Multi-Objective Design Optimization of a Hybrid Electric Vehicle

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1. Setup and HEV Model
2. Automation and Process Integration
3. Selection of Parameters
4. Optimization Strategy
5. Conclusion and Results

Process Integration and Optimization of a Mathematics-based HEV

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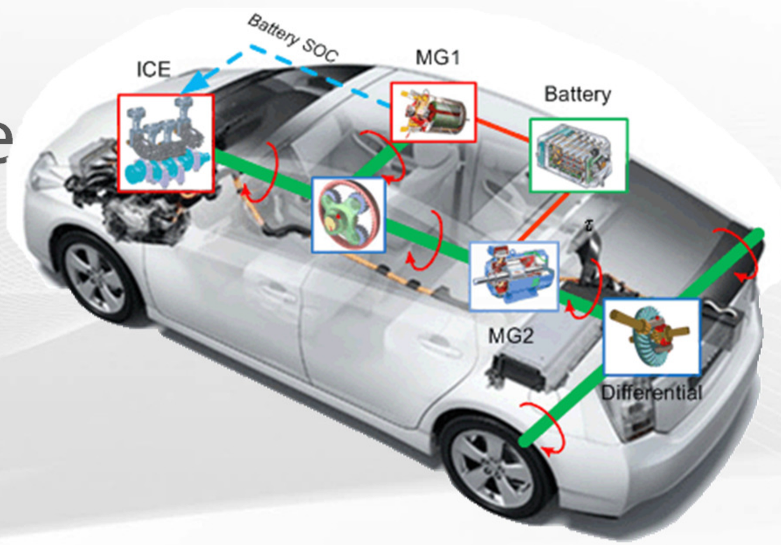
1. HEV Challenges

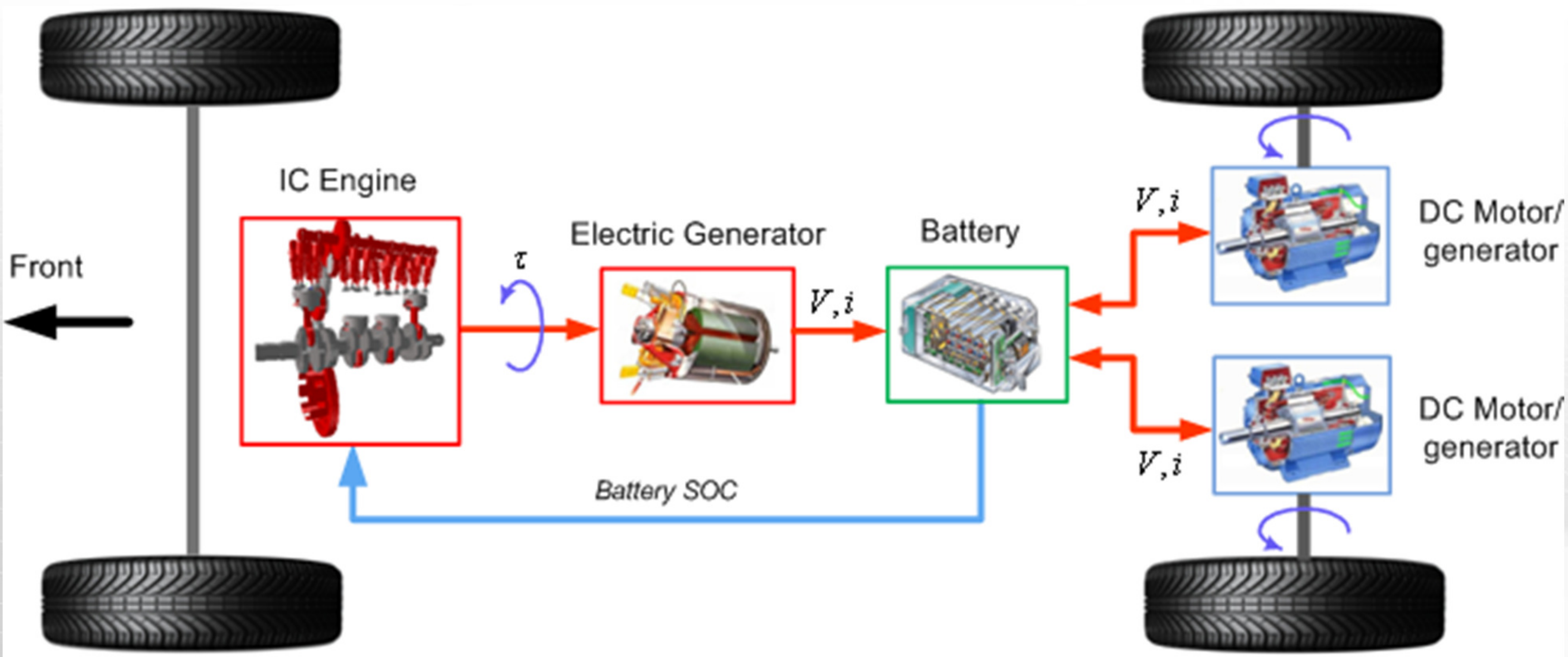
- Many new components
- Less experience
- More interaction of more components
- New thermal effects
- More need for sharing

→ More need for optimization

Power-split HEV



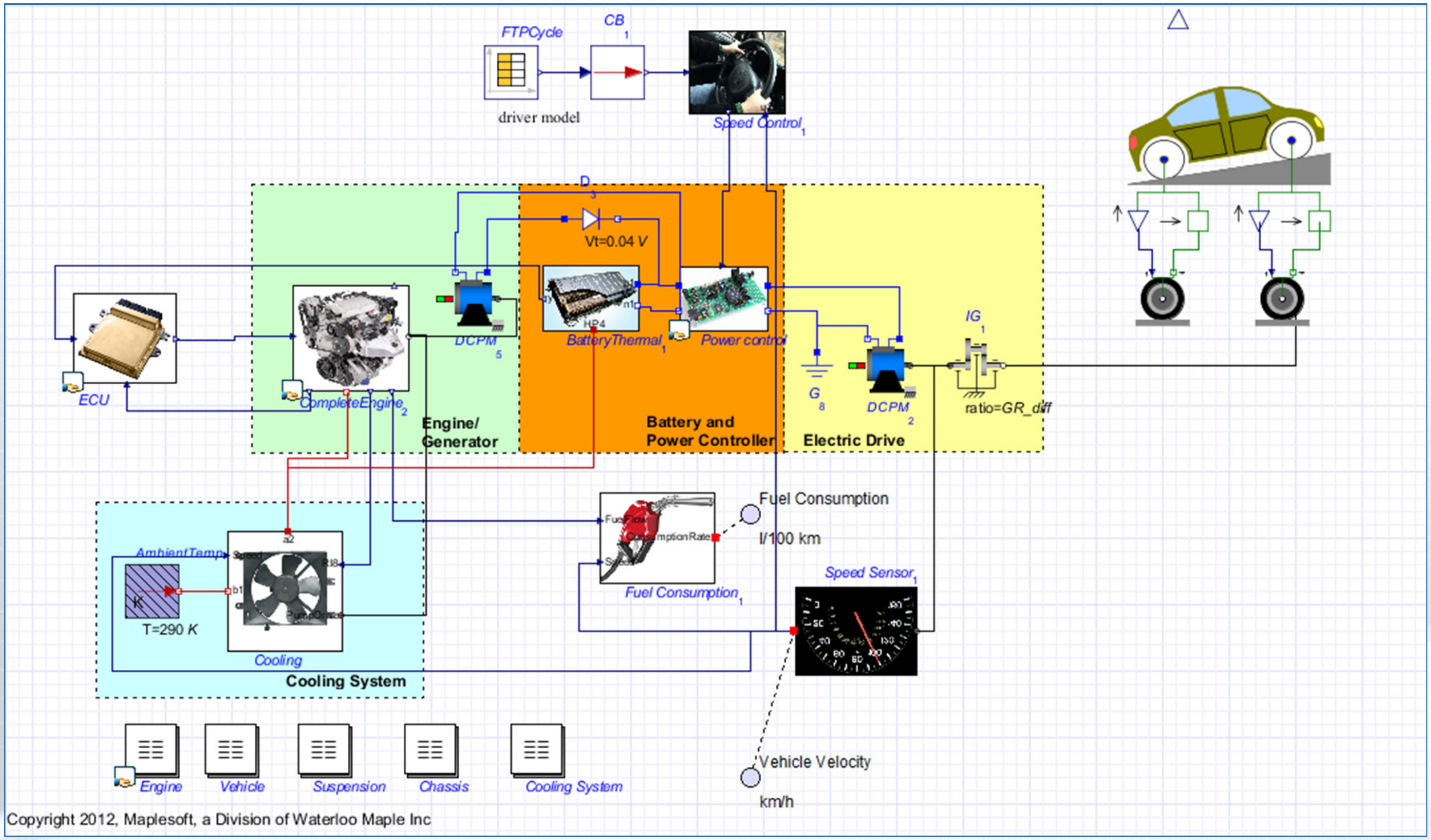
1. Hybrid and E-Vehicle Components



1. Variable Parameters

Parameter	Description [unit]	Range
MinSoCThreshold	Minimum SOC Threshold	0.3 – 0.6
ncell	Number of battery cells	100 – 200
Vmanifold	Engine manifold volume [m^3]	0.003 – 0.005
Bore	Engine bore [m]	0.0855 – 0.1
Stroke	Engine stroke [m]	0.0814 – 0.19
Apos	Area of battery pos.electrode [cm^2]	100 – 500
Aneg	Area of battery neg.electrode [cm^2]	100 – 500
apos	Specific surface of Apos [cm^2/cm^3]	3000 – 5000
aneg	Specific surface of Aneg [cm^2/cm^3]	2000 – 4000
Va	Nominal voltage of e-motor [V]	400 – 1000
Ia	Nominal current of e-motor [mA]	50 – 100
Vas	Phase voltage of e-motor [V]	50 – 150
Ias	Phase current of e-motor [mA]	50 – 150

1. Setup and HEV Model



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1. Setup and HEV Model

Goal: the optimization goal is to minimize fuel consumption, while simultaneously keeping the maximum torque at a maximum

→ Two objective functions have to be considered

→ Multi-objective optimization strategies have to be applied

1. Setup and HEV Model

Constraints: Two target requirements have to be considered during the optimization process

- Maximum temperature < 315 K
- Battery current < 500 A

→ Violation of these constraints leads to a non feasible design and it will be marked as a failed experiment

1. Output Parameters

Parameter	
Power loss	Output parameter

Objective	
Fuel consumption	Minimization
Engine torque	Maximization

Constraint	
Battery temperature	Smaller than 315 K, because higher values can damage the durability of the battery (< 315)
Battery current	Smaller than 500 A, because higher values can damage the durability of the battery (< 500)

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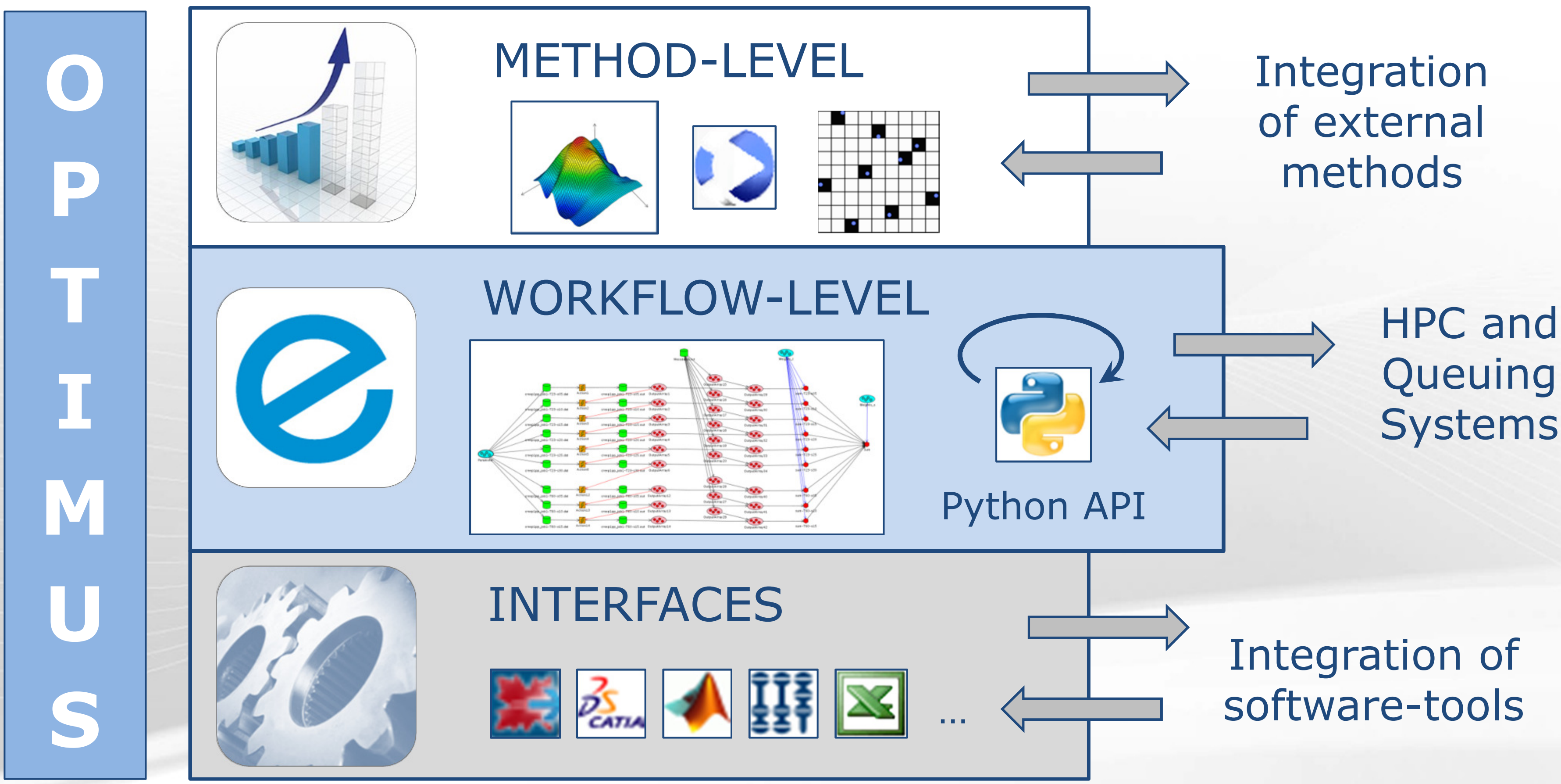
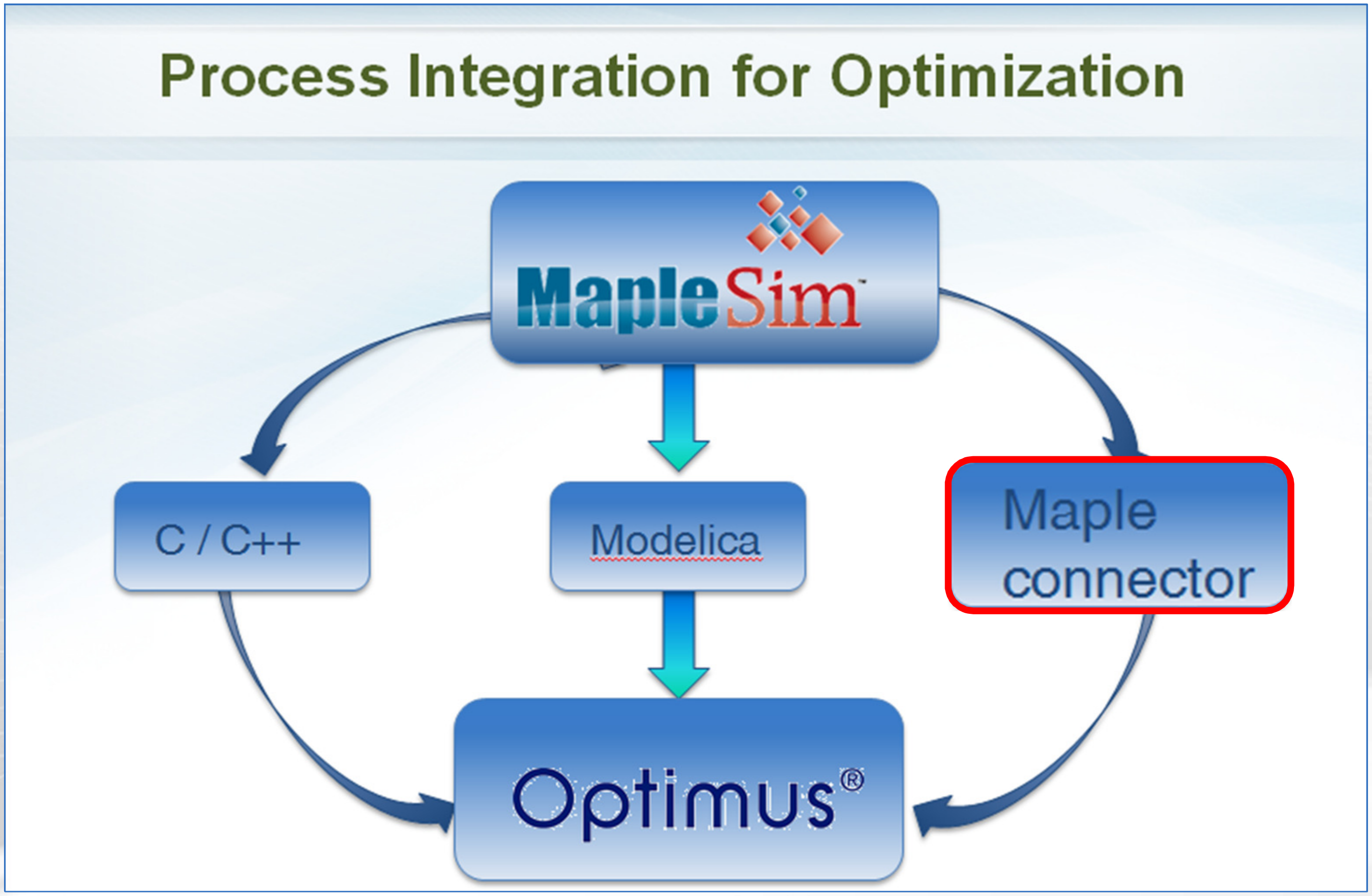
2. Automation and Process Integration

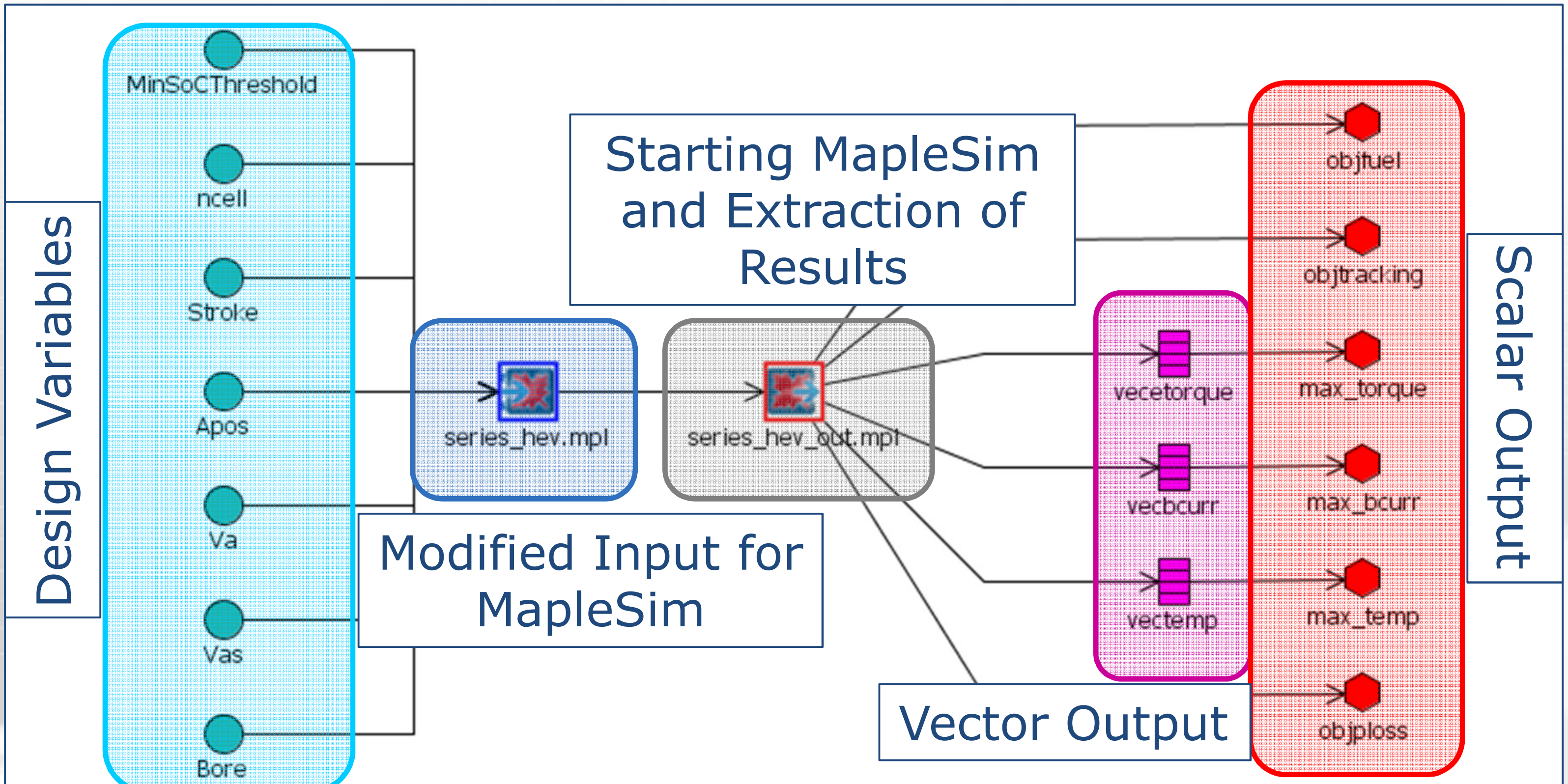


2. Automation and Process Integration



2. Automation and Process Integration

Workflow in OPTIMUS



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3. Selection of Parameters

Parameter	Description [unit]	Range
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3. Selection of Parameters

Linear Correlation Factors

≥ 0.1

Pearson (Spearman)	MinSoCThreshold	ncell	Vmanifold	Bore	Stroke	Apos	Aneg	apos	aneg	Va	Ia	Vas	Ias
objfuel	0.377 (0.429)	-0.087 (-0.239)	0.013 (-0.006)	0.023 (0.002)	0.029 (0.011)	-0.521 (-0.611)	-0.015 (0.010)	0.000 (-0.028)	-0.021 (-0.020)	0.014 (0.017)	0.017 (0.009)	-0.406 (-0.422)	0.042 (0.003)
objtracking	-0.120 (-0.074)	-0.090 (-0.037)	0.004 (-0.004)	0.009 (0.022)	-0.065 (-0.025)	-0.076 (-0.049)	0.003 (-0.005)	0.046 (0.012)	0.001 (0.002)	-0.861 (-0.961)	-0.013 (-0.006)	0.013 (0.013)	0.011 (0.006)
objploss	0.027 (0.087)	0.241 (0.264)	-0.010 (-0.010)	0.005 (-0.018)	-0.028 (-0.069)	-0.087 (-0.144)	0.000 (0.019)	-0.002 (-0.008)	-0.044 (-0.010)	0.005 (0.001)	0.047 (0.001)	-0.613 (-0.865)	0.065 (0.043)
objbcurr	-0.127 (-0.165)	-0.252 (-0.245)	-0.027 (-0.035)	0.156 (0.164)	0.482 (0.563)	0.126 (0.174)	0.003 (0.003)	-0.026 (-0.024)	-0.032 (-0.022)	0.016 (0.006)	0.006 (0.013)	-0.453 (-0.458)	0.000 (-0.003)
objtemp	0.011 (0.070)	0.273 (0.273)	-0.017 (0.003)	-0.019 (-0.038)	-0.065 (-0.082)	0.019 (0.046)	0.017 (0.016)	-0.010 (-0.006)	-0.028 (0.008)	0.012 (0.026)	0.046 (0.024)	-0.698 (-0.797)	0.047 (0.033)
objetorque	-0.117 (-0.124)	-0.232 (-0.224)	-0.025 (-0.027)	0.173 (0.159)	0.553 (0.555)	0.153 (0.156)	-0.002 (-0.008)	-0.021 (-0.017)	-0.029 (-0.032)	0.015 (0.014)	0.009 (0.013)	0.521 (0.533)	-0.015 (-0.018)

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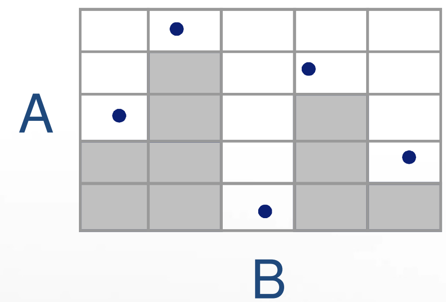
4. Optimization Strategy

1. Decide for an optimization strategy

2. Study: Investigate the behavior of the system and the Pareto points

3. Study: Investigate the influence of swarm size on mPSO

4. Optimization Strategy



STEP1   Design of Experiments

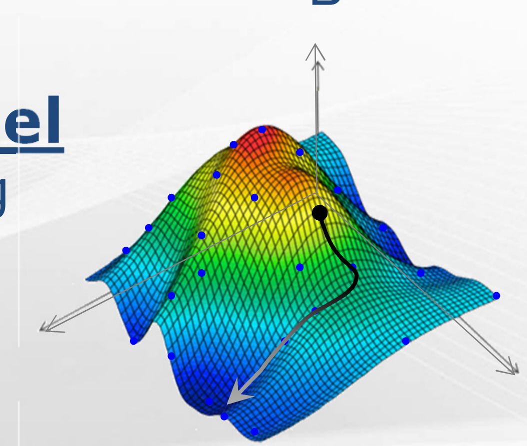
Exploration of the design space

Latin Hypercube Sampling with n experiments

QUALITY

STEP2   Response Surface Model

Describing the system behavior using mathematical models (Kriging)



VERIFY

STEP3   Multiobjective Optimization

Determine an optimal parameter combination on the model using evolution strategies (NSEA+/mPSO algorithm)

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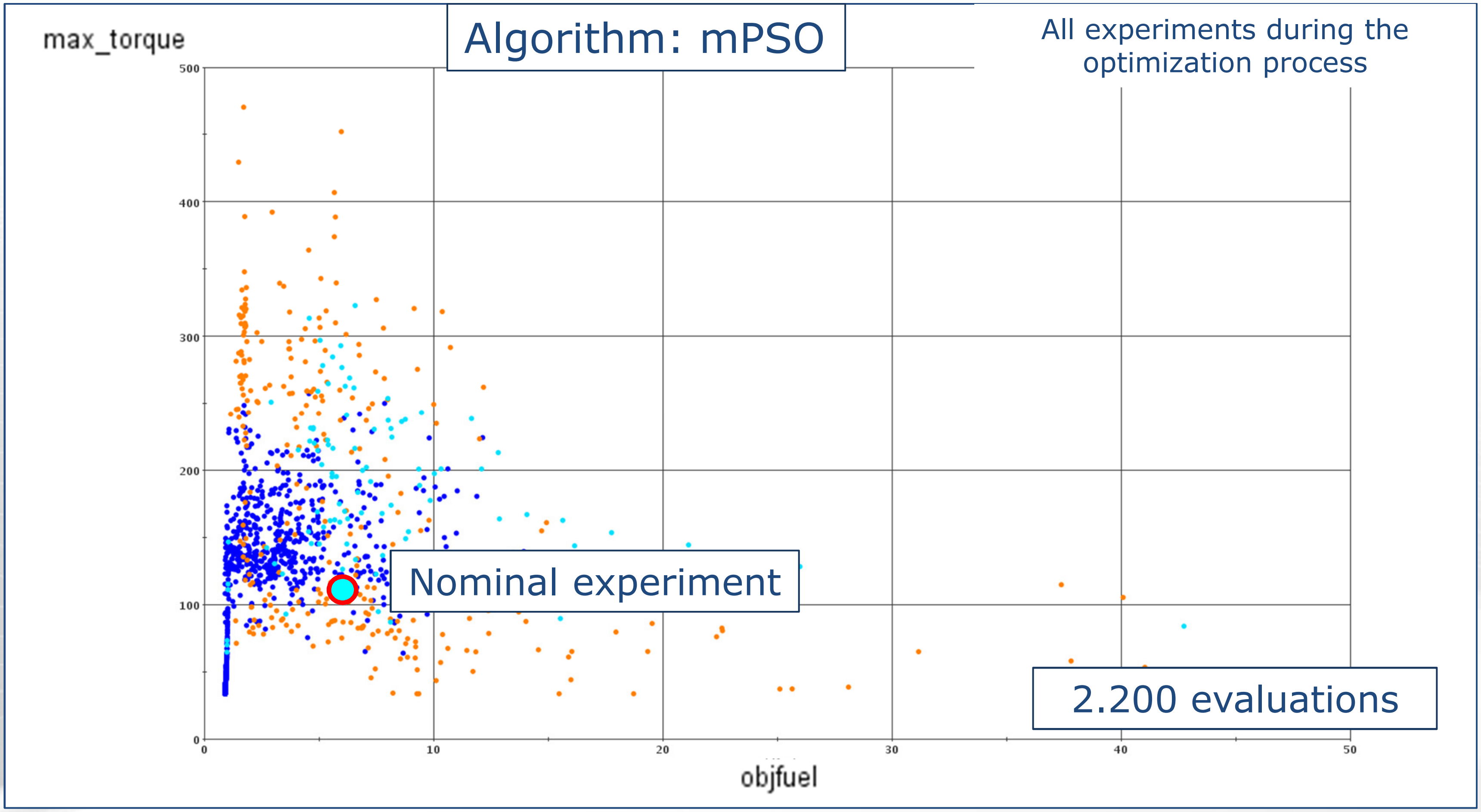

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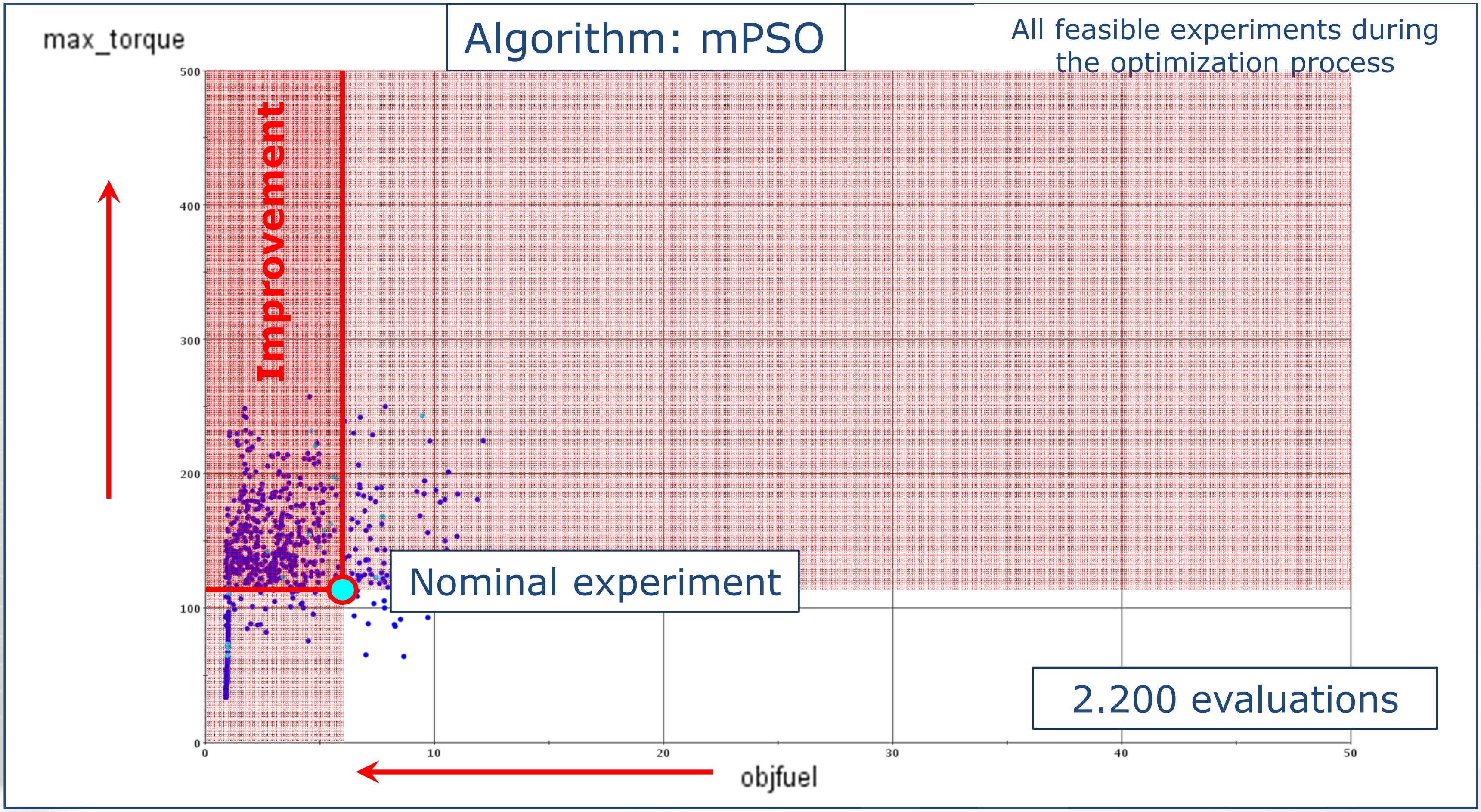
4. Optimization Strategy



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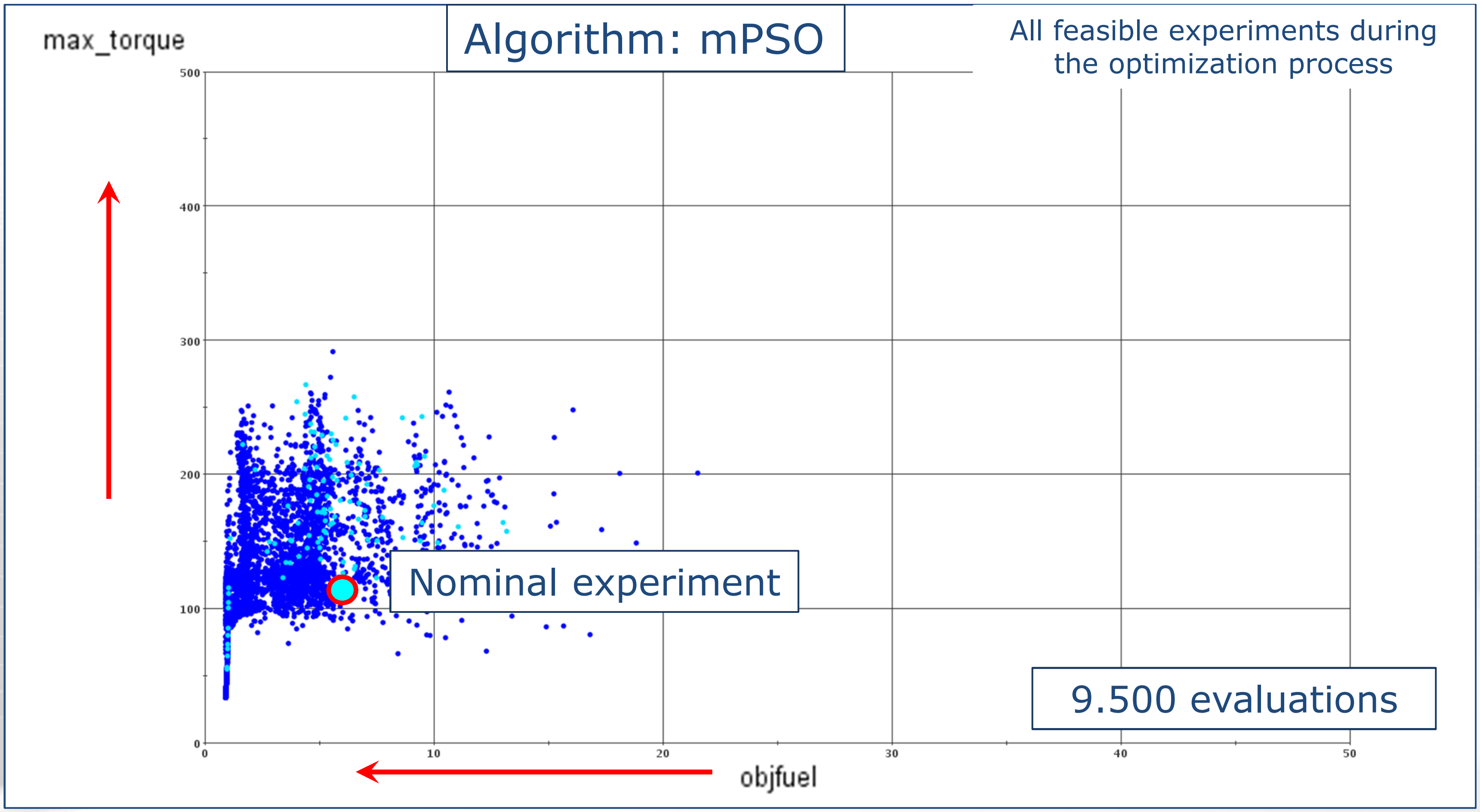

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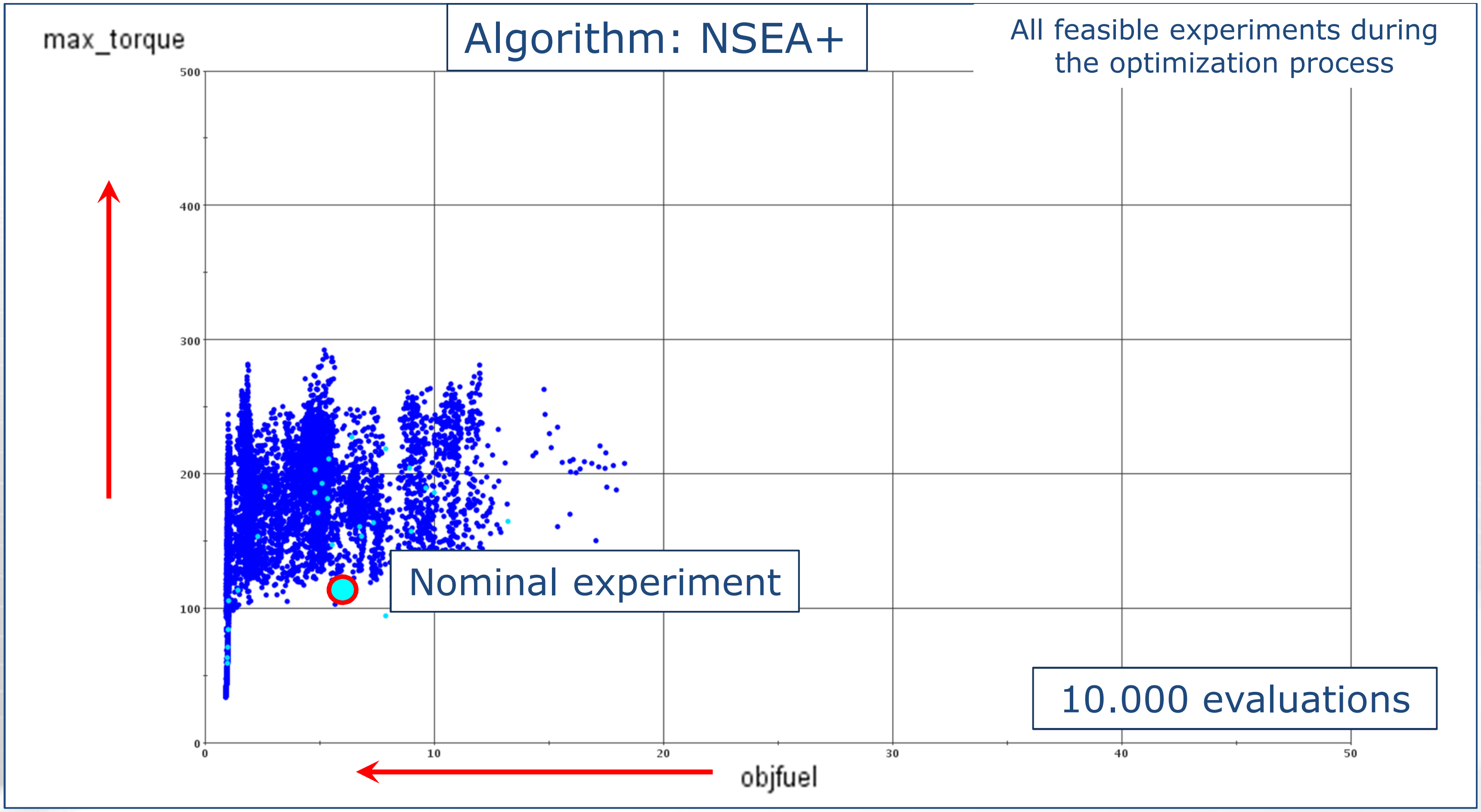

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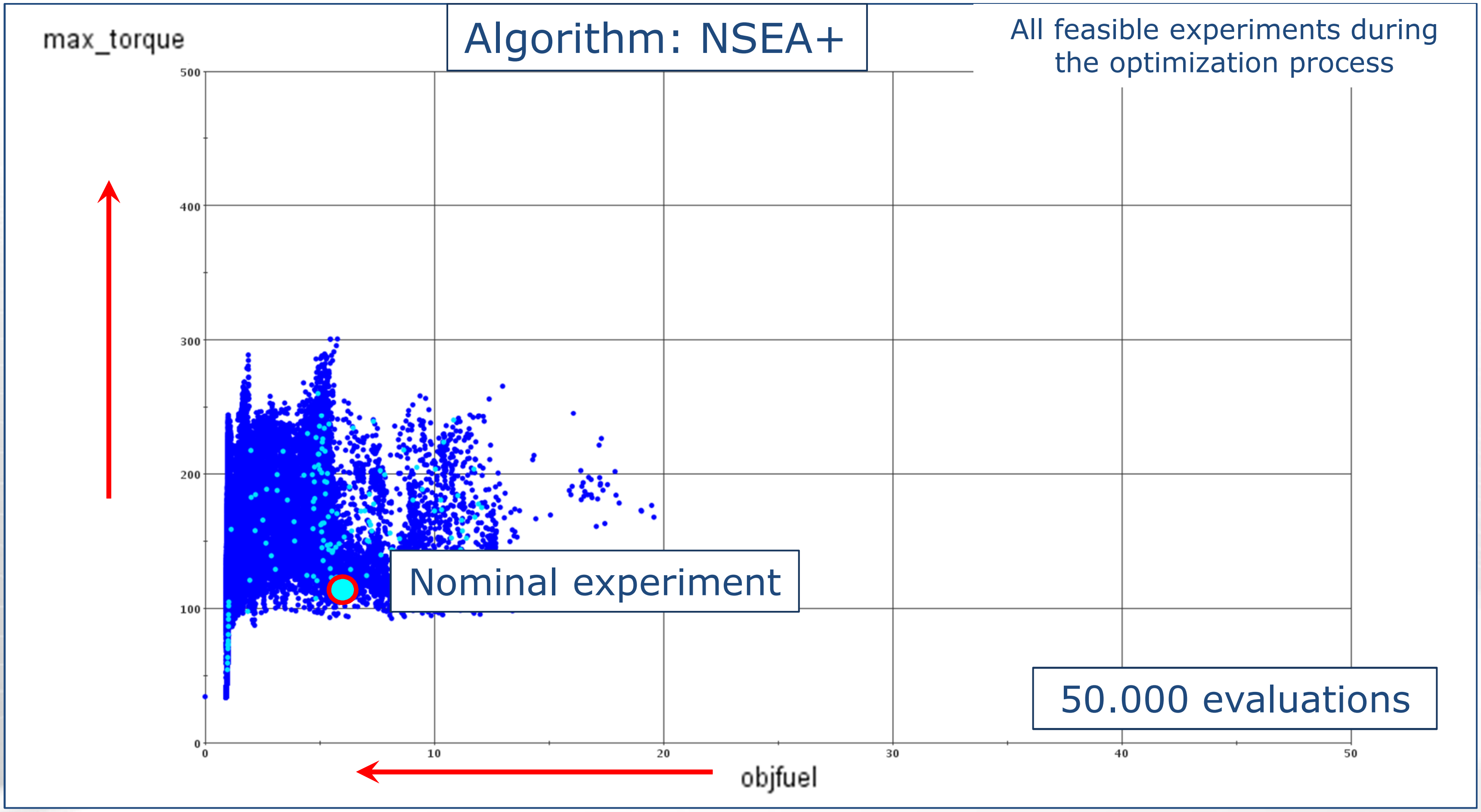

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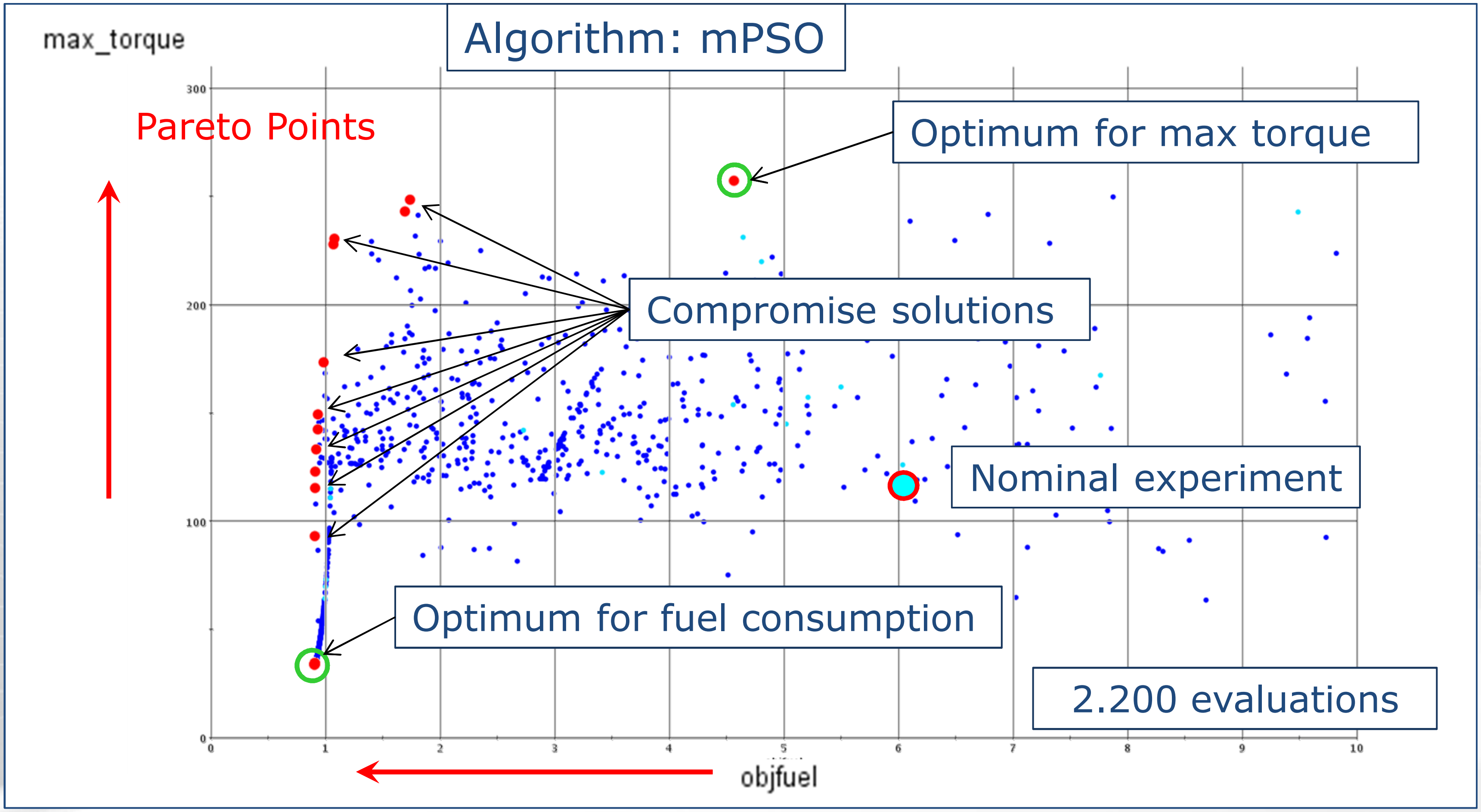

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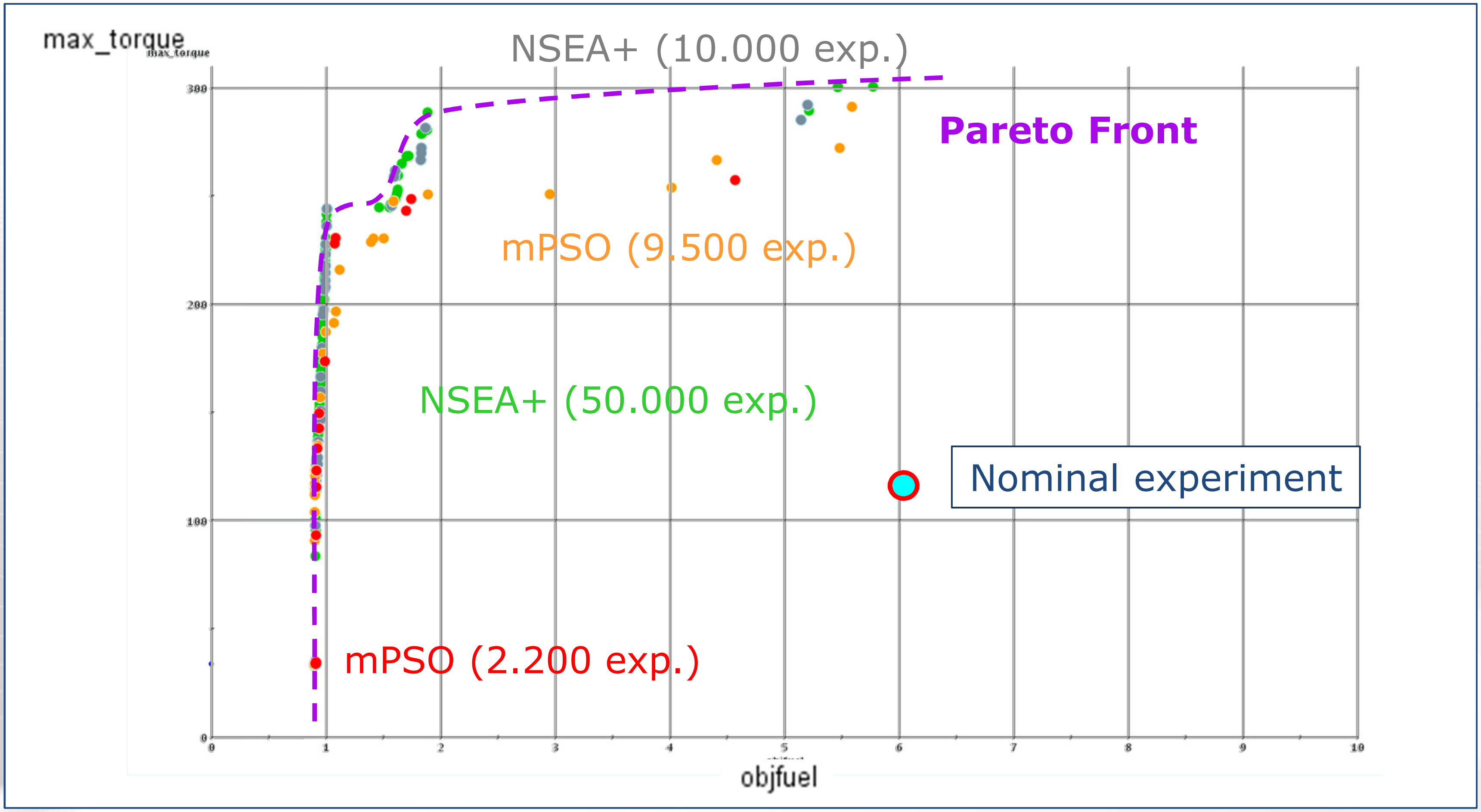

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4. Optimization Strategy

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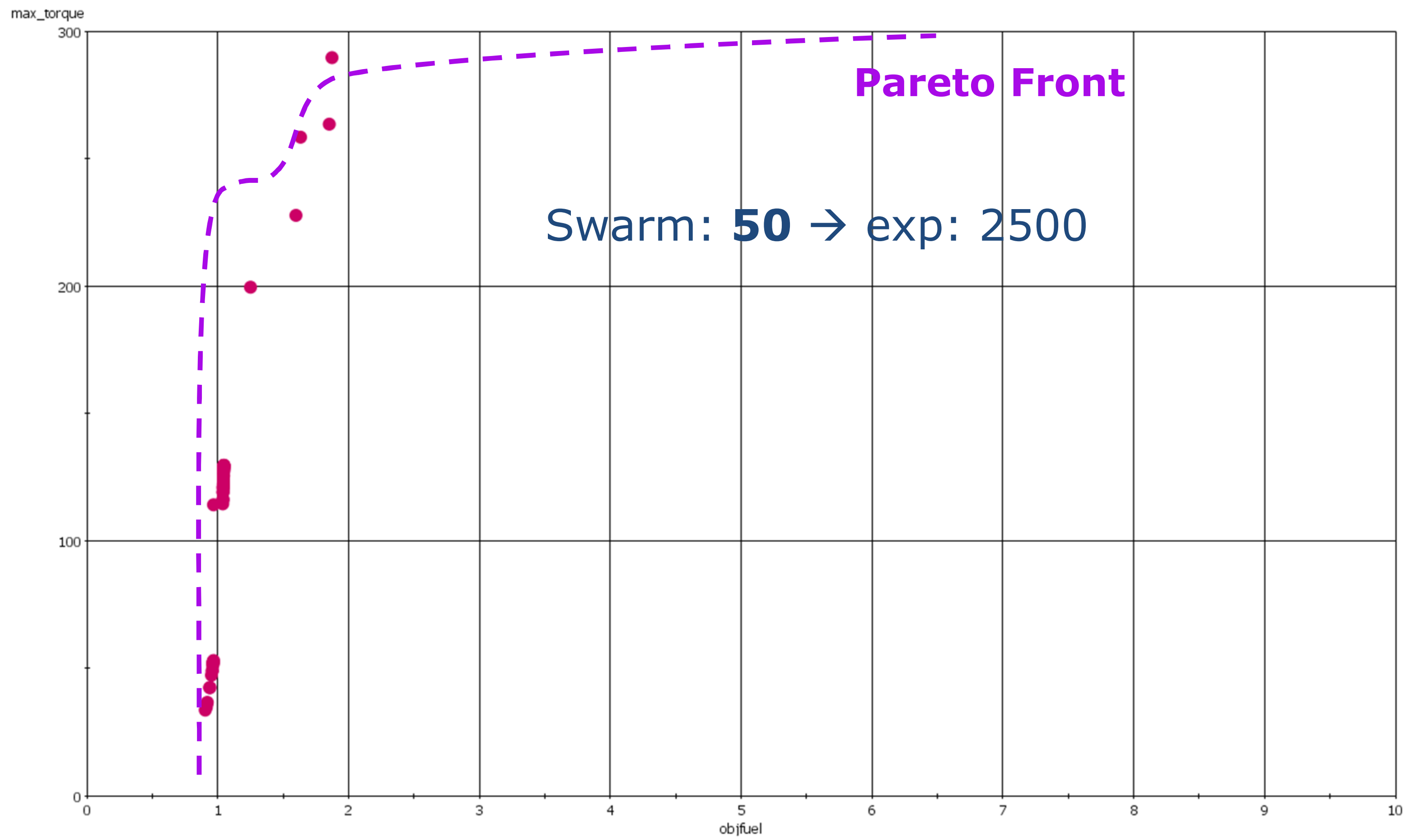
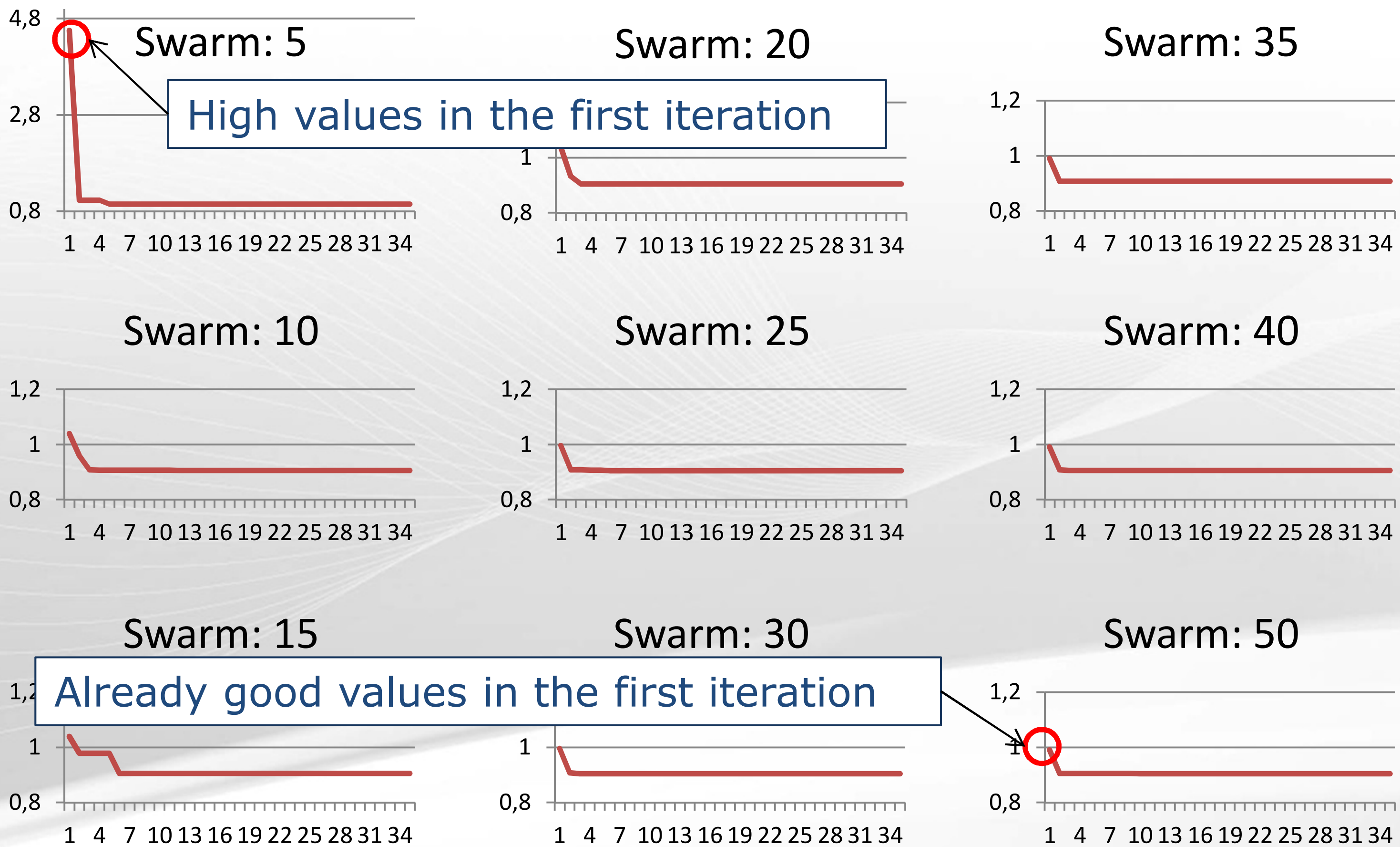
4. Optimization Strategy



4. Optimization Strategy

Best objfuel value



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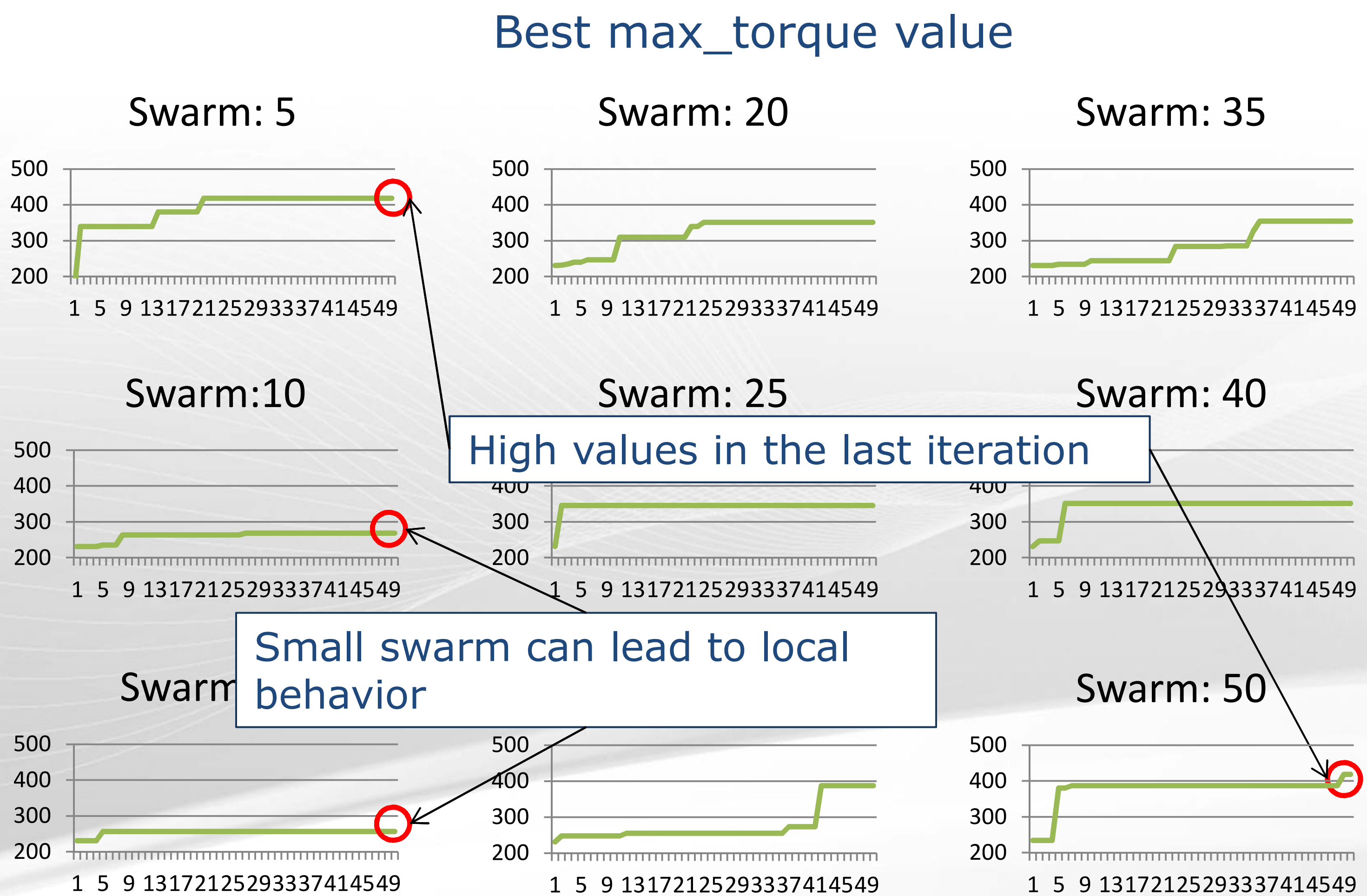
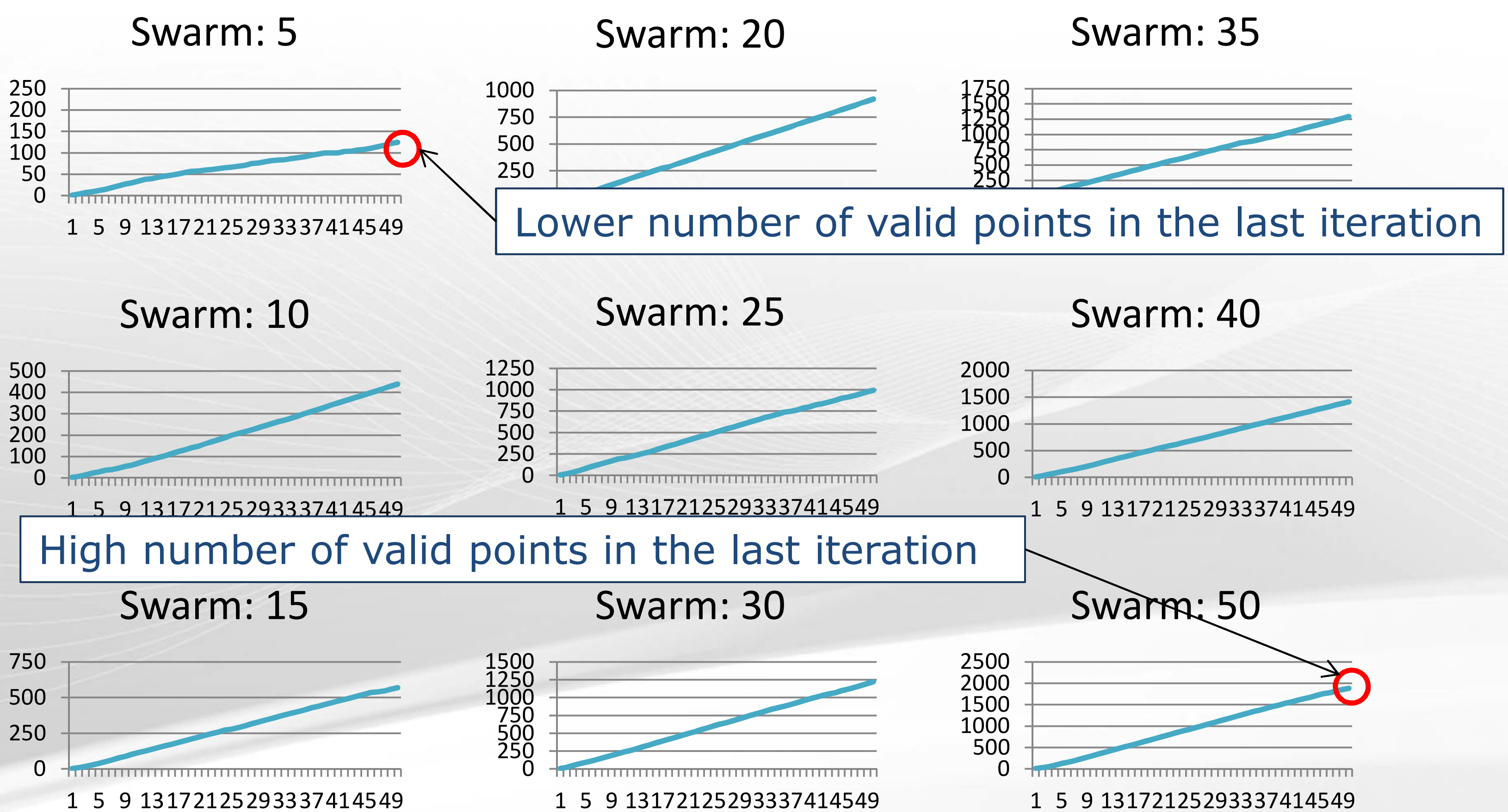


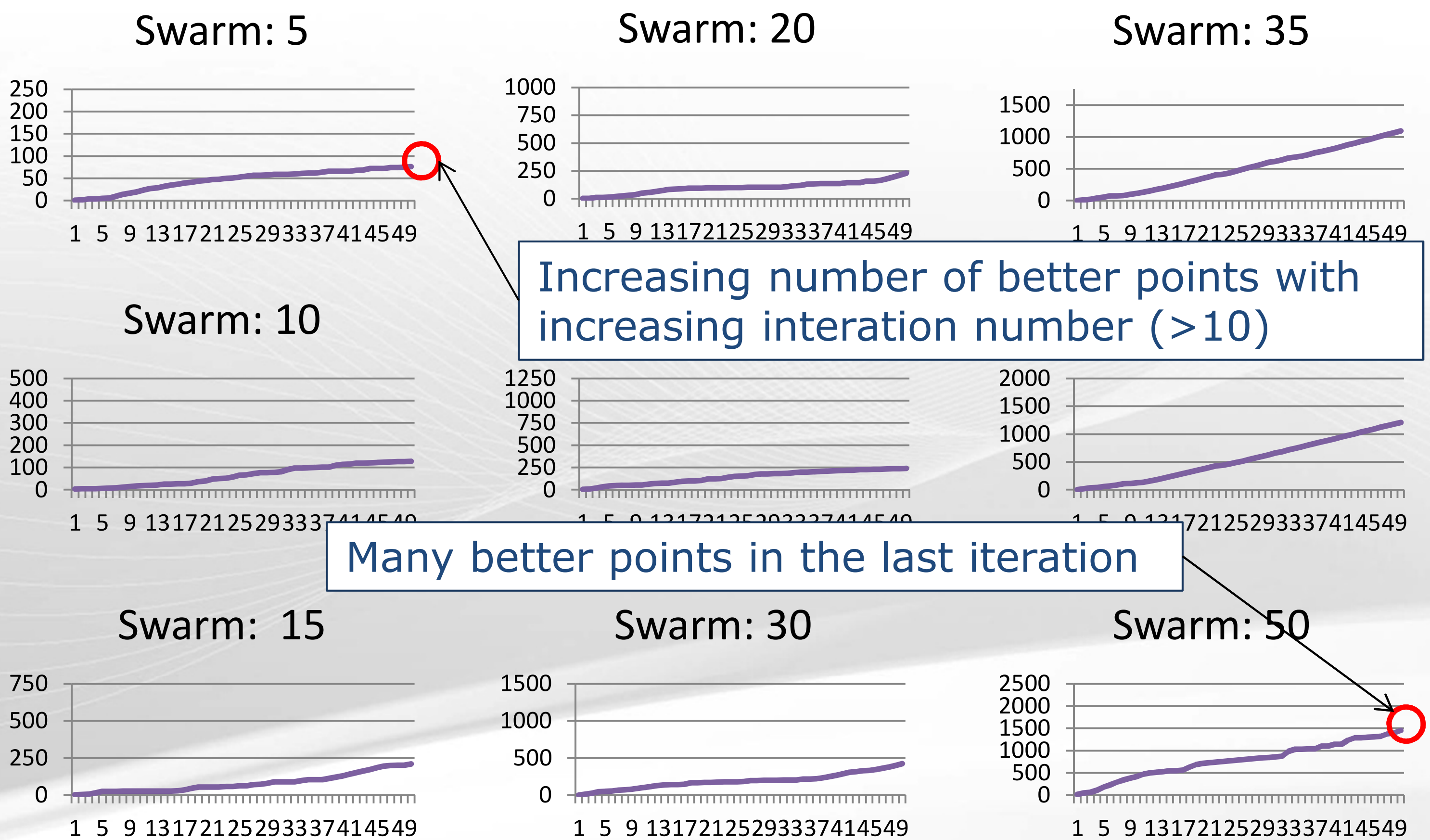
4. Optimization Strategy

valid points



4. Optimization Strategy

better points (compared to nominal)



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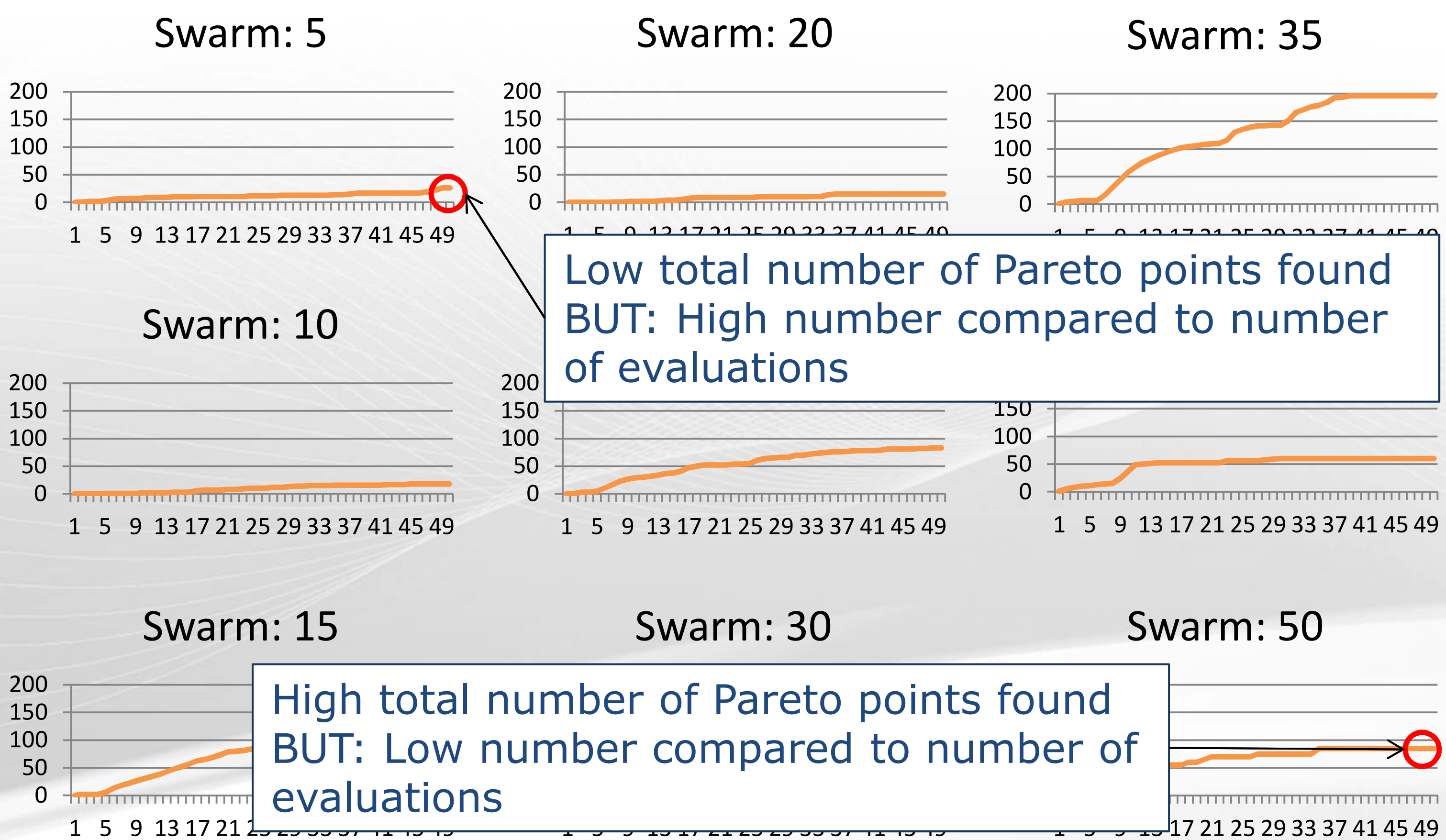
4. Optimization Strategy

Pareto points



Low total number of Pareto points found
BUT: High number compared to number of evaluations

High total number of Pareto points found
BUT: Low number compared to number of evaluations

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5. Conclusion and Results

- Optimus offers the user a lot of flexibility by allowing the selection of many options for the algorithm

→ For inexperienced users good default values are predefined

→ Advanced users have the possibility to change the settings to improve the optimization behavior

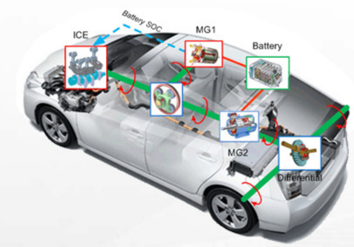
5. Conclusion and Results

- In case of expensive simulations or a small amount of time, the user can afford less evaluations than suggested

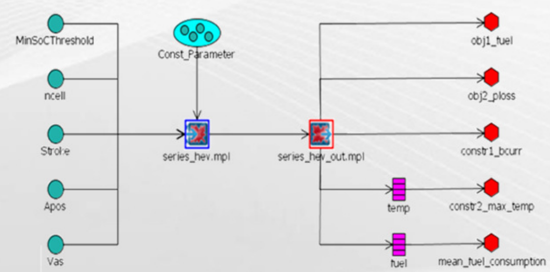
→ The user can decrease the swarm size and therefore perform more iterations

5. Conclusion and Results

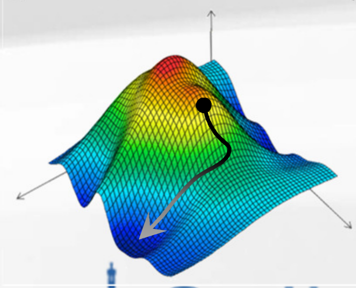
- ✓ Easy-to-use procedure to set up and handle a complex vehicle model in MapleSim



- ✓ Efficient automation possibility using OPTIMUS



- ✓ Application of advanced optimization algorithms without additional effort



QUESTIONS ? ? ?

Thank you for your attention

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