Yield-Area Optimizations of Digital Circuits Using Non-dominated Sorting Genetic Algorithm (YOGA)

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Outline

- Introduction – Timing Yield
- Previous Work – Gate Sizing
- Disadvantages of Previous Techniques
- Yield Optimization by Genetic Algorithm
  - Non-Dominated Sorting Genetic Algorithm
- Experimental Results
- Conclusion

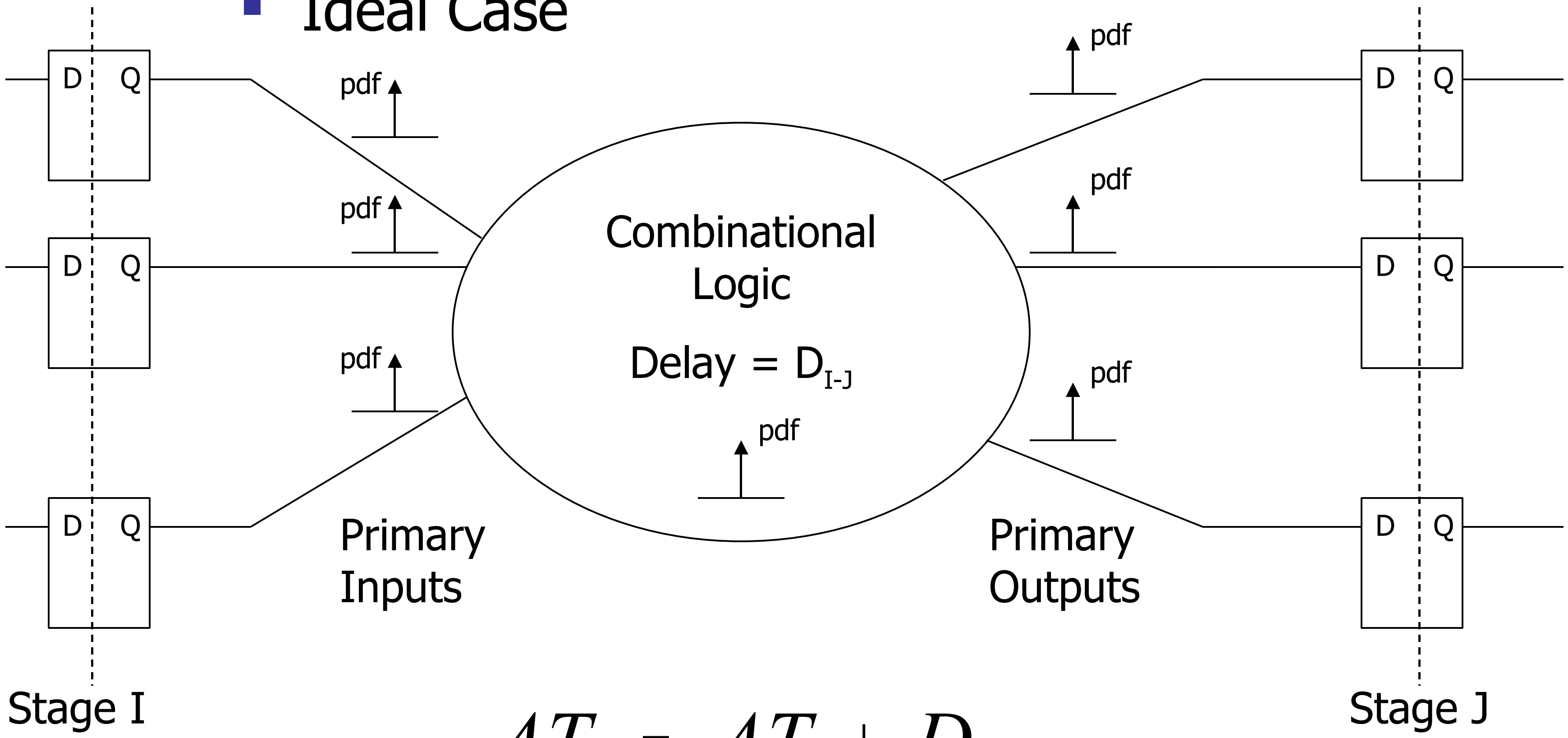
What is Timing Yield?

- Timing is an important Factor in synchronized circuit
- Arrival times (AT) at Primary output have an upper bound called Latest Arrival Time
- Ideally, AT are deterministic and can be computed as

$$AT_J = AT_I + D_{I-J}$$

What is Timing Yield?

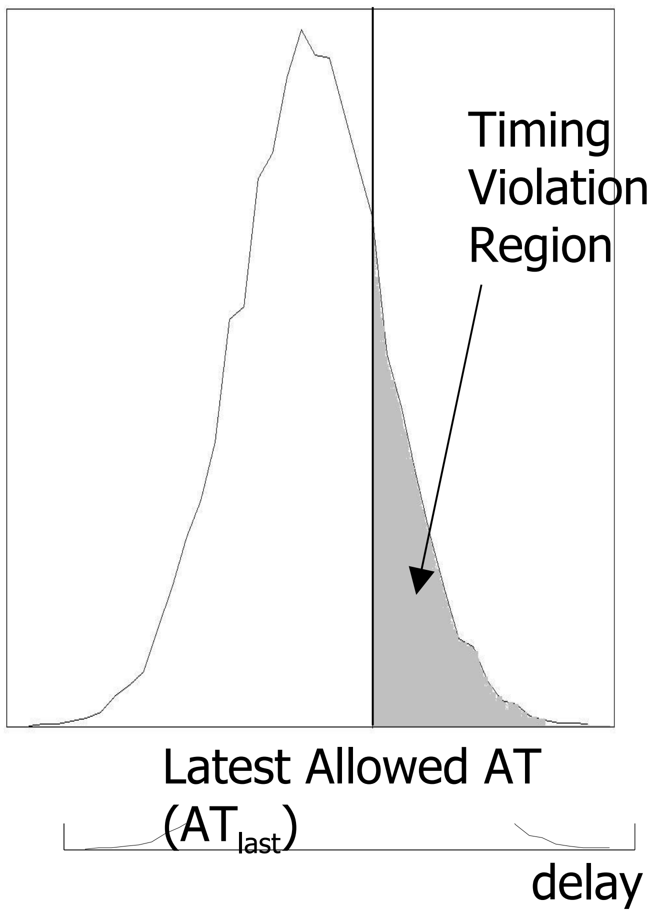
- Ideal Case



$$AT_J = AT_I + D_{I-J}$$

What is Timing Yield?

- But delay of Combinational Logic is not deterministic
- Process variations up to 10-15%
- Results in ‘spreading’ of Arrival Time Probability Distribution Function (*pdf*)
- Larger Variation implies larger spread



What is Timing Yield?

- Probability of timing violation $\uparrow \Rightarrow$ Yield $\downarrow$
- Solution – Decrease Timing Variation at the Primary Outputs
- An effective solution is GATE SIZING

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Previous Work – Gate Sizing

- Larger Gate implies lesser % variation
- Variation cannot be removed completely due to presence of random fluctuations but its effect can be subsided considerably
- Theory - Gate Sizes can be scaled selectively to reduce overall variation
- Previous Technique - Constrained Single-Objective optimization

Gate Sizing Optimization

$$\textit{find} \quad \mathbf{s}$$

$$\min \quad \sigma^2\left(d_O(\mathbf{s})\right)$$

$$\textit{subject to} \quad \mu\left(d_O(\mathbf{s})\right) \rfloor \mu_{\max}$$

$$\pi(\mathbf{s}) \rfloor \pi_{\max}$$

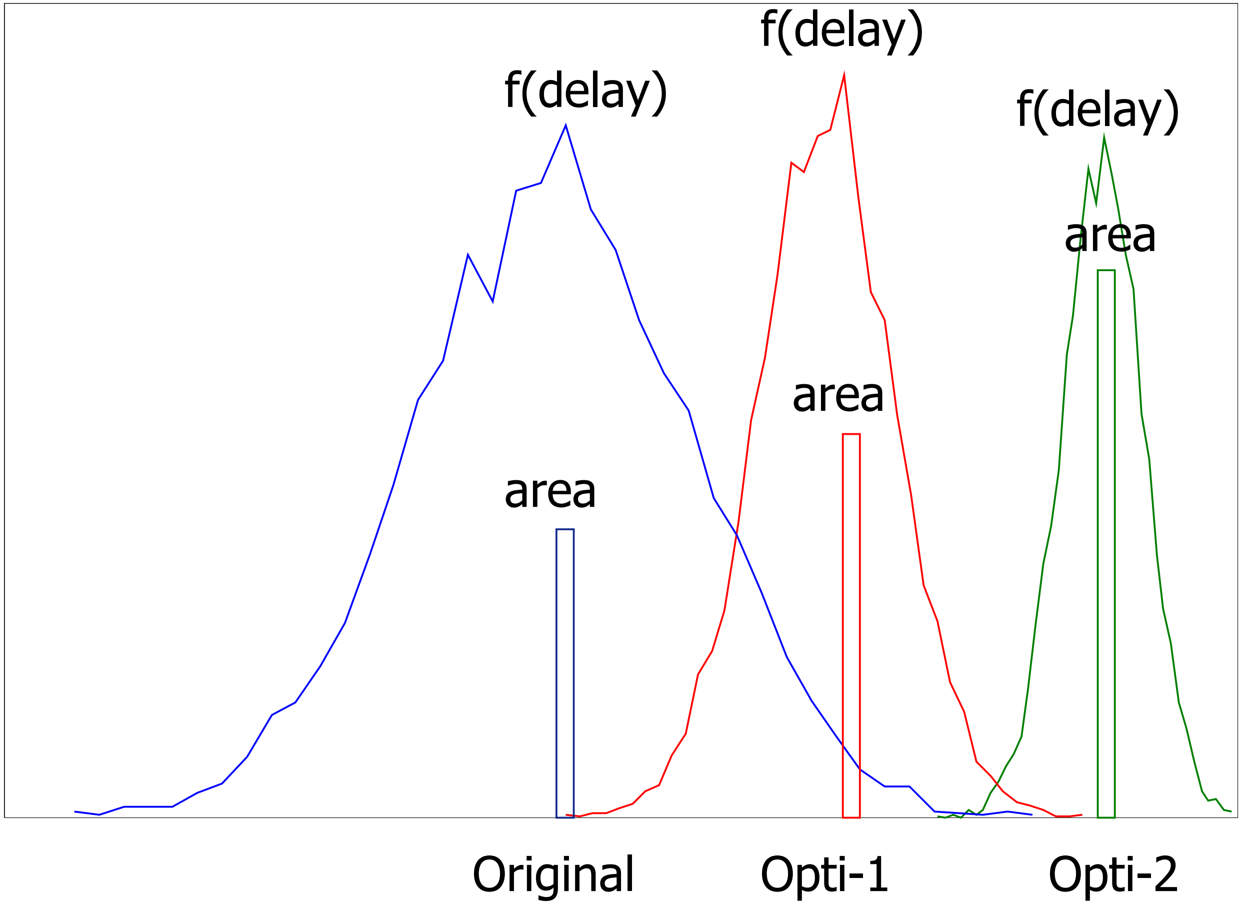
$\mathbf{s}$ - Solution Gate Size Vector

$\sigma^2\left(d_O(\mathbf{s})\right)$ - Output delay variance

$\mu\left(d_O(\mathbf{s})\right)$ - Output delay mean

$\pi(\mathbf{s})$ - Circuit Area

Gate Sizing Demonstration



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Disadvantages

- Provides only 1 solution
- User (Constraint) Dependent
- Fails to perform under too stringent condition
- Quality of final solution may depend on choice of starting point
- For optimizing in multi-domain, same procedure has to be repeated sequentially
- If sequential procedure is adopted, optimization in step 2 can cause the objective of step 1 to deteriorate

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Yield Optimization by Genetic Algorithm (YOGA)

- Overcomes the previous disadvantages
  - Provides more than 1 solution of equal quality (pareto-optimal)
  - Final solutions independent of initial starting points
  - More flexibility at the user end
  - User - Constraint Independent
  - Optimizes Multi-objectives simultaneously
  - Visual trade-off for more prudent choice
- Based on Non-Dominated Sorting Genetic Algorithm (NSGA)

Non-Dominated Sorting Genetic Algorithm (NSGA)

- Starts with absolutely random solutions
- Converges to Pareto-optimal solutions
- Follows Same principle as Genes follow in natural world

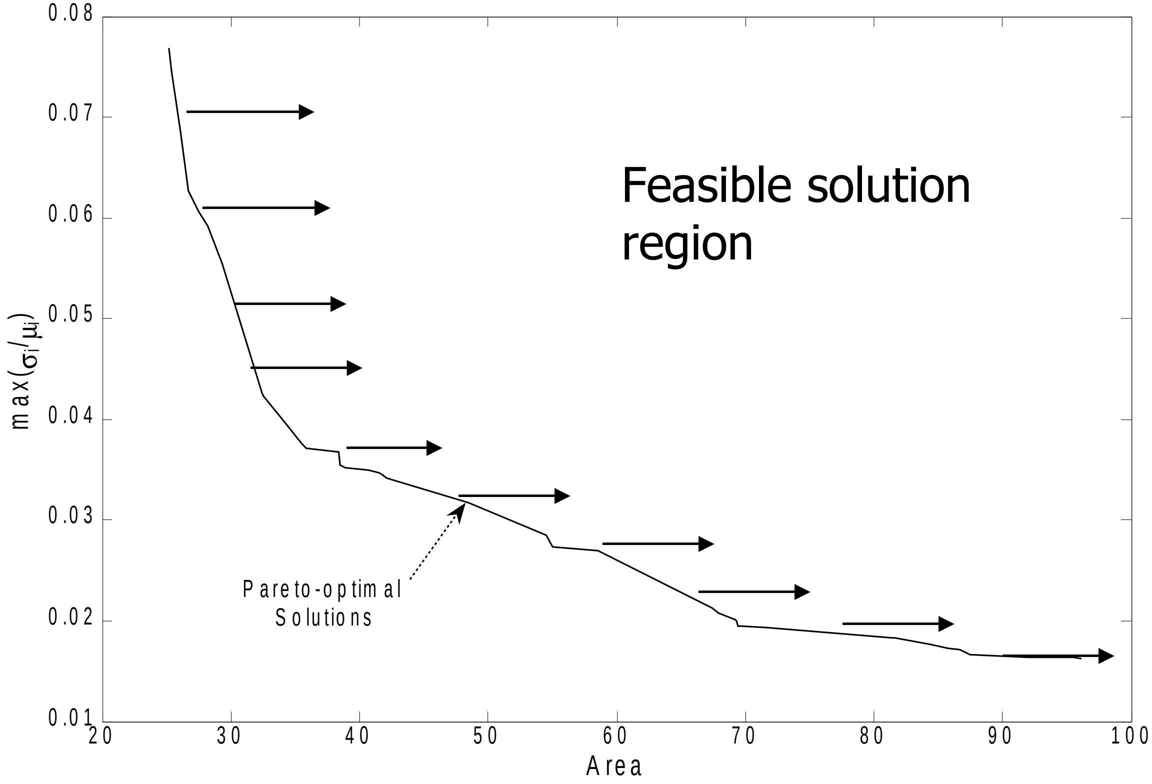
Pareto-optimal Solution

- Definition - A solution is called *Pareto-optimal solution*, if there exist no other solution for which at least one of its criterion has a better value while values of remaining criteria are the same or better.
- In other words, one can not improve any criterion without deteriorating a value of at least one other criterion.

If x^* is a pareto-optimal solution and for any *i if*

$$f_1(x_i) < f_1(x^*) \quad f_2(x_i) > f_2(x^*)$$

Pareto-optimal Solution



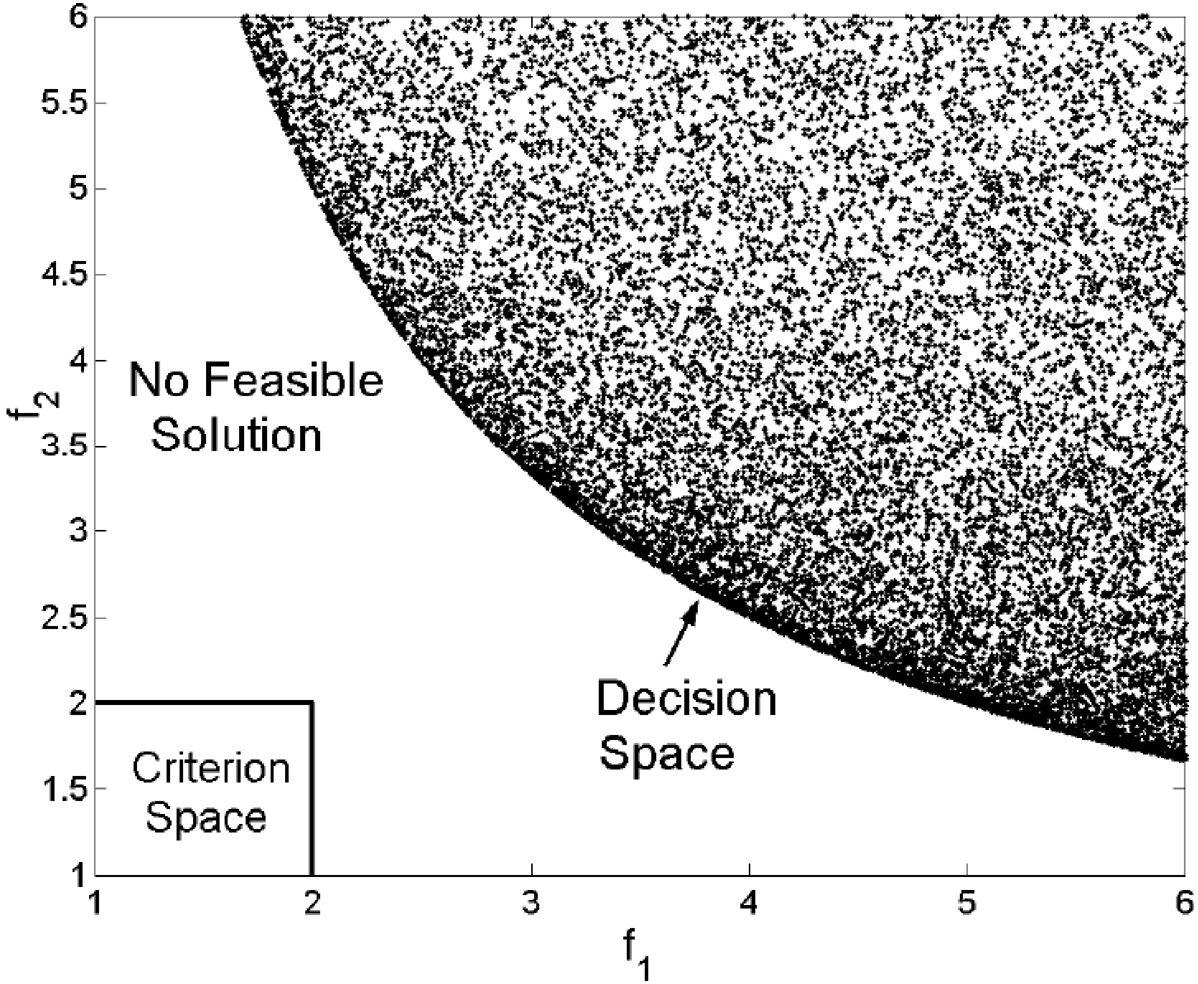
- YOGA generates such pareto-optimal solutions

NSGA - Demonstration

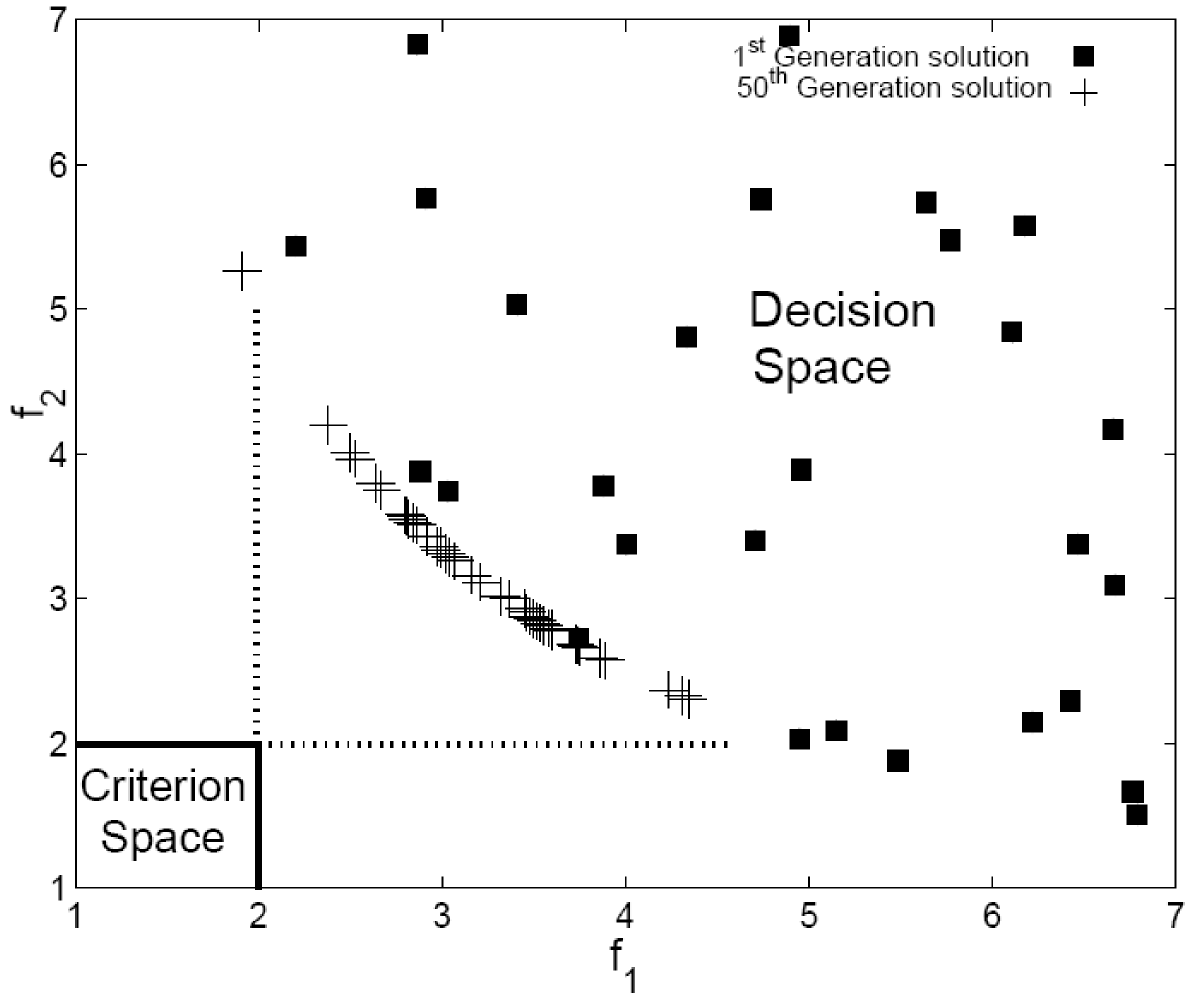
$$\begin{aligned} goal \quad & f_1 = 10x_1 \leq 2 \equiv \min \langle f_1 - 2 \rangle \\ goal \quad & f_2 = \frac{10+(x_2-5)^2}{10x_1} \leq 2 \equiv \min \langle f_2 - 2 \rangle \\ Subject\ to\ \mathbb{F} \equiv \quad & (0.1 \leq x_1 \leq 1, 0 \leq x_2 \leq 10) \end{aligned}$$

- 2 objectives & single constraint
- No possible solution provided by sequential traditional single – objective optimization techniques

NSGA – Demonstration (2)



NSGA – Demonstration (3)



NSGA - Algorithm

Algorithm 1 NSGA Algorithm

$pop \leftarrow$ `GenerateInitialPopulation`

if $generation \leq \max\ generation$ **then**

  $rank \leftarrow$ `NonDominatedRanking`(pop)

  $fitness \leftarrow$ `FitnessAssignment`$(pop, rank)$

  for $i = 1$ to N step 2 **do**

    $parent_1 \leftarrow$ `Selection`$(pop, fitness)$

    $parent_2 \leftarrow$ `Selection`$(pop, fitness)$

    $(child_1, child_2) \leftarrow$ `Crossover`$(parent_1, parent_2)$

    $newpop_i \leftarrow$ `Mutation`$(child_1)$

    $newpop_{i+1} \leftarrow$ `Mutation`$(child_2)$

  end for

  $pop \leftarrow newpop$

  $generation \leftarrow generation + 1$

end if

$final\_rank \leftarrow$ `NonDominatedRanking`(pop)

NonDominatedSolutions $\leftarrow pop_i, \forall i \in final\_rank_i = 1$

return NonDominatedSolutions

YOGA

$$
\begin{array}{rl}
find & \mathbf{s} \\
Minimize & \max\left(\overrightarrow{\sigma}_{\mathcal{O}} / \overrightarrow{\mu}_{\mathcal{O}}\right) \\
Minimize & \pi\left(\mathcal{G}\right) \\
Subject\ to & s_j^L \leq s_j \leq s_j^U, \quad \forall j \in [1, N], \ g_j \in \mathcal{G}
\end{array}
$$

- NSGA concentrated on convergence of Pareto-optimal solutions
- YOGA concentrates on divergence of such set to provide wide range of solutions

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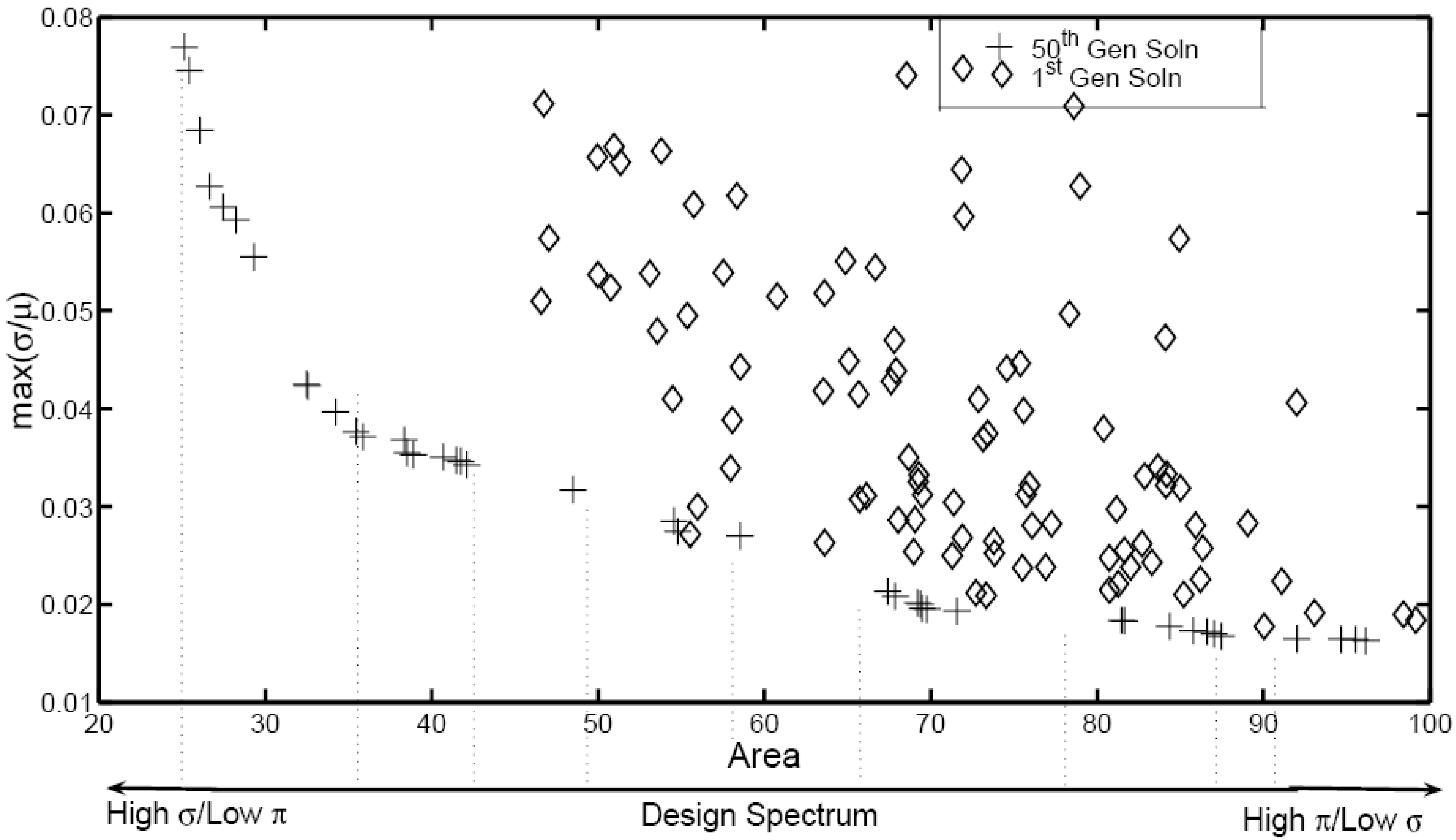
YOGA – Experimental Results c17 – ISCAS Benchmark



YOGA – Experimental Results – Run Time – ISCAS Benchmark

Circuit Name	No. of Gates	Run time (s)	Circuit Name	No. of Gates	Run time (s)
C17	6	4.42	C432	160	43.43
C499	202	51.37	C880	383	94.25
C1355	546	137.18	C1908	880	227.20
C2670	1193	341.68	C3540	1669	470.75

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Conclusion

- Highlighted the shortcomings of previous techniques
- Proposed YOGA for choosing the best solution
- Provided more flexibility while design.
- Presented experimental results to support our claim

Questions?

Thank you

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