CSE/ECE 848 Introduction to Evolutionary Computation

Module 5, Lecture 22, Part 1

Engineering Component Design

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Overview

- EC methods are routinely applied to engineering design and process optimization tasks
  - Flexibility in modifying EC methods
    - Plug-and-play (!), easily customizable, modular, unified single and multi-objective, multi-level, robust/reliable, dynamic, etc.
  - No hard requirement for gradients
  - Often, an approximate feasible solution is enough
- Hybrid EC-local search approaches are more efficient

Six-Objective Blackbox Problem from Practice

- **Black-box** functions computed from responses surfaces from expensive simulation models
- **145 input variables:** $\boldsymbol{x} = [x_1, x_2, \ldots, x_{145}]$
- **147 responses:** $\boldsymbol{y} = [y_1, y_2, \ldots, y_{147}]$
- A single call of **`eval()`**, for any input $x = [x_1, x_2, \ldots, x_{145}]$ returns the corresponding responses $y = [y_1, y_2, \ldots, y_{147}]$ and Jacobian $\boldsymbol{J}$: $(\boldsymbol{y}, \boldsymbol{J}) = \mathtt{eval}(\boldsymbol{x})$, where $dim(\boldsymbol{J}) = 147 \times 145$ and $\boldsymbol{J}_{i,j} = \partial y_i / \partial x_j$
- Gradients are available!

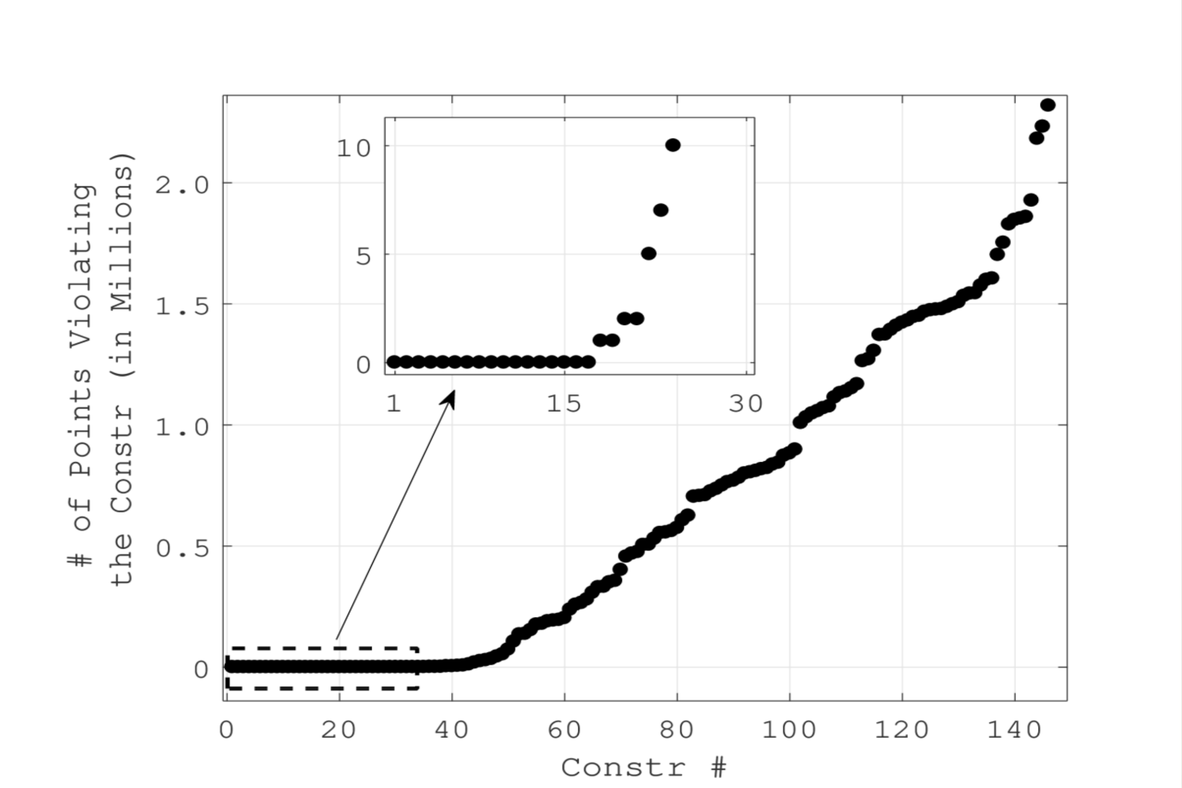
Reference: Gaur, A., Talukder, K., Deb, K., Tiwari, S., Xu, S., and Jones, D. (2020). Unconventional Optimization for Achieving Well-Informed Design Solutions for an Automobile Industry. *Engineering Optimization, 52* (9). 1542–1560.

The Problem (Contd...)

- Each design variable is bounded and **discretized** at 0.05 interval
- **146 Constraints**: Responses [y_2, y_3, ..., y_{147}] have either upper or lower bound, but not both
- **6 Objectives:** y_1 is the **primary objective** and [y_6, y_{14}, y_{29}, y_{108}, y_{146}] are **secondary objectives**. The rest of the y_i's are constraints
  - One supplied solution y_1 = 184 (improvement by 10 is target!)
- The problem has a very narrow and disconnected feasible region, because of 146 inequality constraints (mostly active) and discrete

Feasibility of Search Space

- 2.5 million Latin Hypercube samples. Here, *x*-axis is the response ID and *y*-axis shows how many solutions are violating them.
- No feasible solution out of 2.5M random solutions
- Matlab's fmincon() failed to produce a feasible solution beyond 184

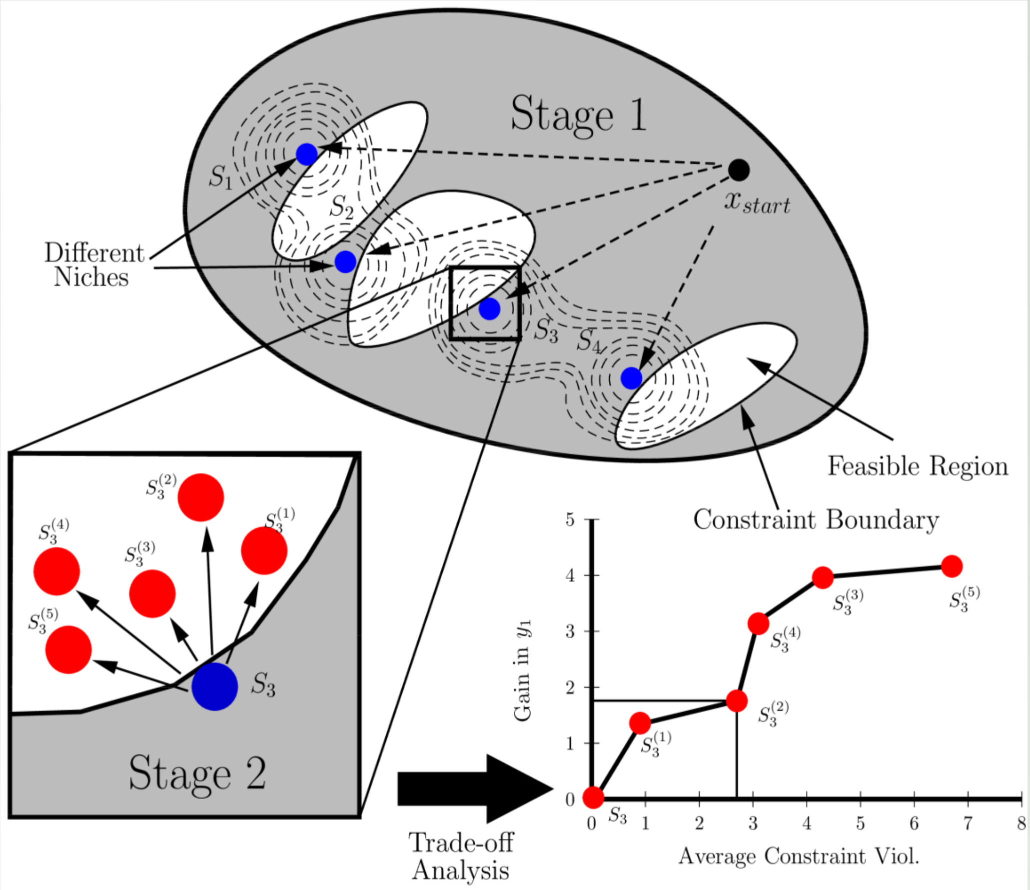


Goal of the Study

- **Convergence:** Solutions in an **acceptable range** of y_1, given a start solution with $y_1 = 184$
- **Trade-offs:** Need to know trade-offs in secondary objectives for good/acceptable designs
- **Niche/Diversity:** Need diverse designs (in *x*-space)
- **Computational Budget:** Maximum 50,000 calls to eval()
- **Post Optimality DSS**: How to choose a single preferred solution from multiple acceptable solutions?
- **Sensitivity analysis:** Choose a preferred solution based on trade-off between y_1 and constraint violation

Multi-objective Trade-off Analyzer (MOTRAN)

- Stage1: Find a diverse set of solutions
- Stage2: Perform sensitivity analysis to choose a preferred solution



MOTRAN Stage-1
(Many-Objective Optimization)

- 6 Objective handling through **NSGA-III** (Deb and Jain, IEEE-TEVC, 2014)
- **Custom NSGA-III** to protect best feasible solutions of Obj-1
  - Add archive of feasible solutions in **Merged Population**
  - Apply Derivative-based **Local-Search** to every new feasible solution and save all intermediate feasible solutions in archive
  - Update reference directions to **protect best ten y_1 and x-niche** solutions with d_{niche} distance
  - Need diverse designs having similar Obj-1 values
- Provide **few promising choices** to DM
  - **Post-optimization DS program** : Choose most diverse three solutions with acceptable values of Obj-1 at the end

MOTRAN Stage-1: Local-Search

A point-based approach

0) $\boldsymbol{x} \leftarrow \boldsymbol{x}_{start}$

$\boldsymbol{x} = [x_1, x_2, \cdots, x_{145}]$

1) Evaluate $\boldsymbol{x}$

$(y_{1x}, \boldsymbol{g}_x, \boldsymbol{y}_{1x}', \boldsymbol{G}_x) = \Psi(\boldsymbol{x})$

y_{1x}: Obj-1 value at $\boldsymbol{x}$
$\boldsymbol{g}_x = [g_1, g_2, \cdots, g_{146}]$: Constraint values at $\boldsymbol{x}$
$\boldsymbol{y}_{1x_i}' = \partial y_1 / \partial x_i$: Gradient values of y_1 at $\boldsymbol{x}$
$\boldsymbol{G}_{x_{i,j}} = \frac{\partial g_i}{\partial x_j}$: Gradient of Constraint g_i w.r.t Variable x_j

2) Find x_k having Max-Feasible-Descent (expected) as per gradient values and a step size of $\delta_k = \pm 0.05$ (based on $\partial y_1 / \partial x_k = \mp$)

CV$_k$ = $\sum_i \nabla g_i\,(x_k)\delta_k$

Choose the x_k having min CV$_k$

3) Evaluate $\boldsymbol{z} = [x_1, x_2, \cdots, x_k + \delta_k, \cdots, x_{145}]$

$(y_{1z}, \boldsymbol{g}_z, \boldsymbol{y}_{1z}', \boldsymbol{G}_z) = \Psi(\boldsymbol{z})$

4) **If** ($\boldsymbol{z}$ is Feasible) AND ($y_{1z} < y_{1x}$)

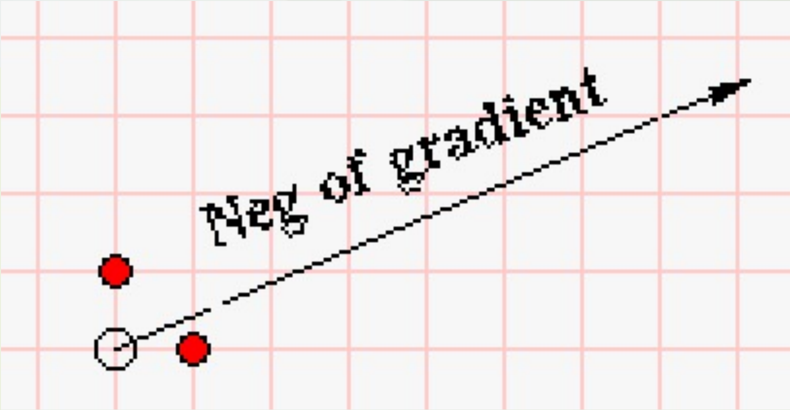
$\boldsymbol{x} \leftarrow \boldsymbol{z}$

Go to Step-2

Else

Return $\boldsymbol{x}$

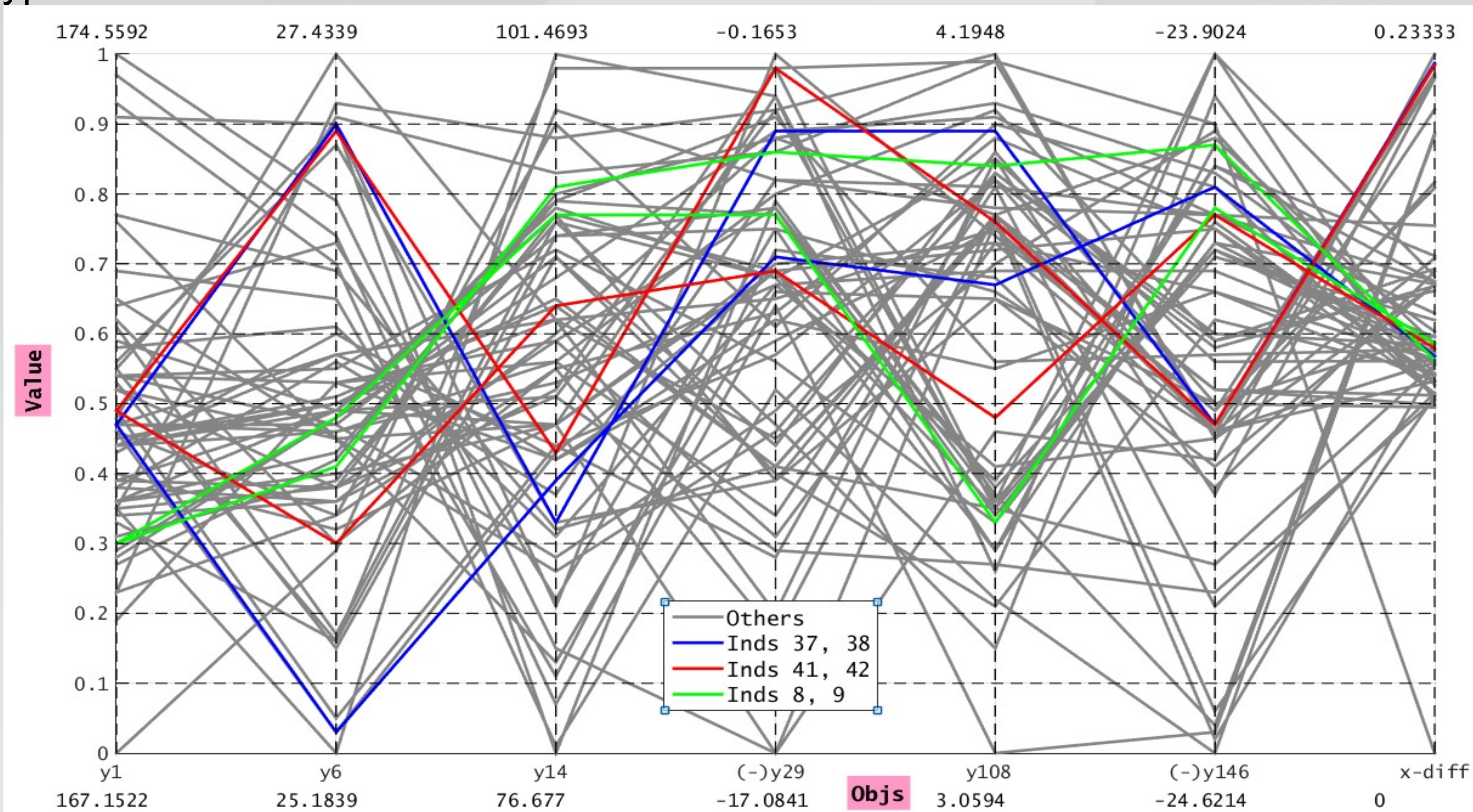
Stop!

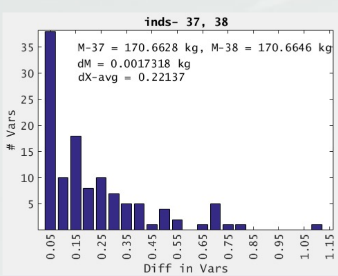


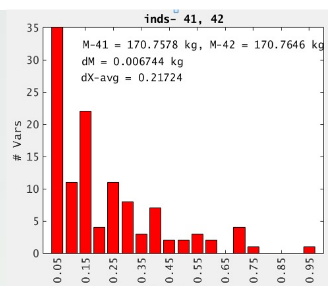
MOTRAN Stage-1 (Results)

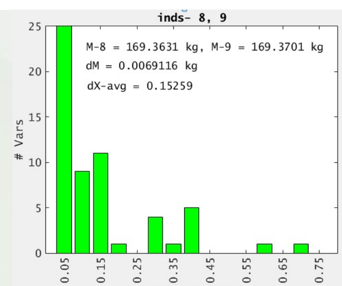
A Typical NSGA-III Run:

Modified NSGA-III Results



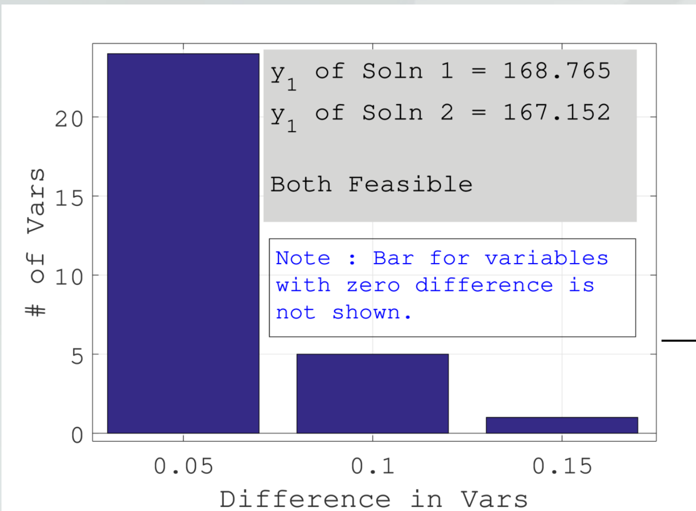






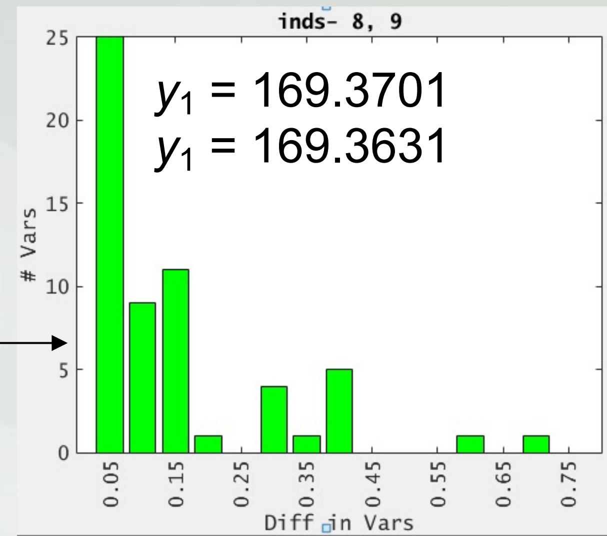
MOTRAN Stage-1
(Diversity Comparison to LS)

- 1.613 difference in y_1



Improvement in Diversity

- 0.007 difference in y_1

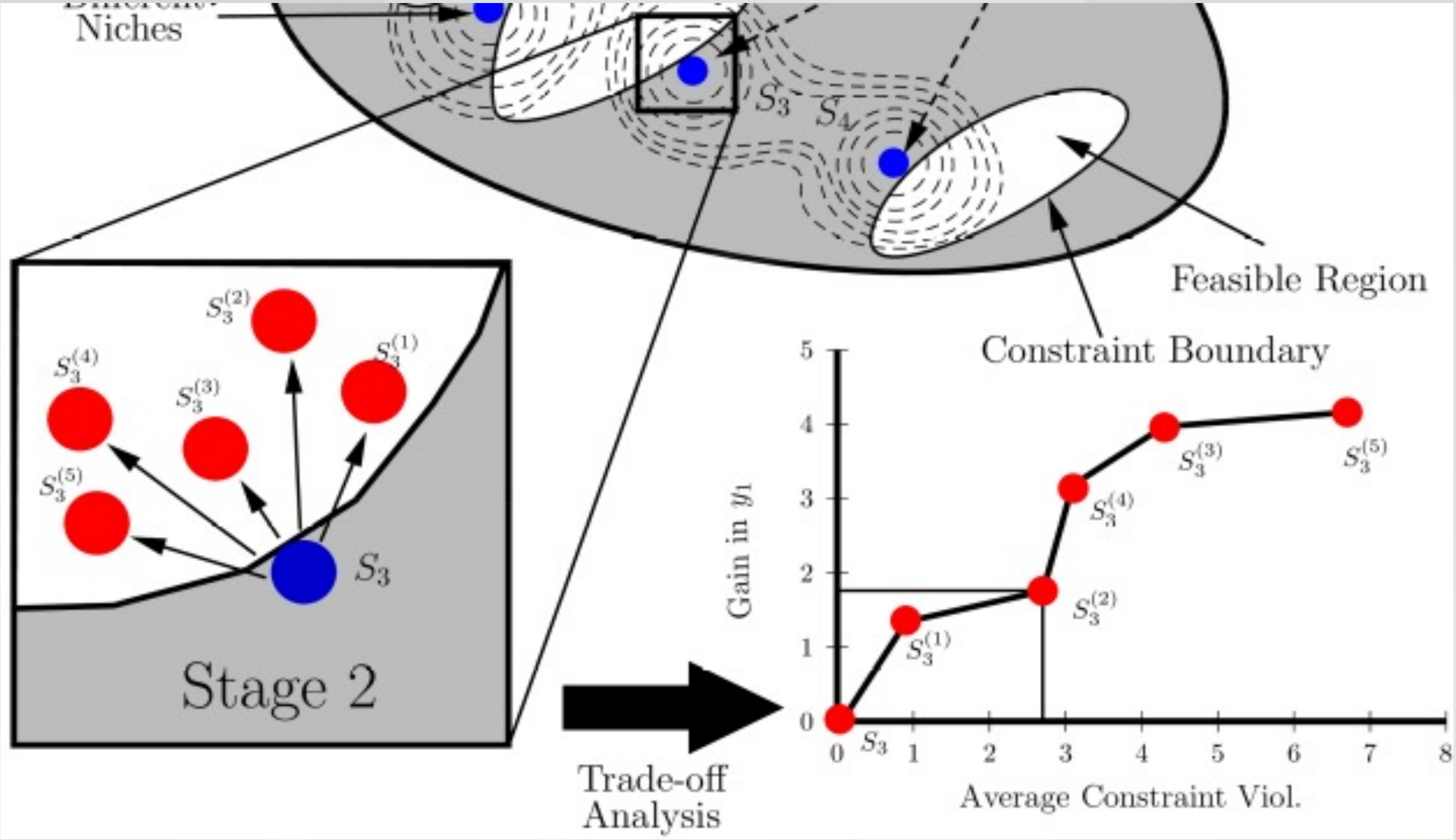


- 30 variables different
- As large as 3 steps different

- 63 variables different
- As large as 14 steps different

EMO capable of finding more diverse solns.

MOTRAN Stage-2



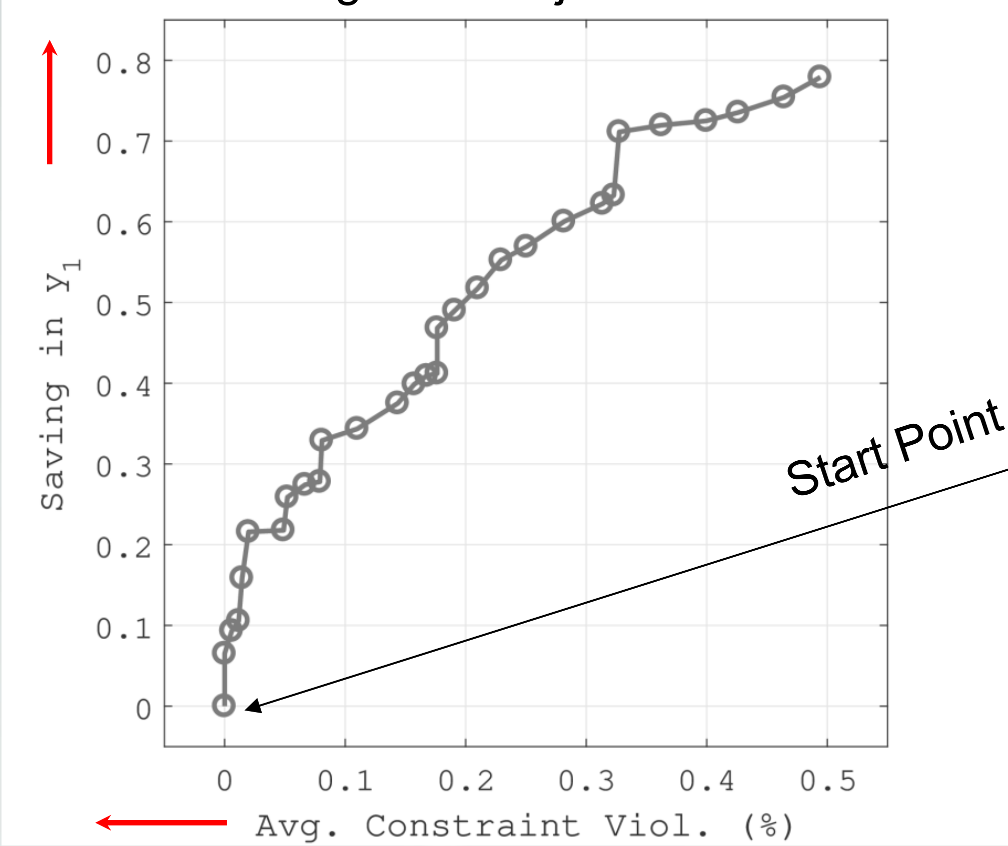
- Stage2: Sensitivity of best y_1 solutions

MOTRAN Stage-2

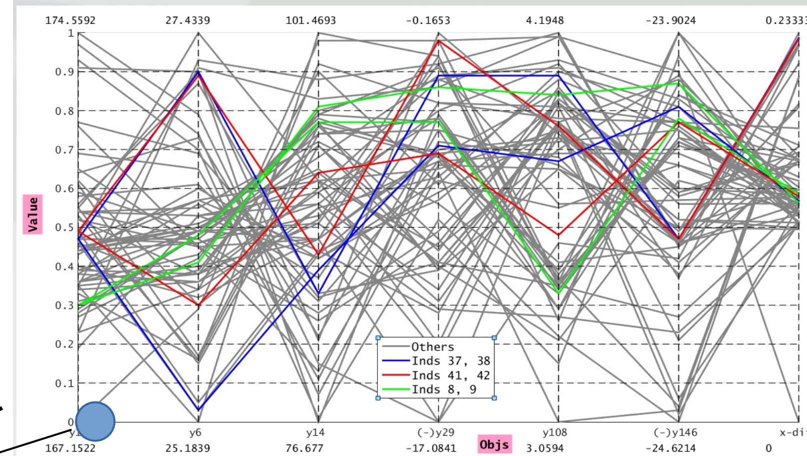
- Two Objectives:
  - Maximize Improvement in y_1
  - Minimize Average Constraint Violation
- Apply **NSGA-II**
- Search restricted within neighborhood
  - No feasible 1-jump is effective
  - Max jump is limited to **3-5 variables** and go one step in each variable, then follow the same CV check as in Phase 1
- Low Computational budget of **5,000 FEs**
- New points aided with **Local-Search**

MOTRAN Stage-2

Stage-2 Bi-objective run



Stage-1 PCP



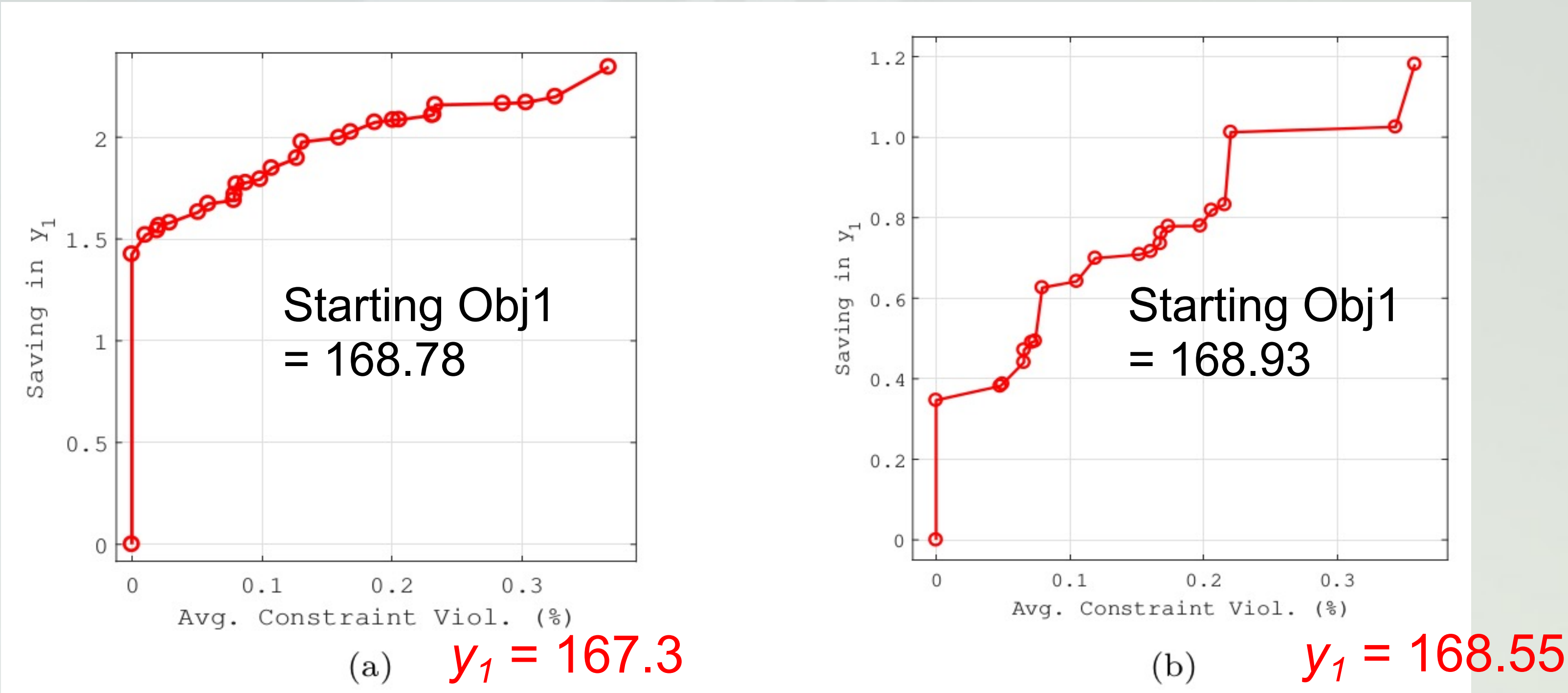
y_1 = 167.16

- Improvement of y_1 of 0.8 in Stage 2 due to focused search
  - y_1 = 166.36

- Start Point : Lowest Obj-1 from Stage-1 or a chosen point

MOTRAN Stage-2 (Comparison of Diff. Stage1 Solutions)

Green solutions



- Neighborhood comparison of two solns. with similar Obj-1 but different Niches

End of Module 5, Lecture 22, Part 1

- Real world problem solving is different from the academic benchmark studies
- Many problems require multiple optimization techniques to come up with desired solutions
  - Many conflicting objectives, niching, uncertainty handling etc.
  - Local Search for faster convergence
  - y_1 reduced from 184 to 166.36 (17.64 reduction, 10 was desired)
- Humans are in charge!