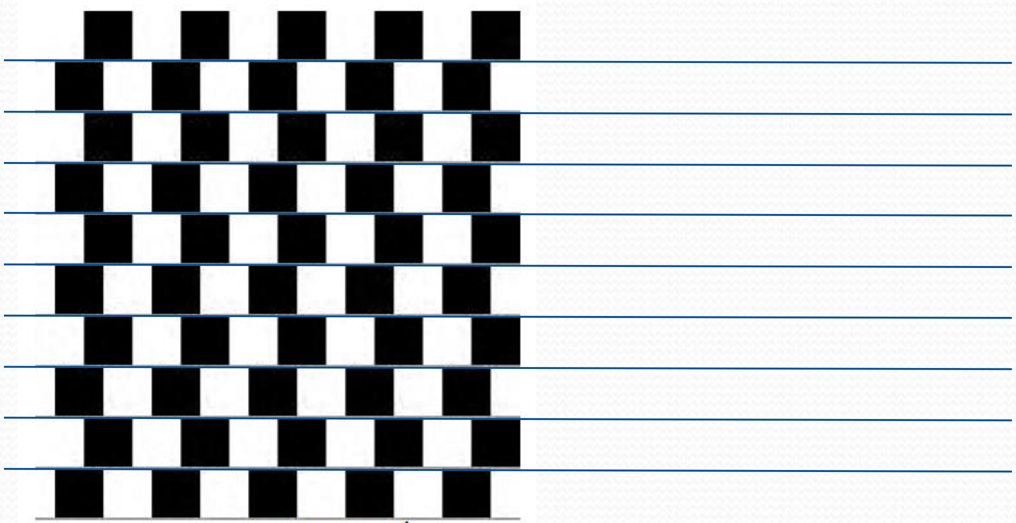


Art Science, Interactive Optimization

Eye Illusion Enhancement Using Interactive Differential Evolution

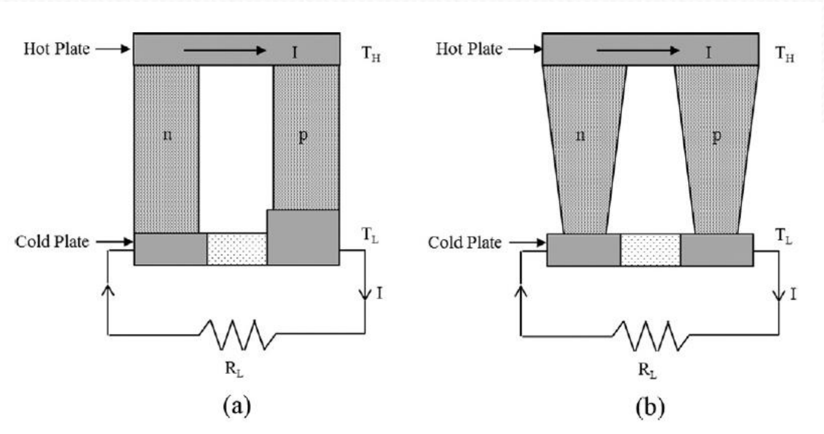


First generation

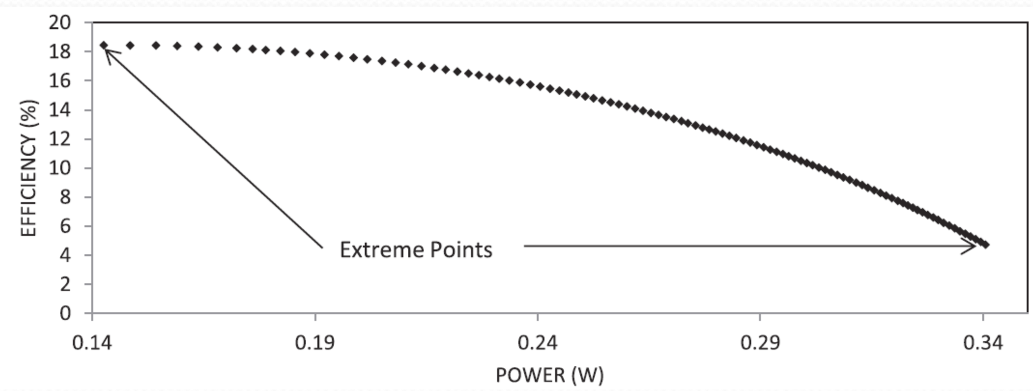


Generation 10^{th}

Multi-objective thermal analysis of a thermoelectric device: Influence of geometric features on device characteristics

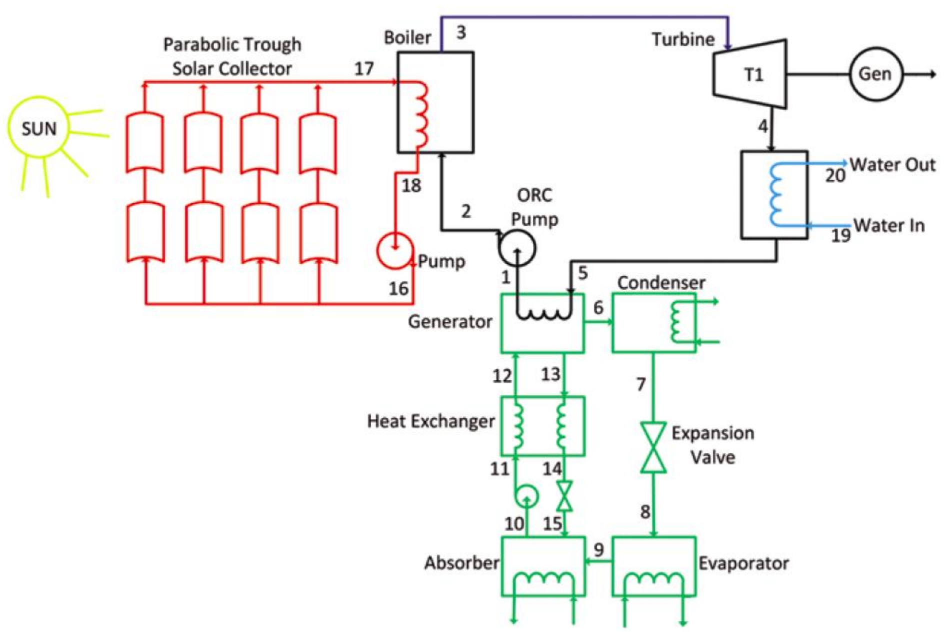


A schematic view of thermoelectric generator for different geometric configurations: a) size of pin legs is different and b) shape factor is different.

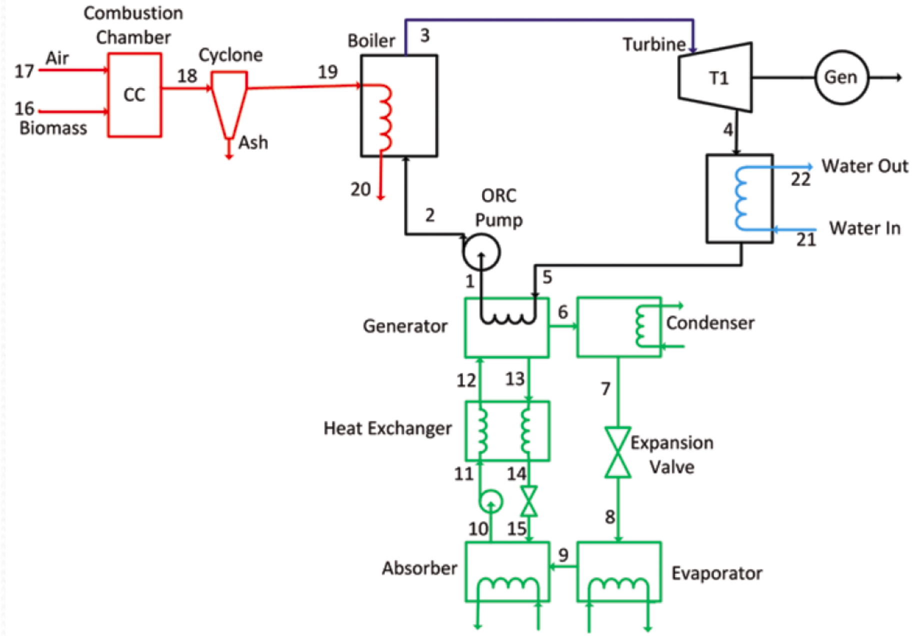


Ibrahim, Amin, et al. "Multi-objective thermal analysis of a thermoelectric device: Influence of geometric features on device characteristics." Energy 77 (2014): 305-317.

Exergetic Optimization of Two Renewable Energy Based Tri-generation Systems



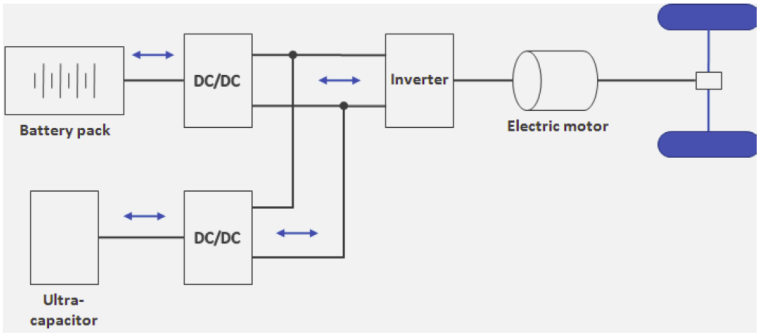
A complete layout of the integrated solar system



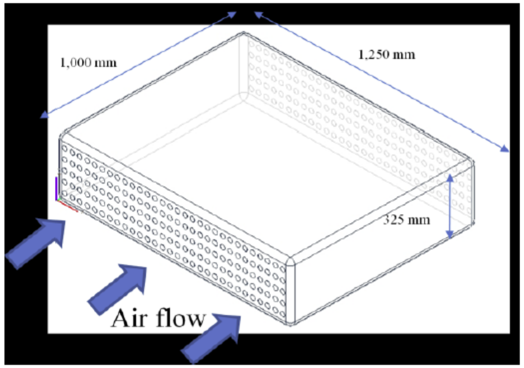
A complete layout of the integrated biomass system

Energy, Single-objective Constraint Optimization

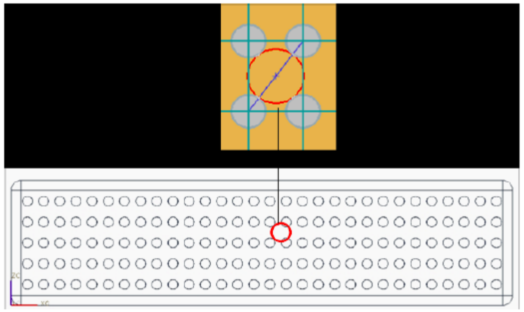
Optimal Design of an Air-Cooling System for a Li-Ion Battery Pack in Electric Vehicles



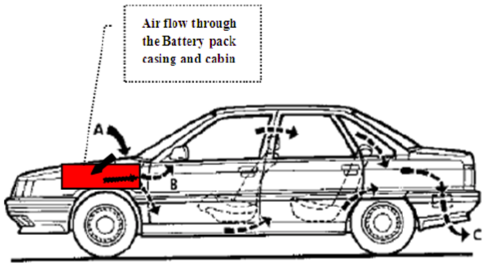
Configuration of an EV with a battery pack and ultra-capacitor *(Li et al., 2009)*



Battery designed with tubes to increase the heat transfer rate

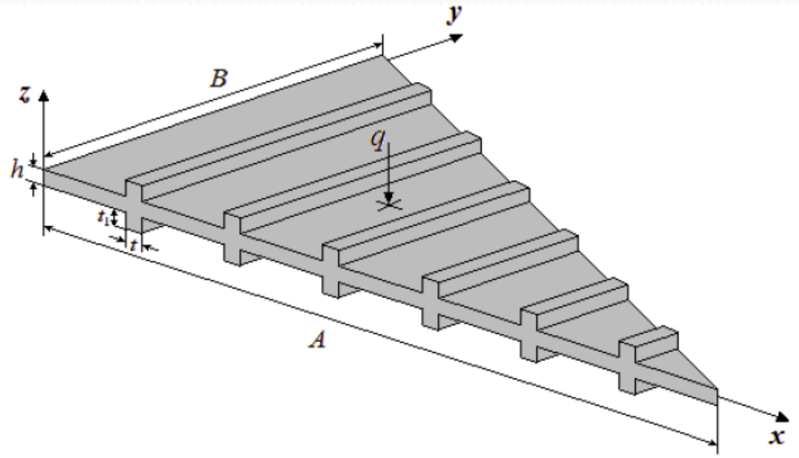


Li-ion battery cells located around the tubes

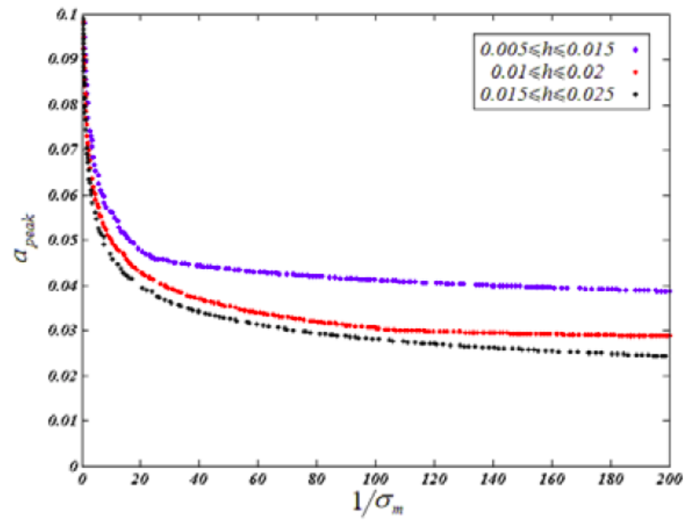


Battery pack located in the front of a vehicle for increased effectiveness of heat transfer

Vibration Analysis and Multi-objective Optimization of Stiffened Triangular Plate



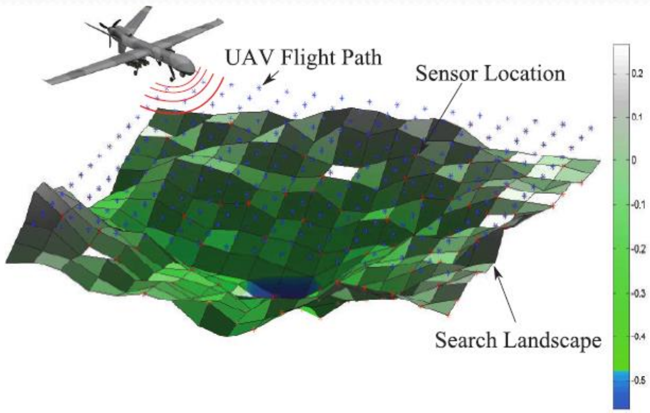
Schematic model of a triangular-shape plate with six stiffeners and excitation load q



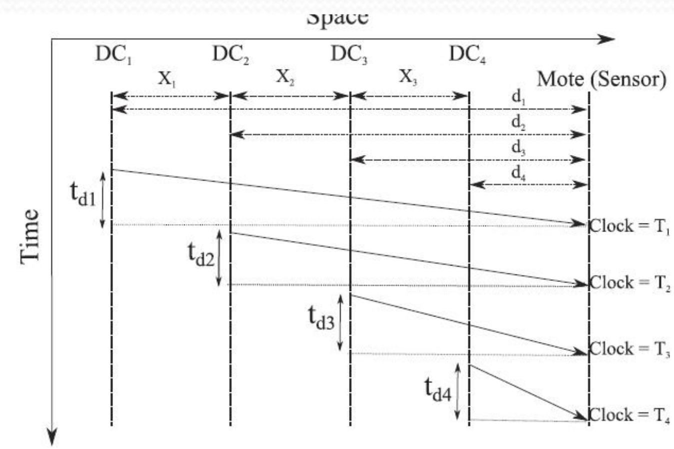
Effects of the thickness boundaries on PF solutions

Vibration, Multi-objective Optimization

3D Localization in Large-Scale Wireless Sensor Networks: A Micro-Differential Evolution Approach

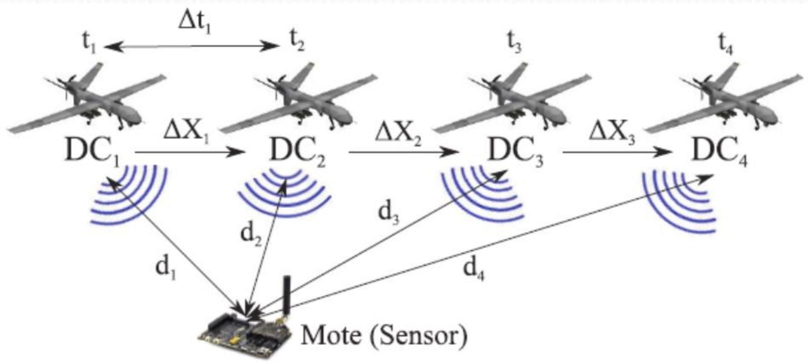


Motes deployment on a sample landscape and corresponding localization with assistance of a UAV, flighting on a random path and broadcasting a detection signal on the landscape.

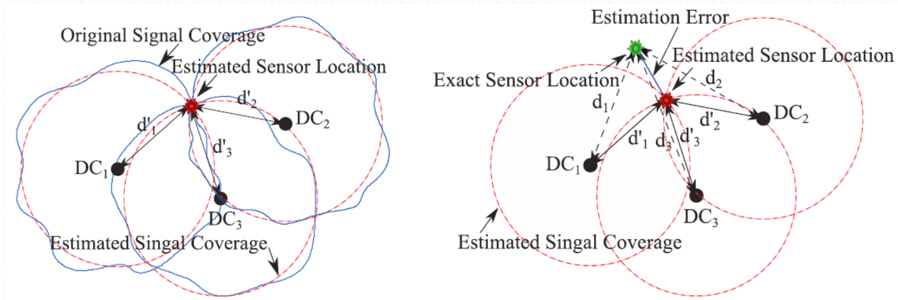


Timing-diagram of packets arrival from four detection coordinates (DCs) to the mote.

3D Localization in Large-Scale Wireless Sensor Networks: A Micro-Differential Evolution Approach (Cont.)



Sample signal coverage model for four detected coordinates (DC) assisting mote localization.



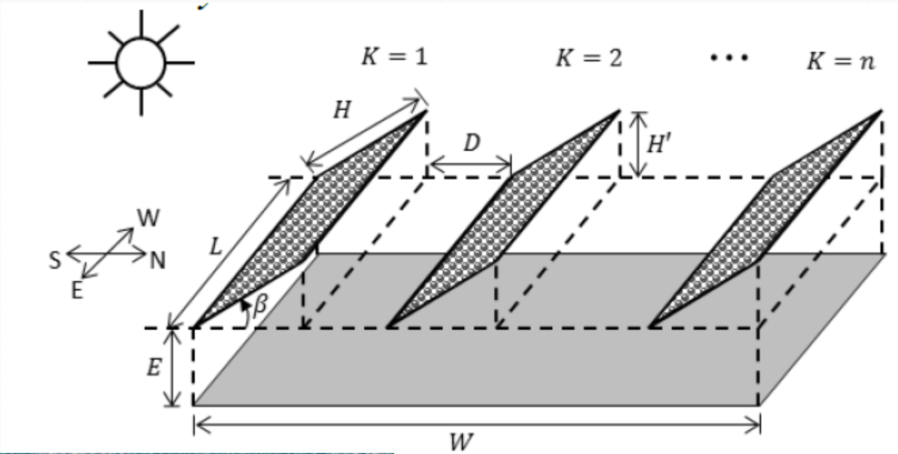
(a) Original signal coverage, estimated signal coverage, and estimated sensor location.

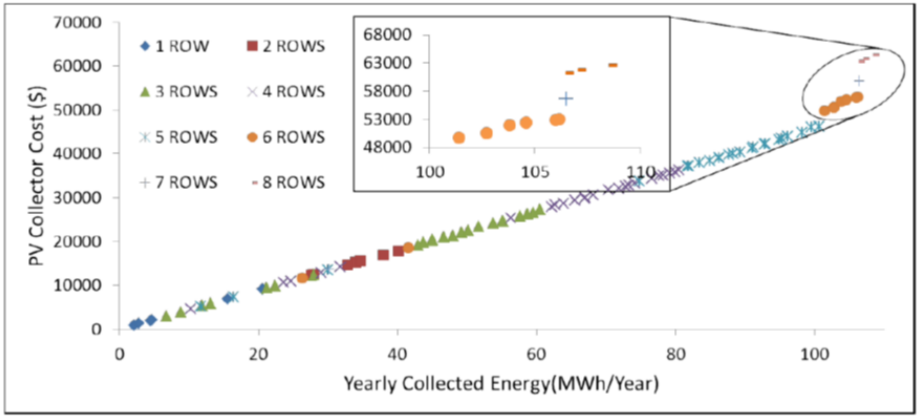
(b) Exact sensor location, estimated sensor location, and estimation error.

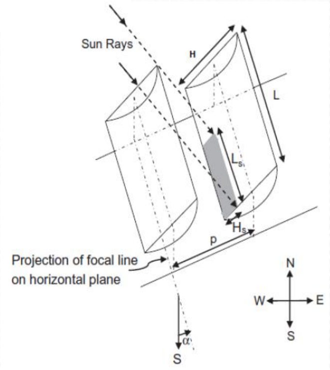
Sample signal coverage model for three detected coordinates (DC) in a 2-D environment.

Wireless Network, Micro Single-objective Optimization

Optimal Photovoltaic System Design with Multi-objective Optimization

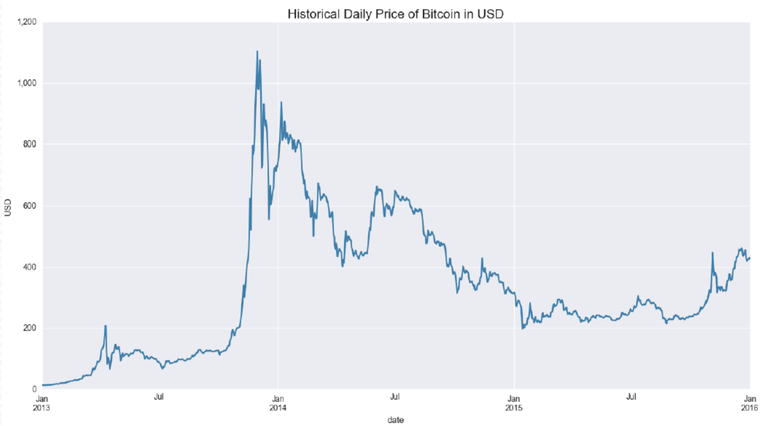




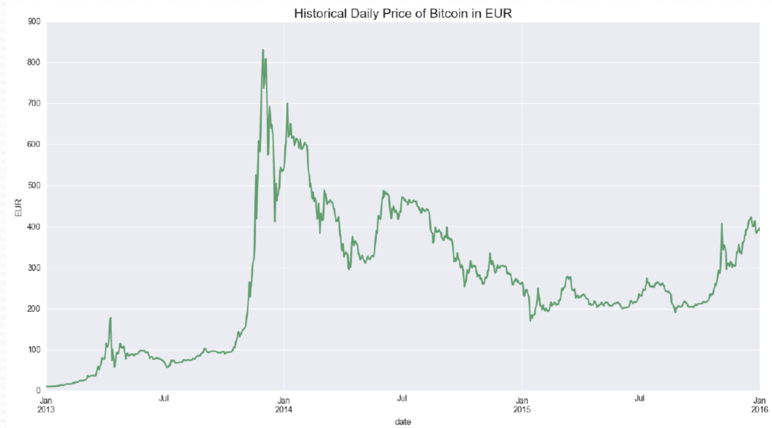


Energy, Multi-objective Optimization

Bitcoin Price Prediction Using Offline and Online Innovization



Historical Bitcoin Price in USD



Historical Bitcoin Price in EUR

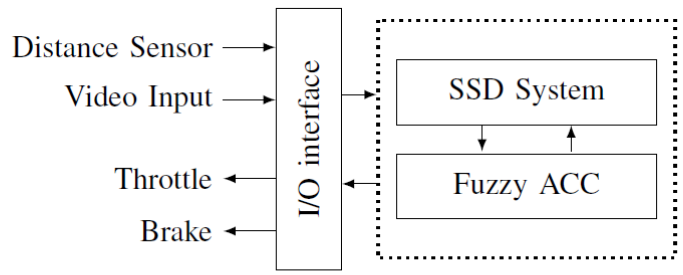
Bitcoin Address Statistics

Metric	Results
Total Addresses	123, 625, 104
Addresses with Balance > 0	6, 944, 381
Avg. Balance	2.183 BTC
Avg. Sent Transactions / Address	2.406
Avg. Received Transactions / Address	2.580
Avg. Volume Sent / Address	22.908 BTC
Avg. Volume Received / Address	22.077 BTC

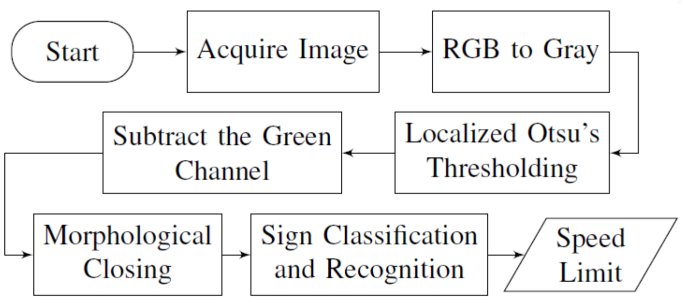
Average BTC Volume

Period	Volume (BTC)	Volume (USD)
Day	976, 714	\$319, 727, 327
Month	29, 638, 618	\$9, 702, 201, 602
Year	355, 663, 427	\$116, 426, 422, 828

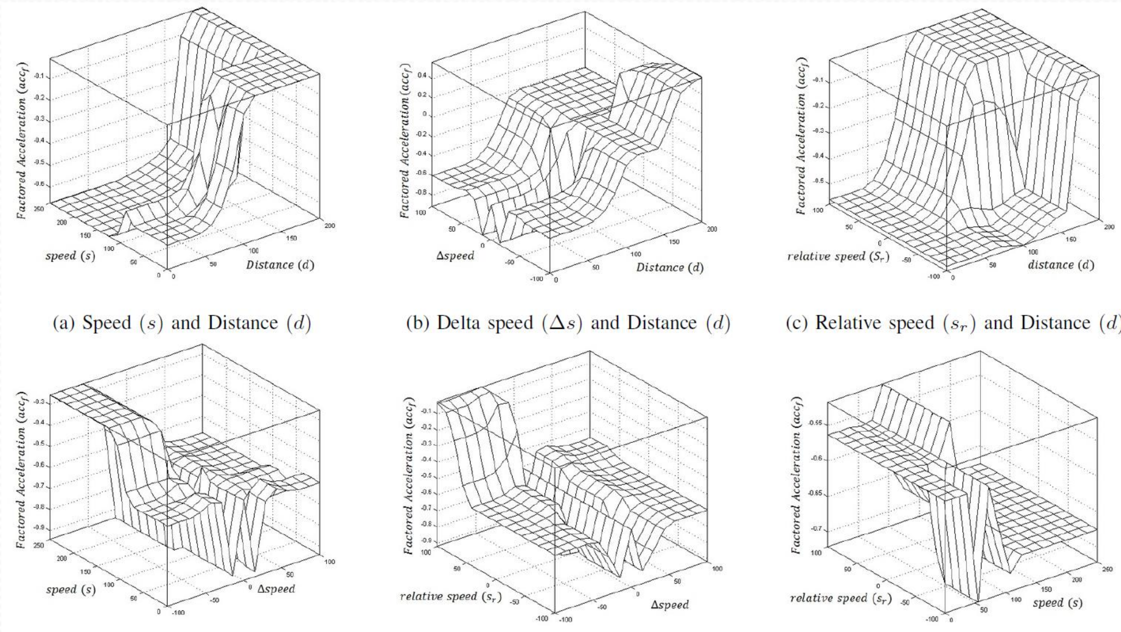
Fuzzy Adaptive Cruise Control System with Speed Sign Detection Capability



System architecture for the proposed ADAS



The speed sign detection and speed limit recognition algorithm



(a) Speed (s) and Distance (d)

(b) Delta speed (Δs) and Distance (d)

(c) Relative speed (s_r) and Distance (d)

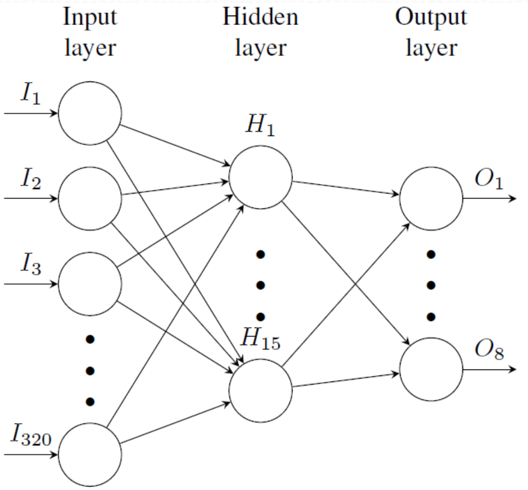
(d) Speed (s) and Delta speed (Δs)

(e) Relative speed (s_r) and Speed (s)

(f) Speed (s) and Relative speed (s_r)

(Ranked first in the capstone competition, 2013)

Fuzzy Adaptive Cruise Control System with Speed Sign Detection Capability (Cont.)



ANN diagram for speed sign recognition.

(a) (b)

(a) shows the original image and (b) shows the locally thresholded image with the subtracted green channel

Yellow colored car is controlled by human driver whereas white and blue colored car is autonomously controlled by fuzzy logic controller.

(a) (b)

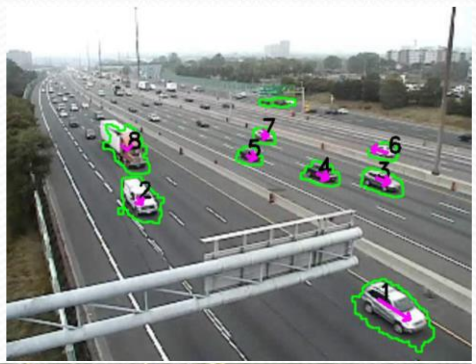
(a) shows the successfully recognized speed sign, and (b) shows an image with a false positive recognition.

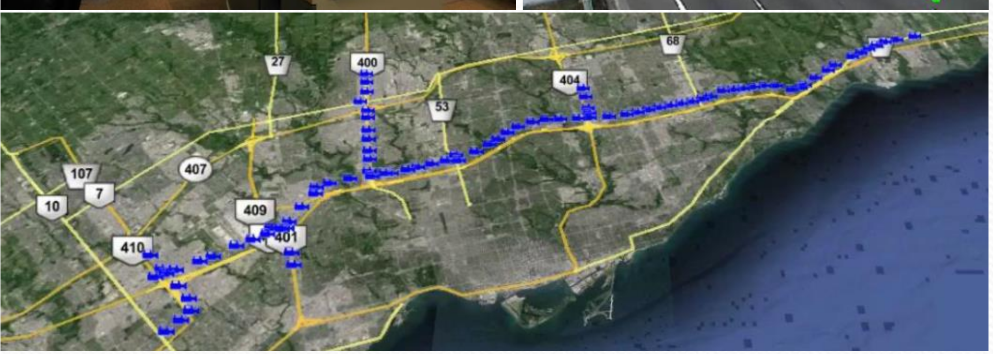
A human controlling a vehicle within TORCS environment to test the fuzzy logic ACC.

(Ranked first in the capstone competition, 2013)

Control and Machine Vision, Hybrid System

Camera-based Automated Highway (i.e., 401) Monitoring System





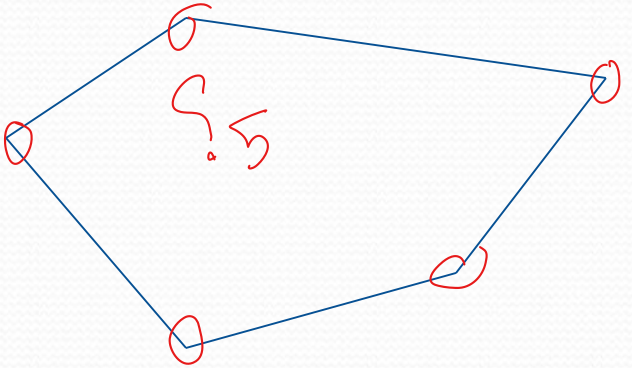
(Ranked first in the capstone competition, 2014)

An Optimization Problem in Art!

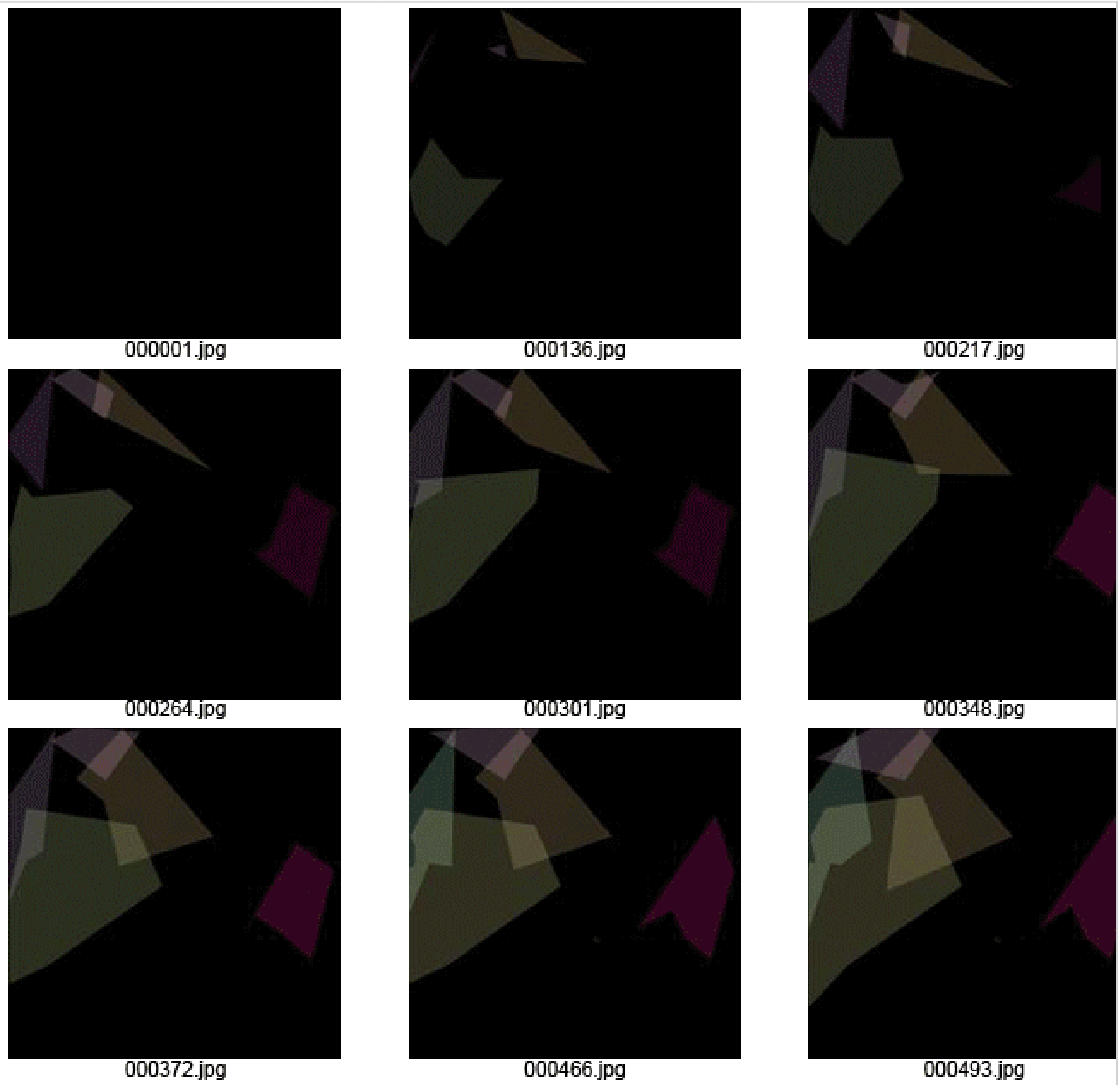
fitness objective (original picture)

Could you paint a replica of the Mona Lisa using only 255 semi transparent polygons?

How many digits is 255! ?



Intermediate results



Intermediate results, Cont.

001185.jpg

001267.jpg

001397.jpg

001497.jpg

001635.jpg

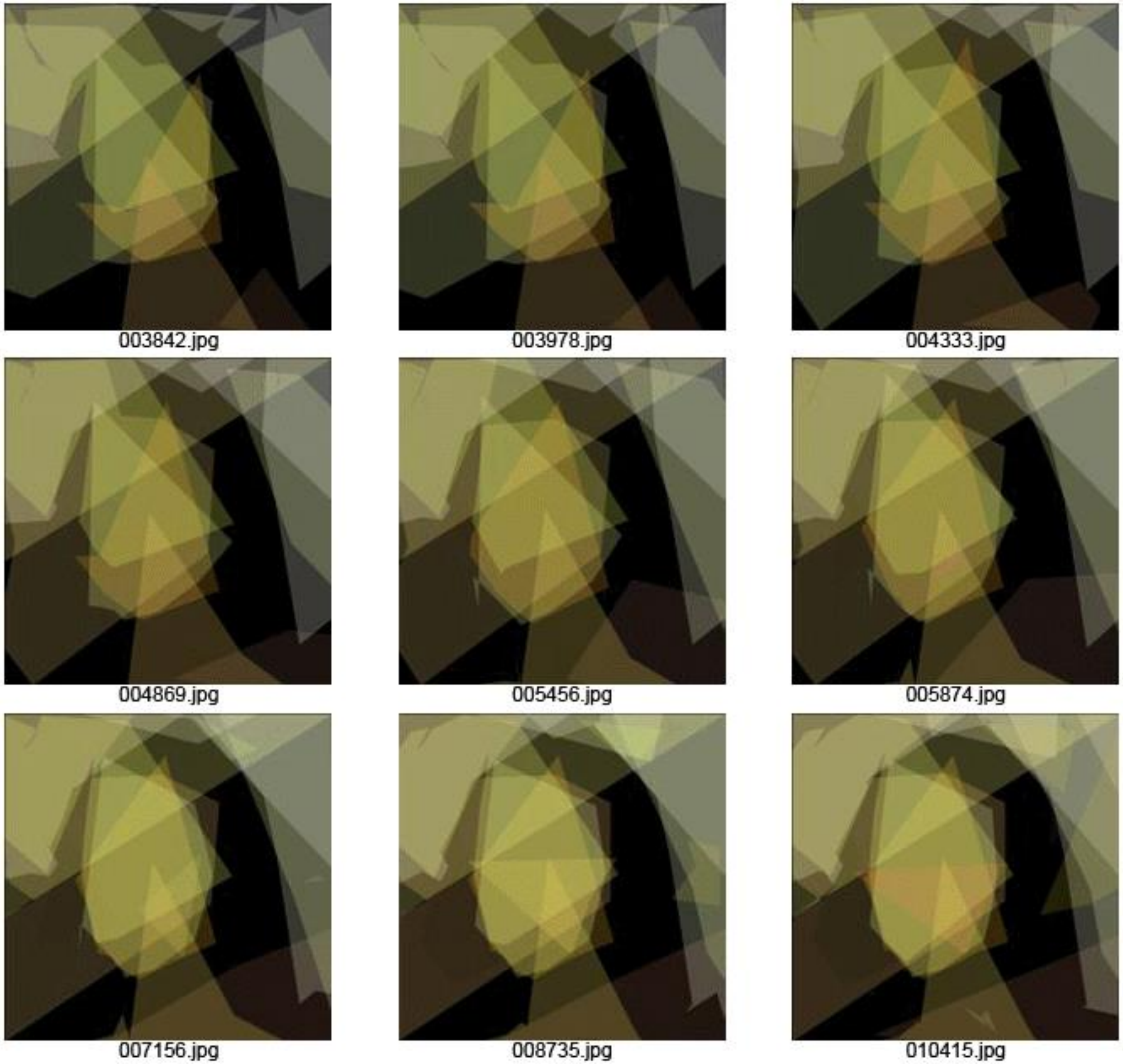
001783.jpg

001906.jpg

002022.jpg

002179.jpg

Intermediate results, Cont.



Intermediate results, Cont.

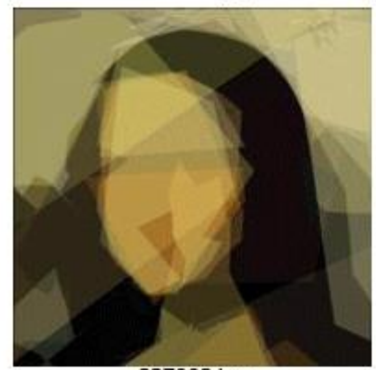

011721.jpg


012974.jpg


014366.jpg


016567.jpg


020930.jpg


027960.jpg


039364.jpg


052025.jpg


069604.jpg

Intermediate results, Cont.


099531.jpg

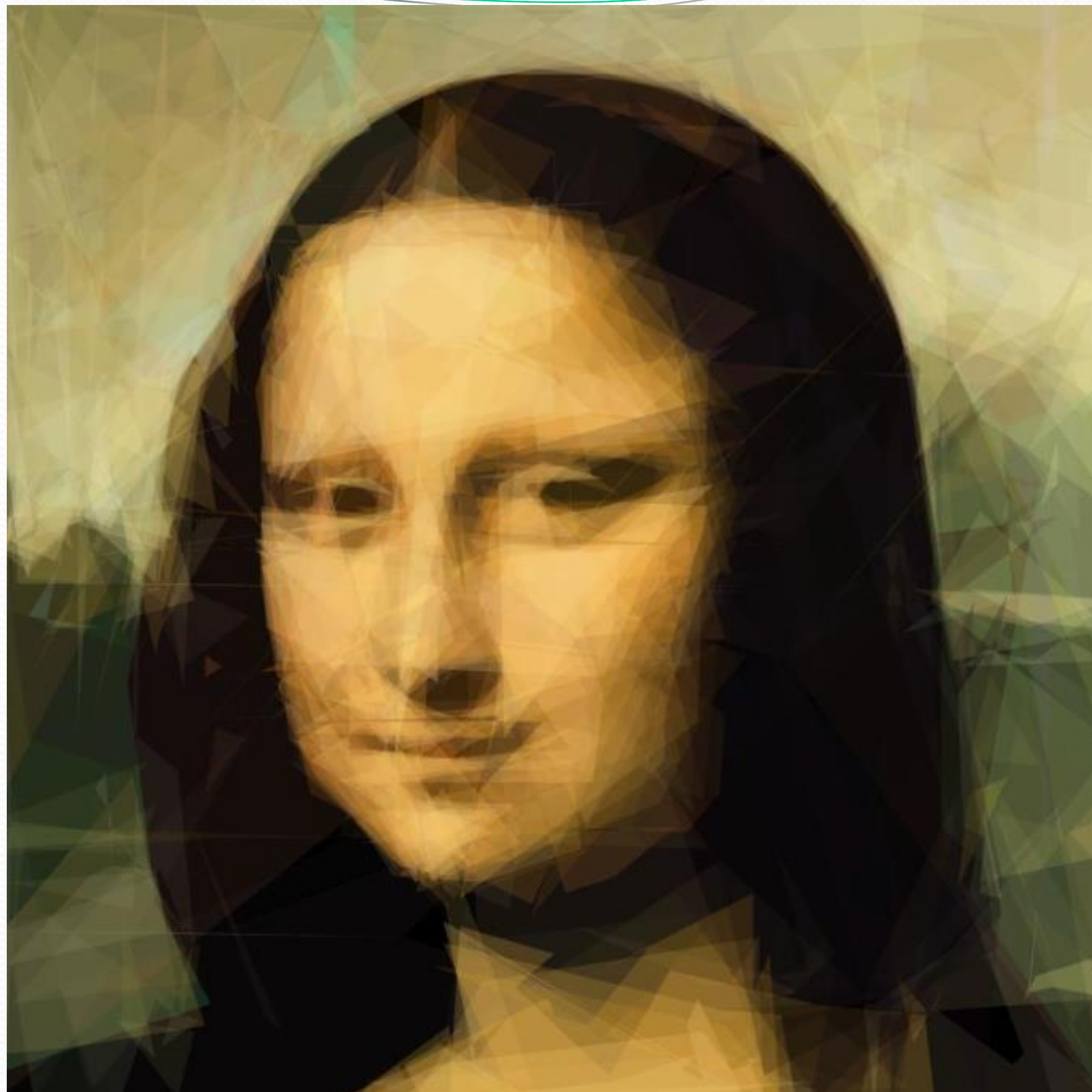

161713.jpg


343336.jpg


649291.jpg


904314.jpg

Running time: ~12 days
polygons: 255
points: 1668
points/polygon: 6



Bonus Q.
What is the dimensionality of this optimization problem?

Dimensionality of Problem?

A) $D<50$
B) $50<D<100$
C) $100<D<500$
D) $500<D<1000$
E) $1000<D<2000$
F) $D>4000$

Let us run the code

Why do we need to design efficient optimization algorithms?

Example: speed comparison of two Computers

Computer A (1000 times faster than computer B)	Computer B (Slower computer)
n= 10^8	n= 10^8
10 billion instruction/second	10 million instruction per second
Algorithm A: 2*n^2 instructions	Algorithm B: 50*n*lgn instructions
Running time:?	Running time:?

Example: speed comparison of two Computers (Cont.)

Computer A (1000 times faster than computer B)	Computer B (Slower computer)
n= 10^8	n= 10^8
10 billion instruction/second	10 million instruction per second
Algorithm A: 2*n^2 instructions	Algorithm B: 50*n*lgn instructions
Running time: more than 23 days	Running time: less than 4 hours, 138 times faster

Why complexity of an optimization algorithm is a very important factor?

Complexity	Size = 10	Size = 20	Size = 30	Size = 40	Size = 50
$O(x)$	0.00001 s	0.00002 s	0.00003 s	0.00004 s	0.00005 s
$O(x^2)$	0.0001 s	0.0004 s	0.0009 s	0.0016 s	0.0025 s
$O(x^5)$	0.1 s	0.32 s	24.3 s	1.7 mn	5.2 mn
$O(2^x)$	0.001 s	1.0 s	17.9 mn	12.7 days	35.7 years
$O(3^x)$	0.059 s	58.0 mn	6.5 years	3855 centuries	2×10^8 centuries

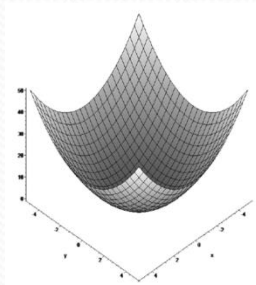
Utilizing 512 CPU.s can reduce optimization time from two years to two days!

Thanks to Sharcnet with more than 20,000 CPU.s, for free:
https://www.sharcnet.ca/my/front/

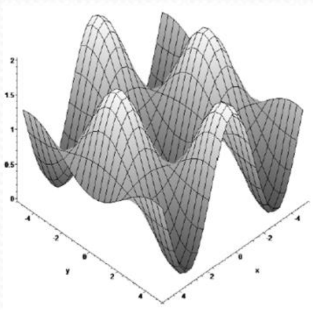
Problem landscape

Landscape and Modality of a Problem

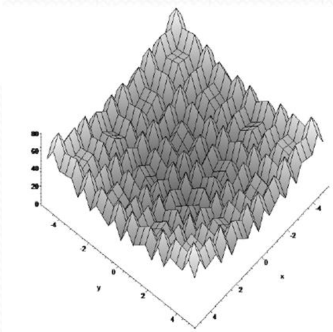
- Unimodal



- Multimodal with a few local optima

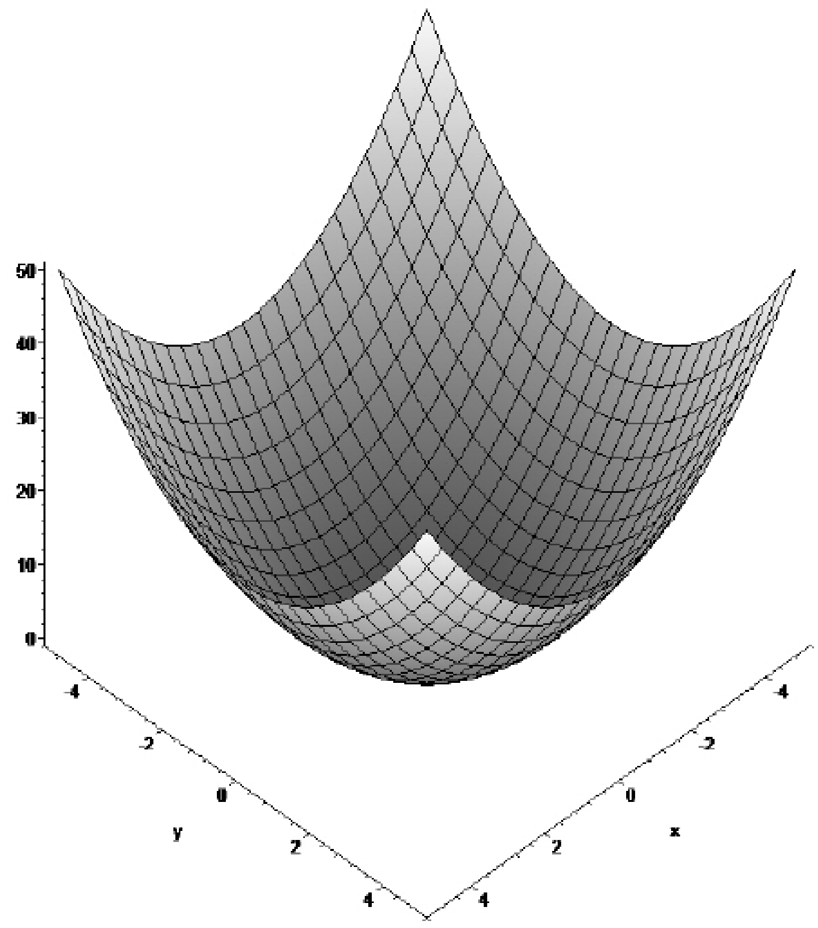


- Multimodal with many local optima

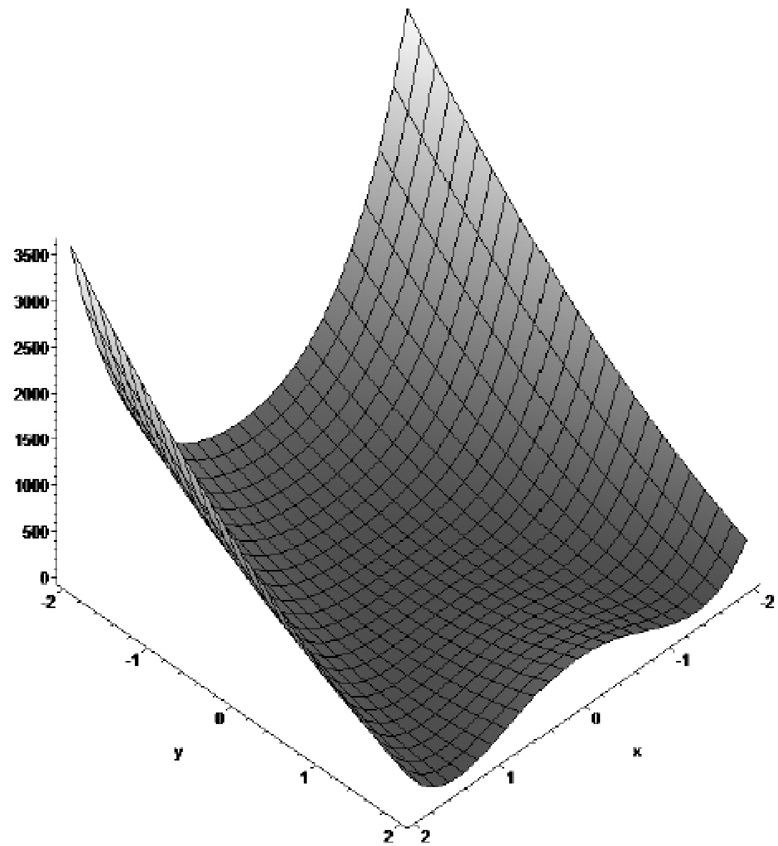


Generally, higher modality problems are harder to solve. Because, the optimizer is prone to trap in a local optimum (i.e., premature convergence).

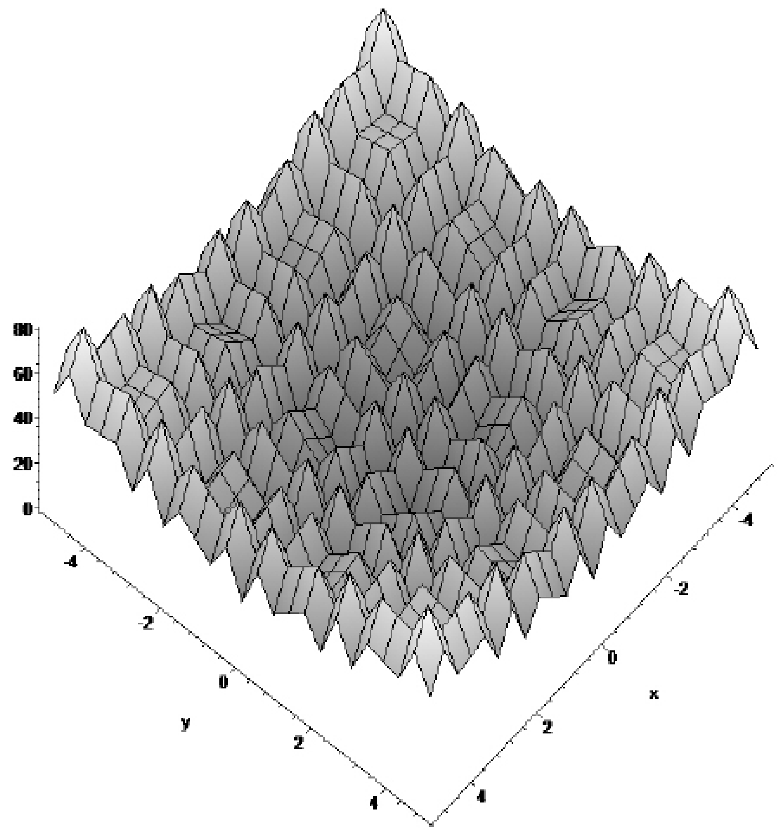
Sample Benchmark Functions



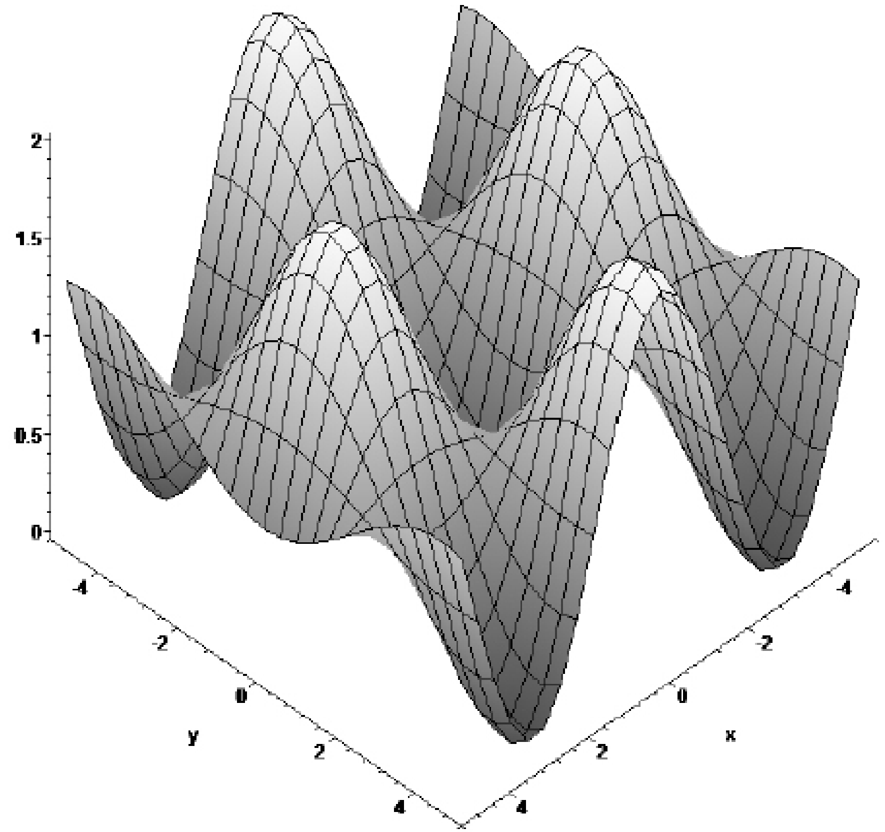
(a) f_1 (1^{st} De Jong) is unimodal, scalable, convex, and easy function.



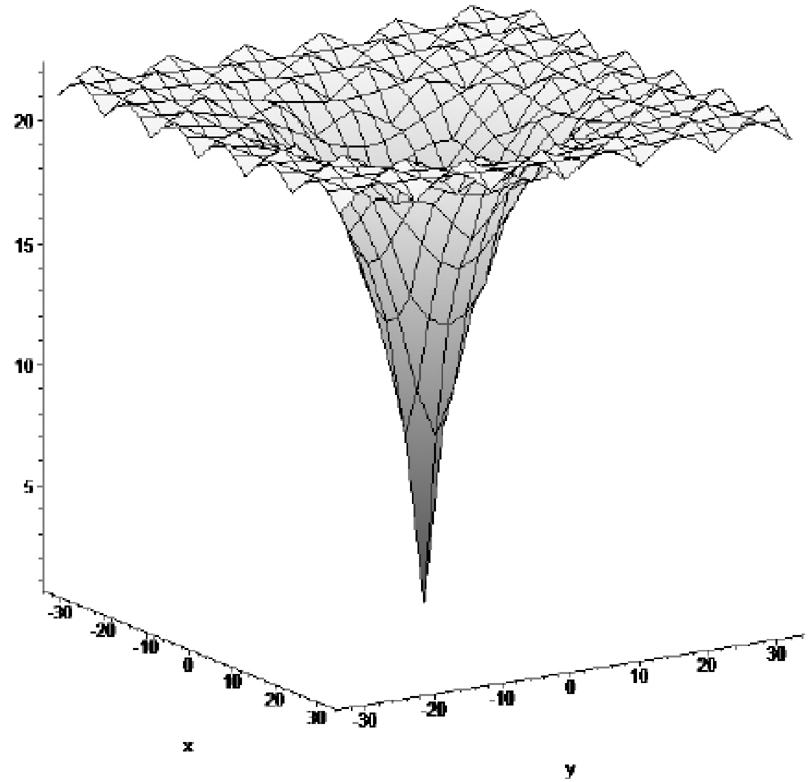
(b) f_4 (Rosenbrock's Valley) is unimodal, scalable, non-convex, and hard function. The minimum is inside a long, narrow, parabolic shaped flat valley



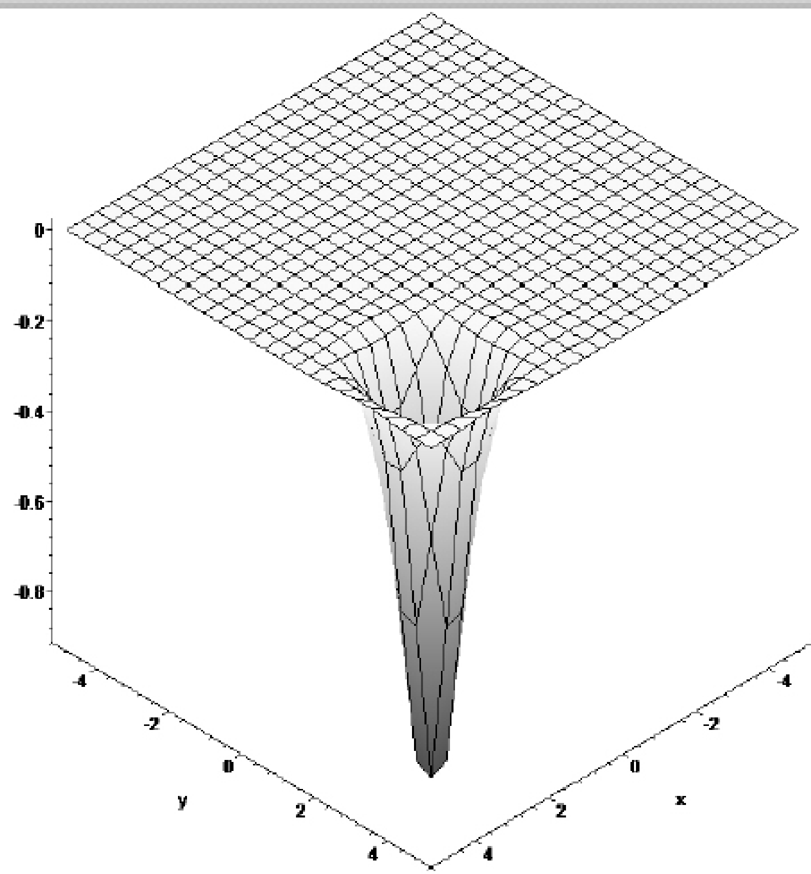
(c) f_5 (Rastrigin's Function) is highly multimodal. The location of the minima are regularly distributed.



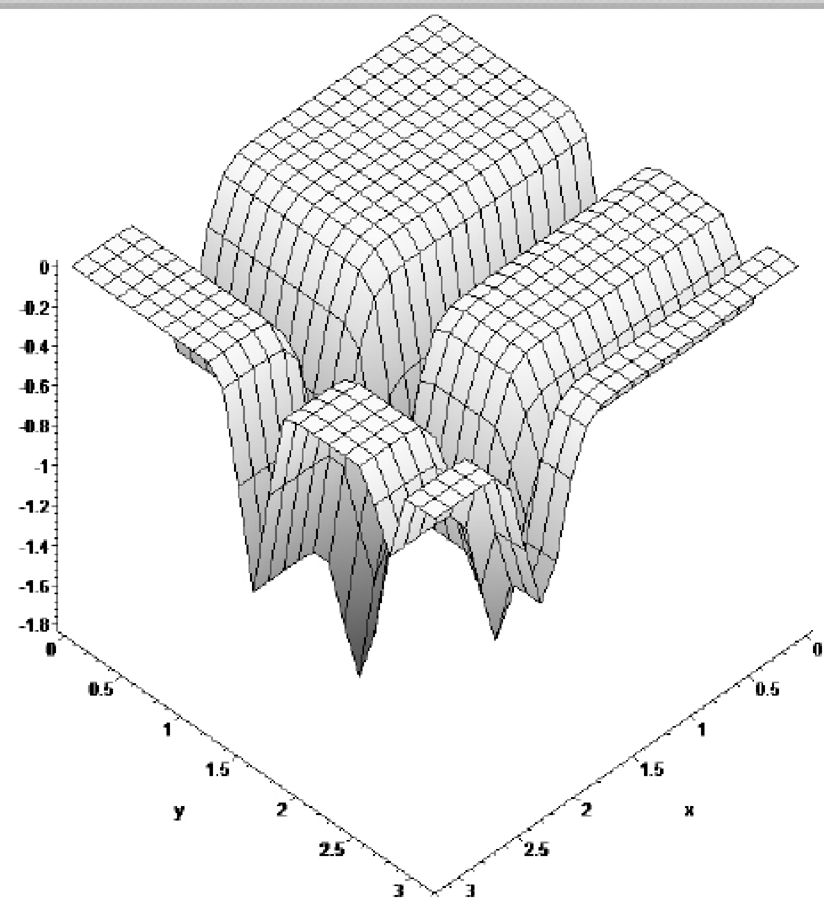
(d) f_6 (Griewangk's Function) has many regularly distributed local minima and hard to locate global minimum.



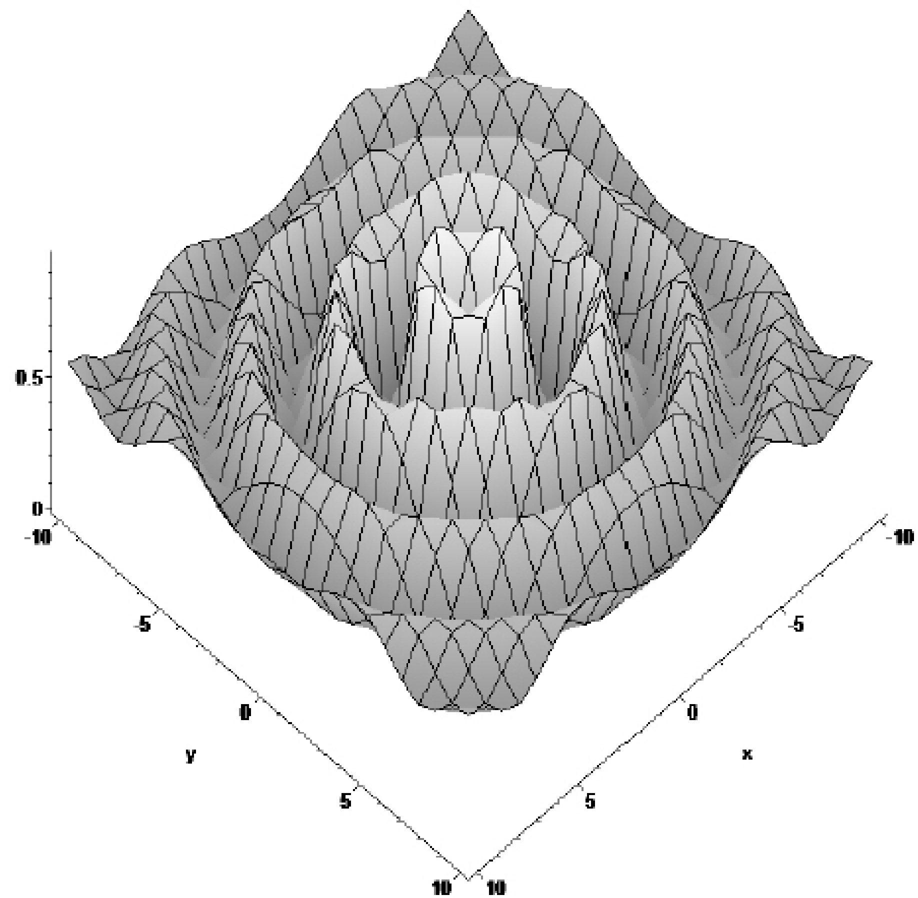
(a) f_8 (Ackley's Problem), the number of local minima is unknown.



(b) f_{11} (Easom Function) is unimodal and the global minimum has a small area relative to the search space.



(c) f_{18} (Michalewicz Function) has $n!$ local minima. Steepness of the valleys or edges makes it a hard optimization problem.



(d) f_{32} (Schaffer's Function 6) is multi-modal and symmetric.

Complex Benchmark Problems (2D)