Blade Design at Siemens Wind Power

Experiences from Industrial Application of MDO

NREL Wind Energy Systems Engineering Workshop
January 30, 2013 • Broomfield, Colorado

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Agenda

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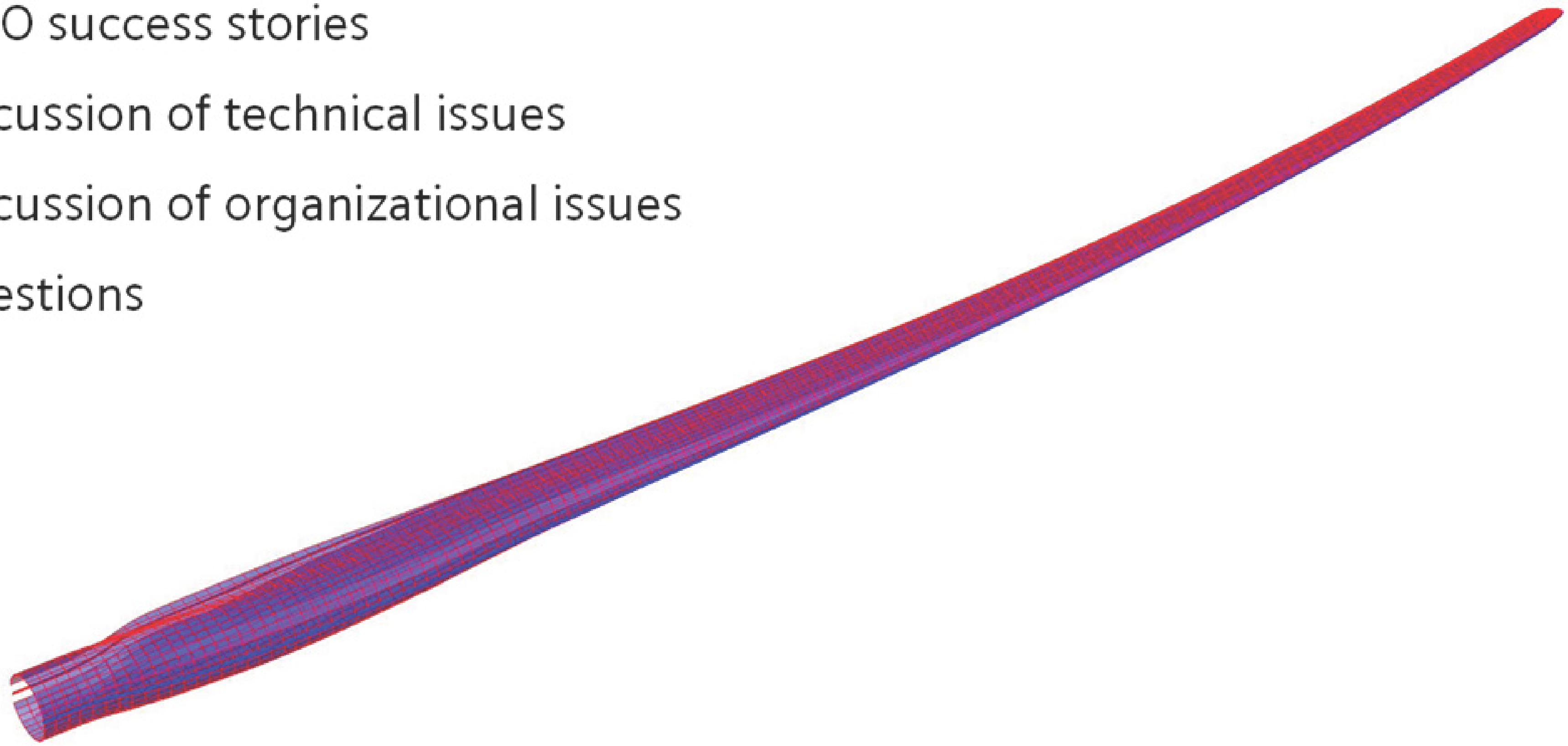
- Introduction – Siemens Wind Power
- Description of the MDO rotor design problem
- Optimization framework at SWP
- MDO success stories
- Discussion of technical issues
- Discussion of organizational issues
- Questions



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Market leader in offshore...

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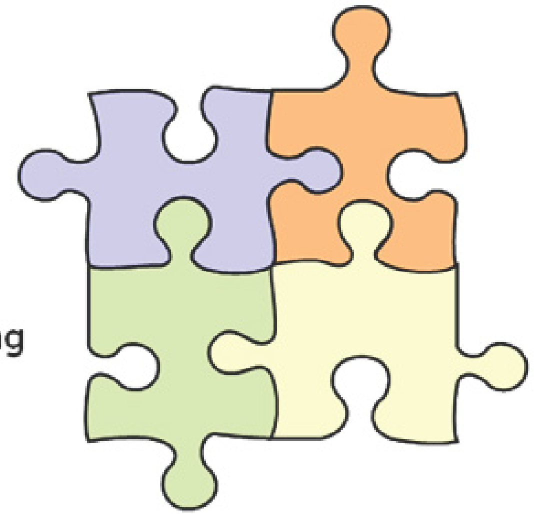
- admin
- BOM
- manufacturing



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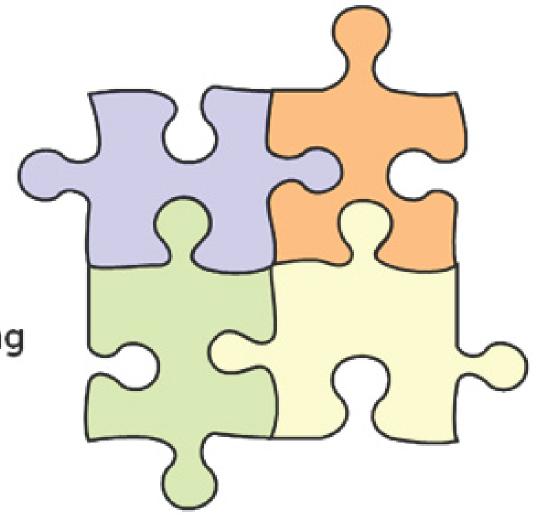

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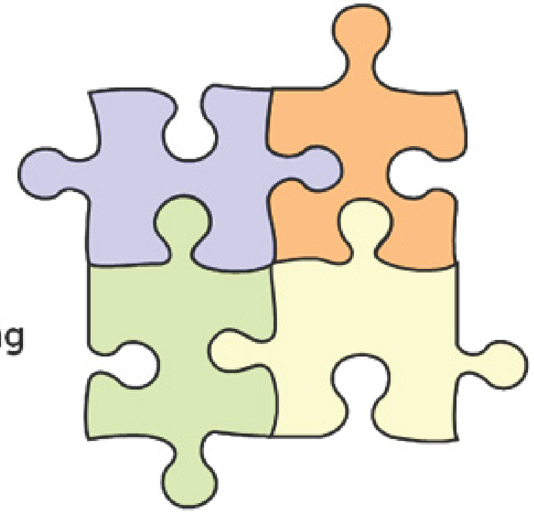

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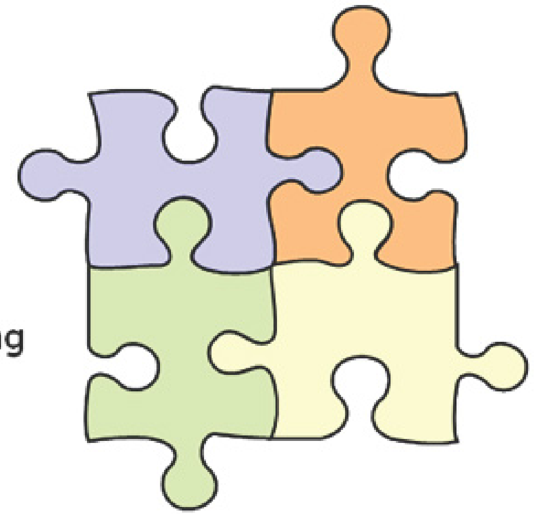

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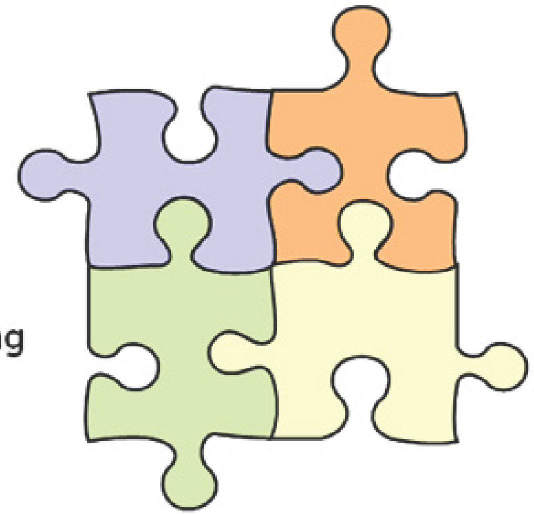

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- Cost model that combines various sub-discipline objectives may not be desirable – *many 'costs' cannot be estimated up-front i.e. organizational cost, market 'fit' etc.*
- Solve the problem using a multi-objective approach – *give decision-makers the data necessary to make trade-off choices directly including 'non-quantifiable' costs*

Multi-Disciplinary Rotor Design Optimization

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GA/EA Methods

Advantages

- Does not require objectives or constraints to be continuous, differentiable or single valued
- Model robustness threshold much lower
- Relatively insensitive to noisy functions
- Random element helps avoid local minima, also discovers new parts of the design space
- Well suited to multi-objective optimization and design for robustness

Disadvantages

- **High number of fn evaluations-** requires fast models, or many processors, preferably both.
- Large population needed for many DOFs or Objectives.
- Non-deterministic- slightly different results each time*
- Does not give exact optimum.

Gradient Based Methods

Advantages

- **Lower number of number of fn evaluations**
- Deterministic- exact optima
- Advanced methods for finding gradients >> even lower comp. cost
- Greater experience
- For feasible problems: guaranteed convergence.

Disadvantages

- Requires continuous and differentiable constraints and objectives
- Model robustness threshold is higher
- No guarantee of global optimum
- Not well suited to multi-objective optimization

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    - Genetic algorithms = best for exploration – "global"
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    - **Regardless of which method chosen – cycle time is key!**
    - For best results, keep human in the loop – not too fast nor too slow
    - More engineering iterations are always better – builds confidence/experience
    - Aim for 'human' scale cycle time ~ 1 day.

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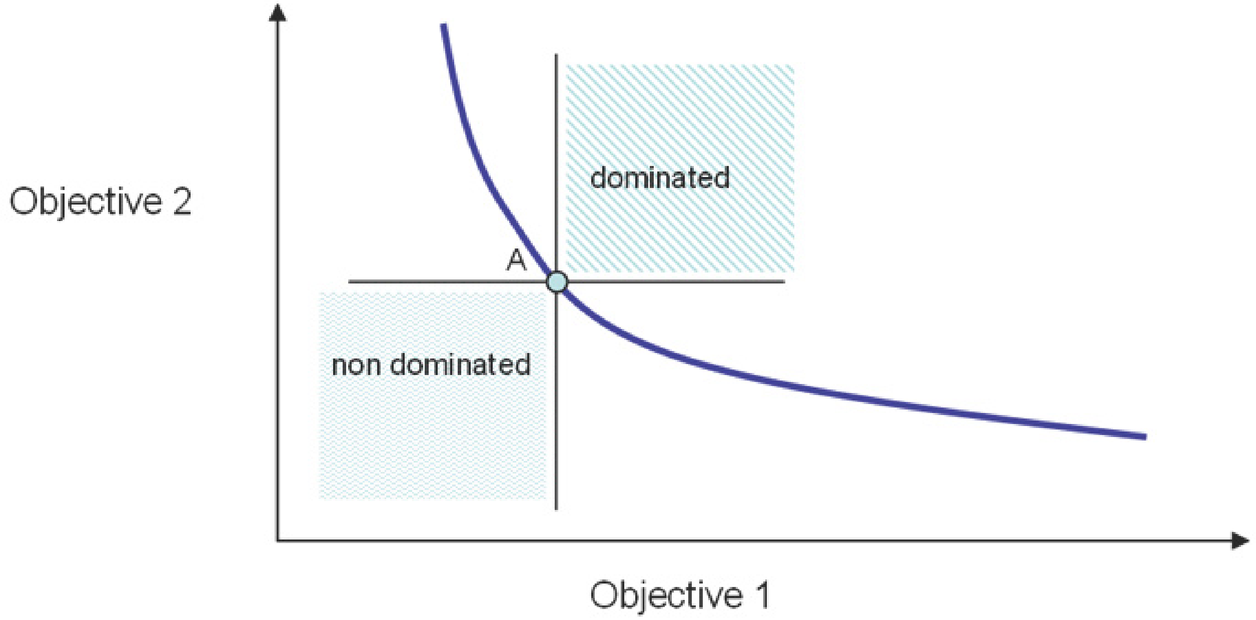
A Pareto front gives the possible trade-offs between objectives



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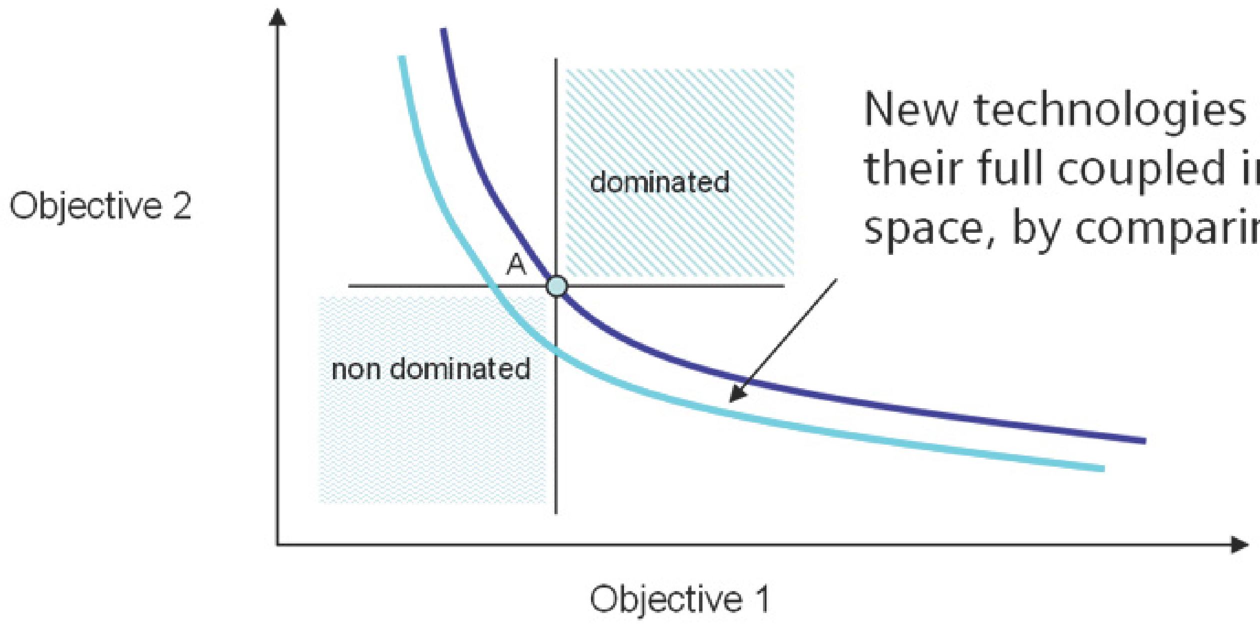

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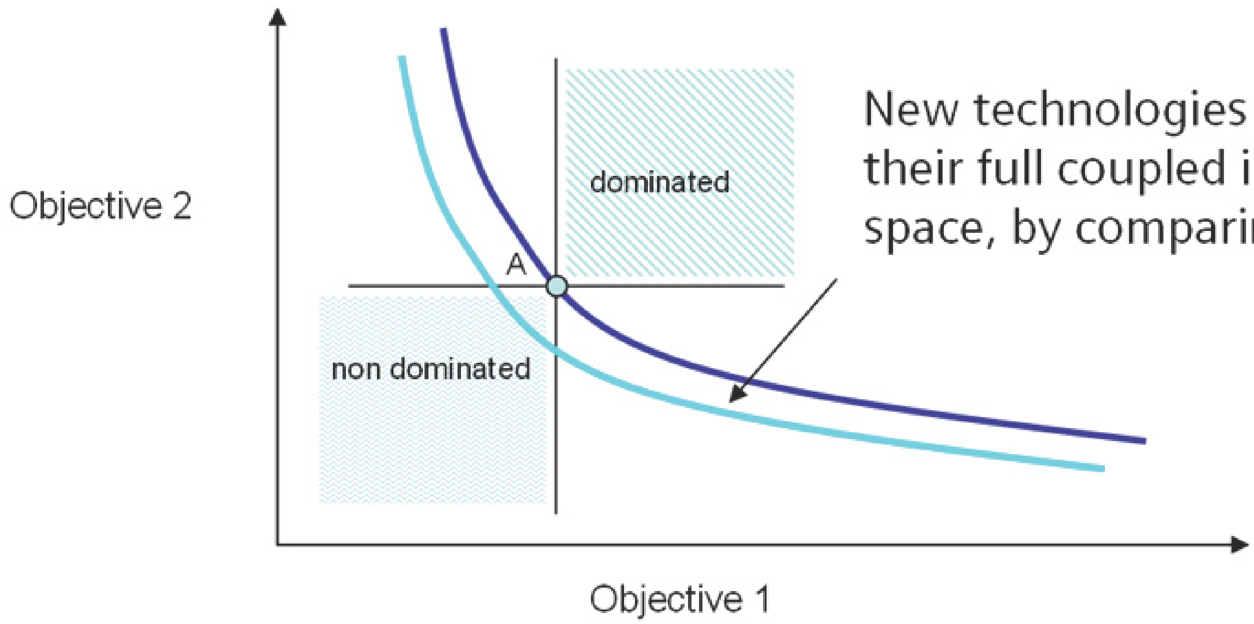

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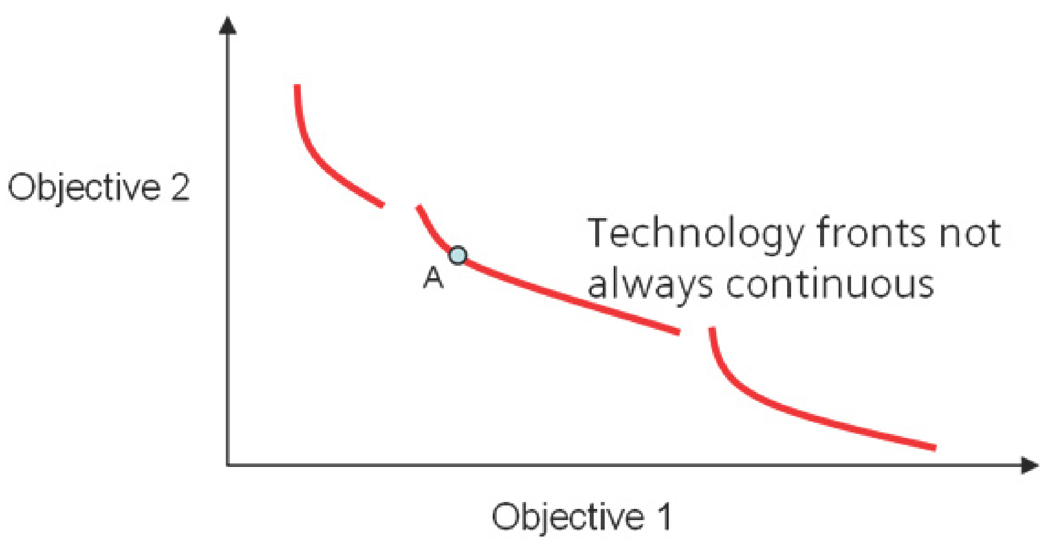

Technology fronts not always continuous

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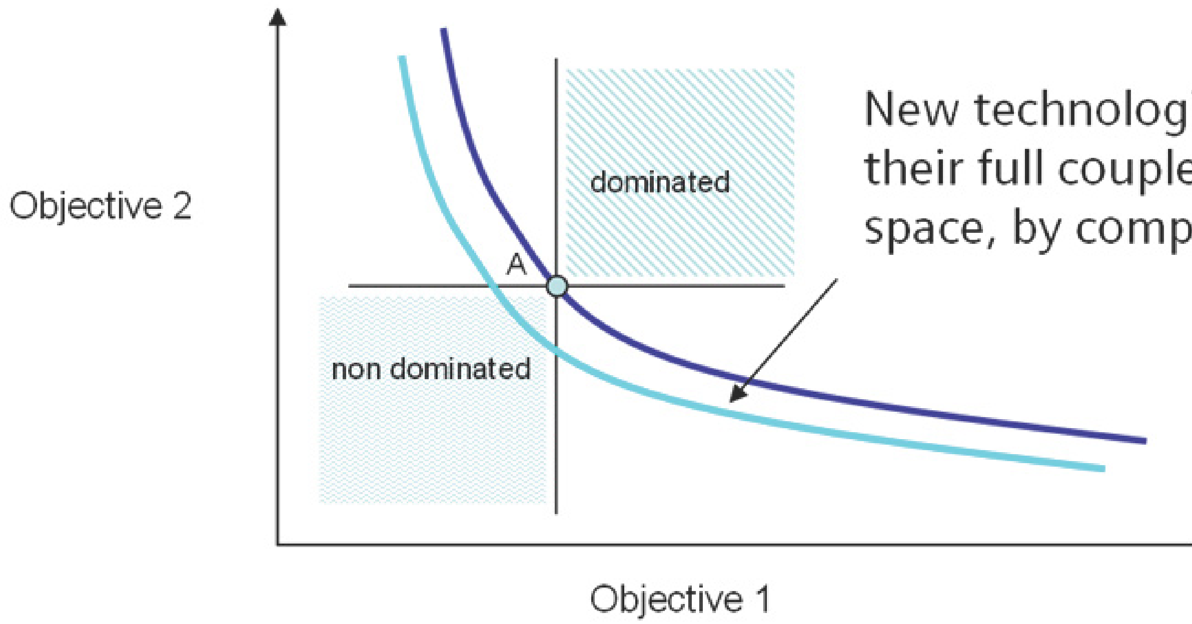

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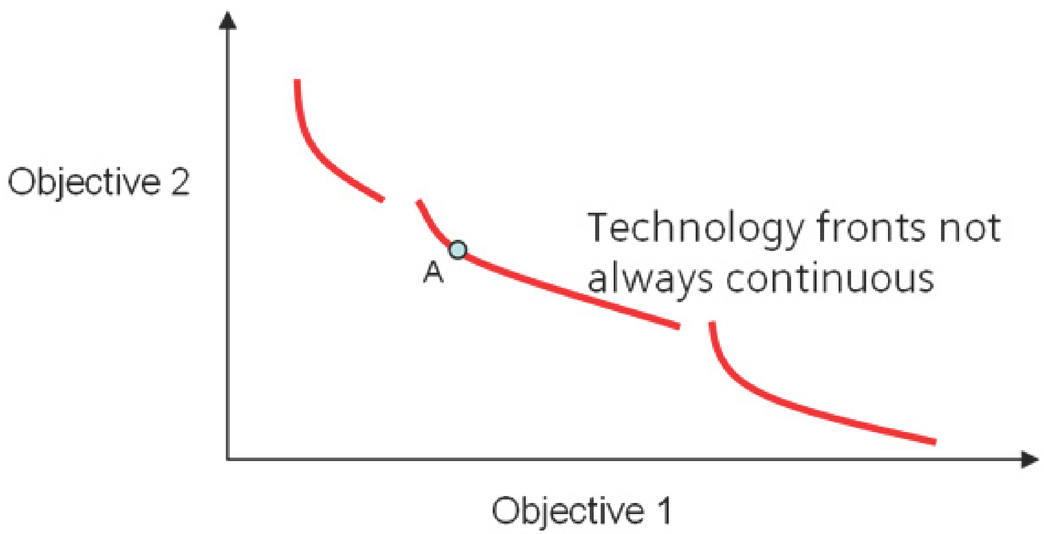

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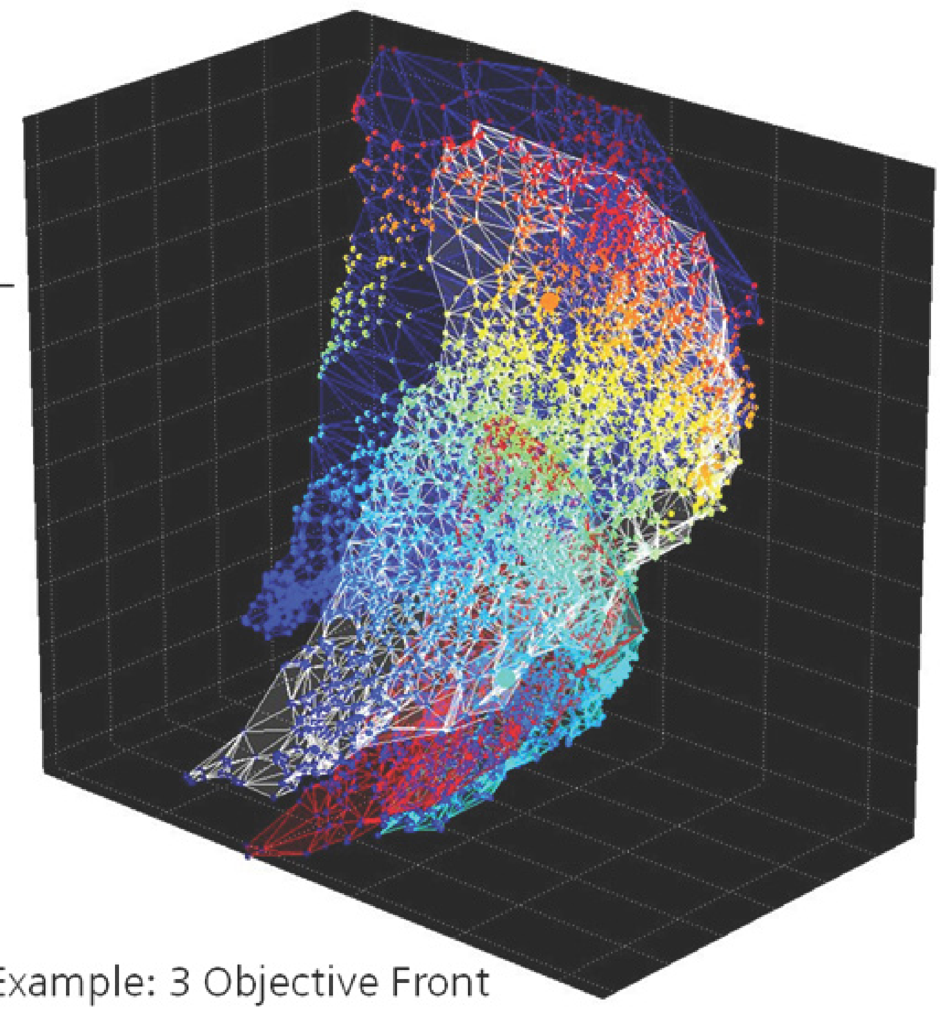

Example: 3 Objective Front

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Multi-objective rotor design problem w/ non-linear constraints:

- Performance
  - AEP
  - Capacity factor (some markets)
  - Robustness / soiling insensitivity
- Acoustics
  - ... complicated!
- Loads & Controls
  - Normal operation, emergency stop, fault conditions,
  - Blade loads- fatigue and extreme
  - Component loads- fatigue and extreme
- Blade Structure
  - Blade mass/cost
  - Fatigue strain / extreme loads, tip deflection constraint
  - Panel buckling, edge buckling
  - Manufacturing constraints
- Drive Train
  - Generator torque limit
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Simplify to ~3 objective problem, with the rest being constraints- for example, find Pareto front in terms of:

1. **AEP**
2. **Loads Analog**
3. **Blade Mass**

Many ways to setup the problem, nesting etc.

More objectives possible, but for every additional objective, computational cost **x10**.

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Multi-objective design problem DOFs:

- Platform Characteristics (sometimes fixed, sometimes not...)
  - Blade length, rated power, max RPM, tower height, wind class, coning, shaft tilt, generator torque etc., allowable acoustic emission
- Blade Planform
  - Chord, relative thickness, twist, sweep shape, pre-deflection
- Airfoil Selection
  - Design lift, soiling insensitivity, Re performance, vortex generator placement etc...
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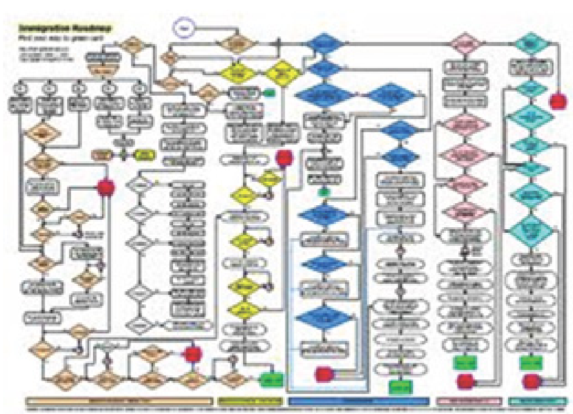

actual green card process

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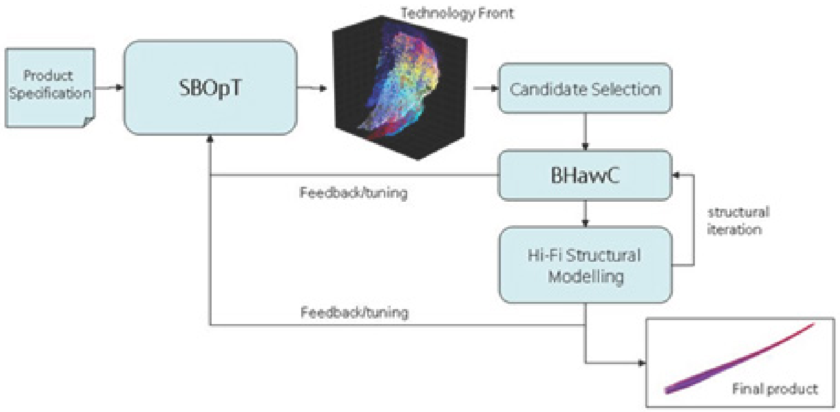
- Simplify; smart parameterization
- Use nested optimization
- Remove weak system couplings where possible.
- Explore design space using low cost models, before using hi-fidelity solvers.



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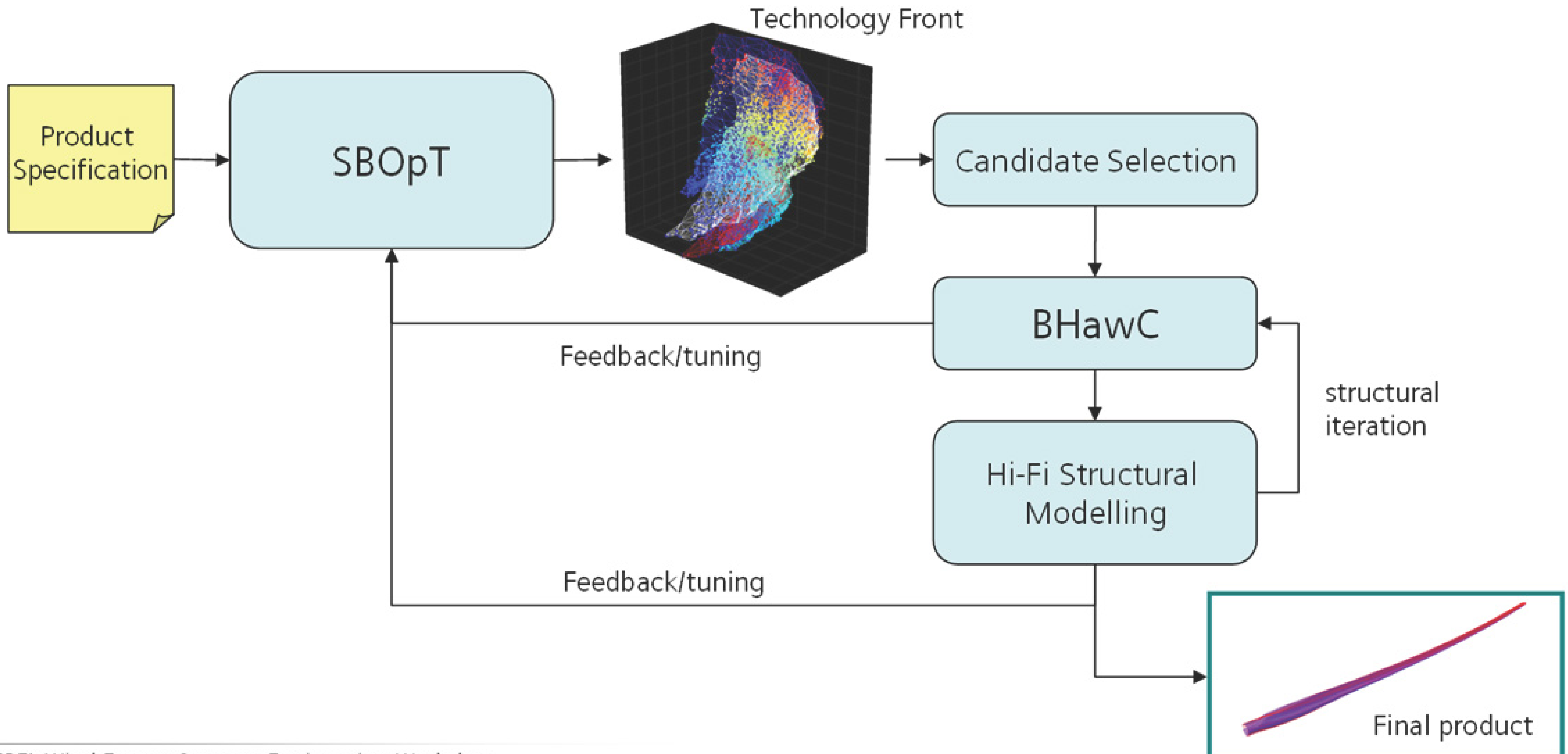
Siemens Blade Optimization Tool (SBOpT)

- Evaluates 100,000+ blades in an evening within GA setup and HPC cluster, produces N-dimensional Pareto front between various design objectives.

BHawC

- High fidelity FEM code for aero-elastic simulation of entire turbine system.



MDO Success Stories

- SWT-6.0-154
  World's largest operational turbine
- SWT-2.3-108
- SWT-3.0-108
- SWT-4.0-130

Technical Challenges

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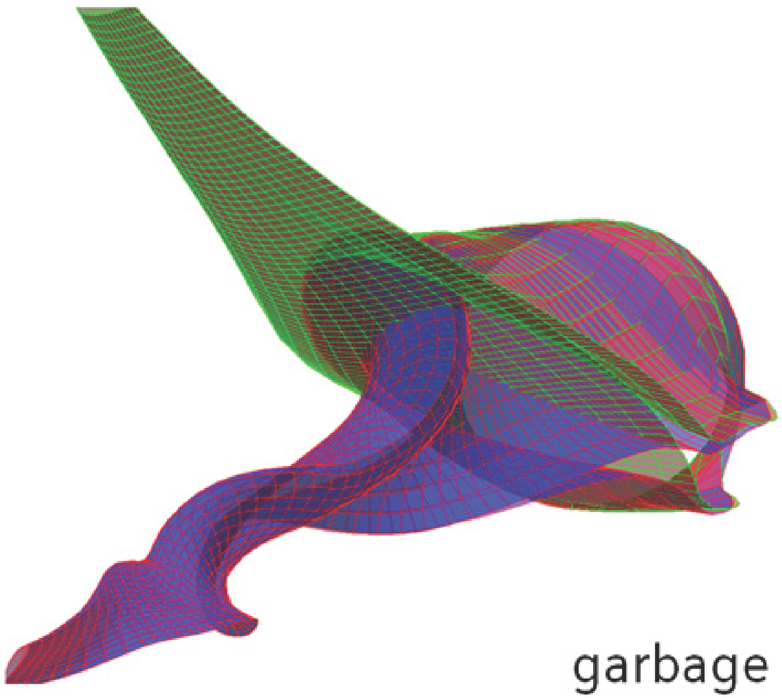

garbage in, garbage out.

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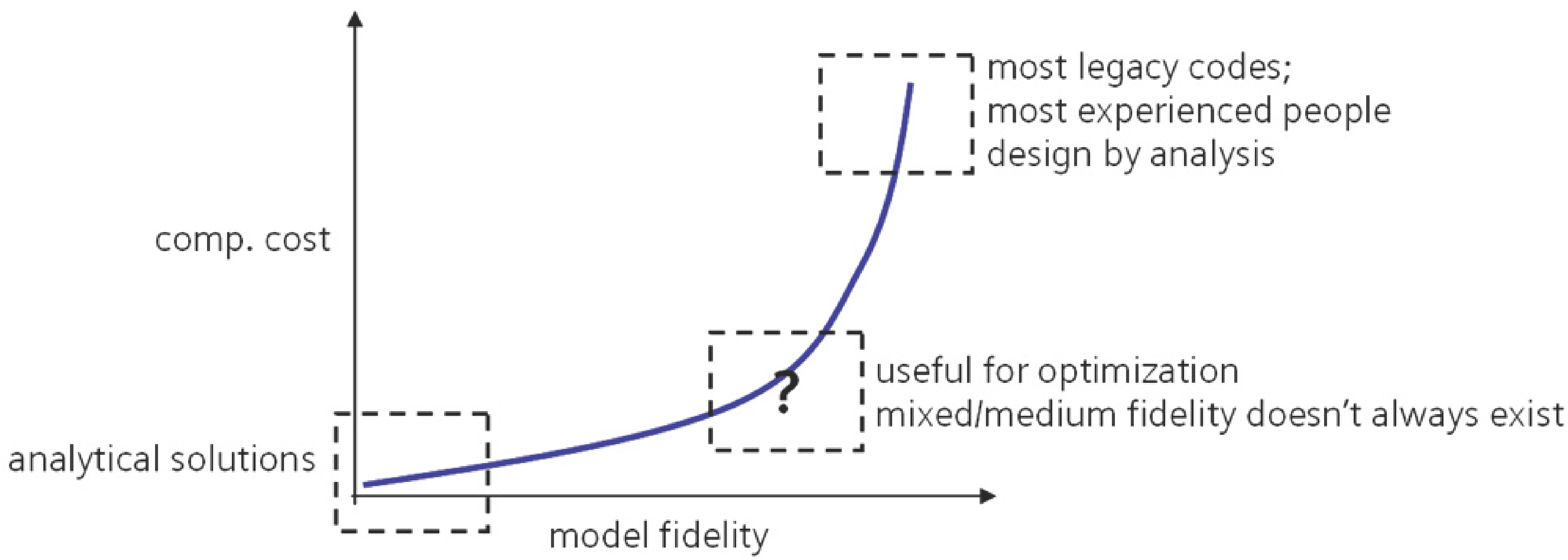

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- Software architecture – working with legacy codes that were not designed with optimization in mind.

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- IT/software challenges often are not fully appreciated. The higher the fidelity used, the more this issue is magnified.

Thanks for your attention - Questions?

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