GridWorld™

Realizing Grid Computing as Engineering System for Collaborative Parameter Study

October 5, 2005

Takehiko Kato

(tak@engineous.com)

Engineous Japan, Inc.

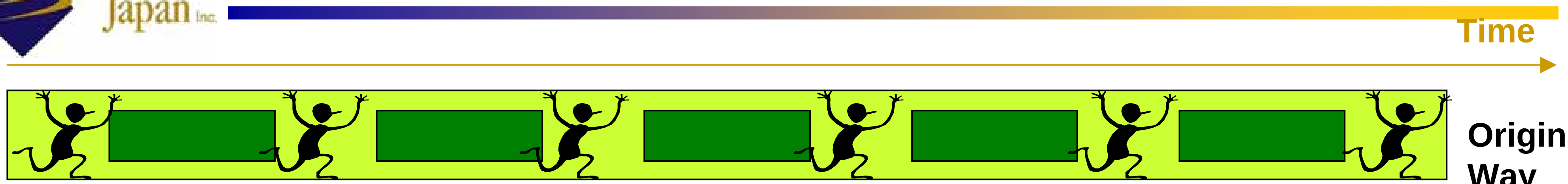
Engineous Japan Inc.

Engineous Software, Inc. ?

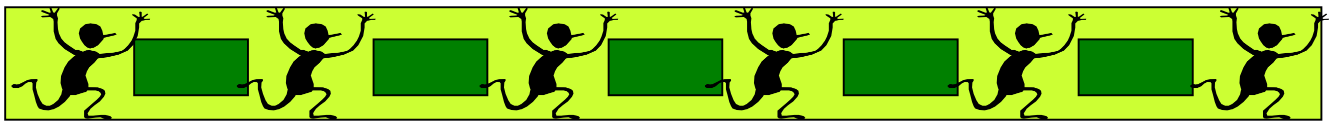
- *Company established in 1996 spun off from "Engineous Project" of General Electric,*
- *Technology "Software Robot" evolved since 1983 at MIT and GE/CRD*
- *Leading CAO System Supplier (Nearly 300 Customers)*
- *Engineous develops sells and maintains Software Robot System iSIGHT for Design Integration/Automation/Optimization/QEM and FIPER for Design Process Collaboration*
- *Headquarter in Cary, North Carolina.*
- *Offices outside of the US*
  - **Engineous Japan, Inc. (Japan)**
  - **Enginrous Korea, Ltd. (Korea)**
  - **Sightna, Inc. (China)**
  - **Engineous Software, GmbH (Germany)**
  - **Engineous Software Ltd. (UK)**
  - **iSIGHT Software SARL (France)**

CAO: Computer Aided Optimization/Collaborative Automation and Optimization

Software Robot System

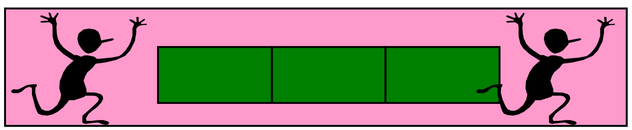


Original Way



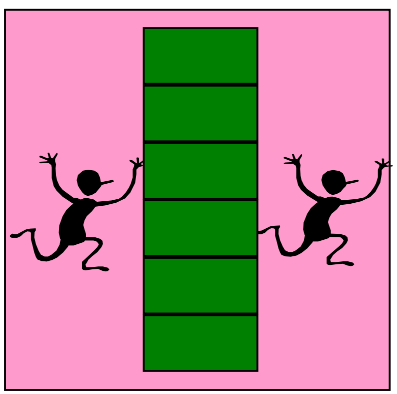
Traditional Improvement

(1) Hardware Performance
(2) Program Tuning



Applying Software Robot

(1) Automation
(2) Integration
(3) Input/Output Data Management
(4) Process Optimization



Software Robot: Parallel Processing

Data Preparation, Results Analysis, Parameter Change

Traditional Trial&Error Engineering Process

Engineering Process with Software Robot

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Six Sigma Success Stories at GE

Nuclear Fuel Reactor
$1.2M Cost Savings

Transformer
$900K Annual Savings

Nuclear Satellite Reactor
140 Kg Lighter >$14M

Aero/Mech Blade Design
2 Staff Years to 6 Weeks

DC Motor
3 Weeks to 1 Hour

Power Supply Circuit
2 Weeks to 10 Hours

Steam Turbine
1 Staff Year to 4 Weeks

Propeller Design
8 Weeks to 3 Weeks

Aircraft Engine Turbine
10 Weeks to 1 Week
GE90: Saved $250K/Engine

Halogen Lamps
60%Energy Cost Saving
Whiter Light, Brighter Color
Longer Life Cycle

X10
Improvement
by
Engineous

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Large Scale Parallel Computing in Engineering

- To be Closer to Physical Phenomenon & Experimental Results
  - Improving Computational Accuracy by High Fidelity Discrete Modeling

    Crash Analysis: 10K Elements (1985) -> 1M Elements (2005)

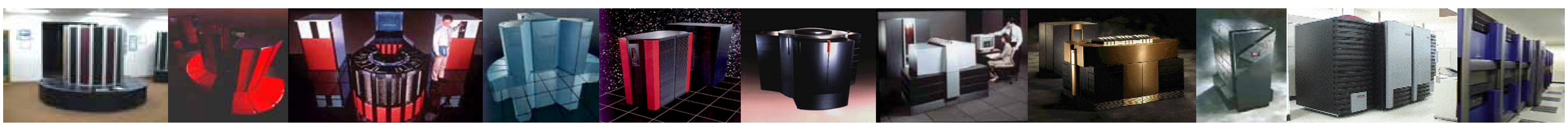
    Structure Analysis (NVH): 65K DOF (1990) -> 10M DOF (2005)

    CFD Analysis : 10M Mesh (1990) -> 1B Mesh (2005)

  - Accuracy Improvement, High-Speed, Parallel Processing of Numerical Integration and Matrix Solvers
  - Parallel Processing of Discrete Models by Domain Decomposition
  - More Precise Convergence Scheme with More Number of Iterations

Solving One Large Model with Higher Accuracy in Shorter or Specific Time

--- Re-trying Modified Models if Objectives/Targets are not Achieved



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Key Subjects in Industries

SPEED: Cycle Reduction in Research/Development/Design/Manufacturing

--- Time to Market

COST: Cost Reduction in Research/Development/Materials/ Manufacturing/Resource/Logistics/Maintenance

--- Operation Efficiency, Competitiveness

QUALITY：Improvement in Quality/Functionality/ Performance/Safety

--- Customer Satisfaction, SPEED、COST

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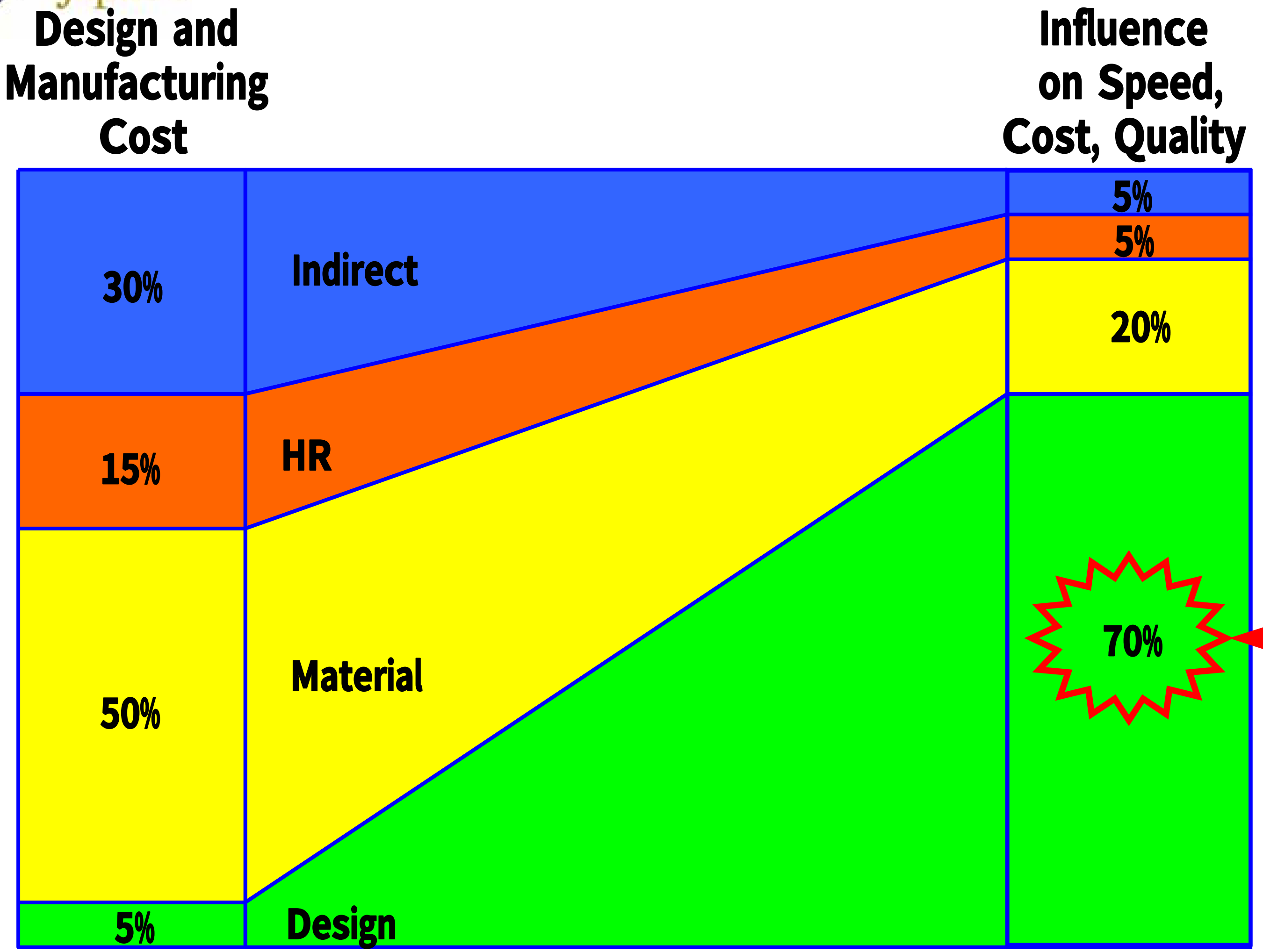
Why Design Process Improvement?



Leveraging to
reduce cost,
cycle time,
and time-to-market
AND improve quality

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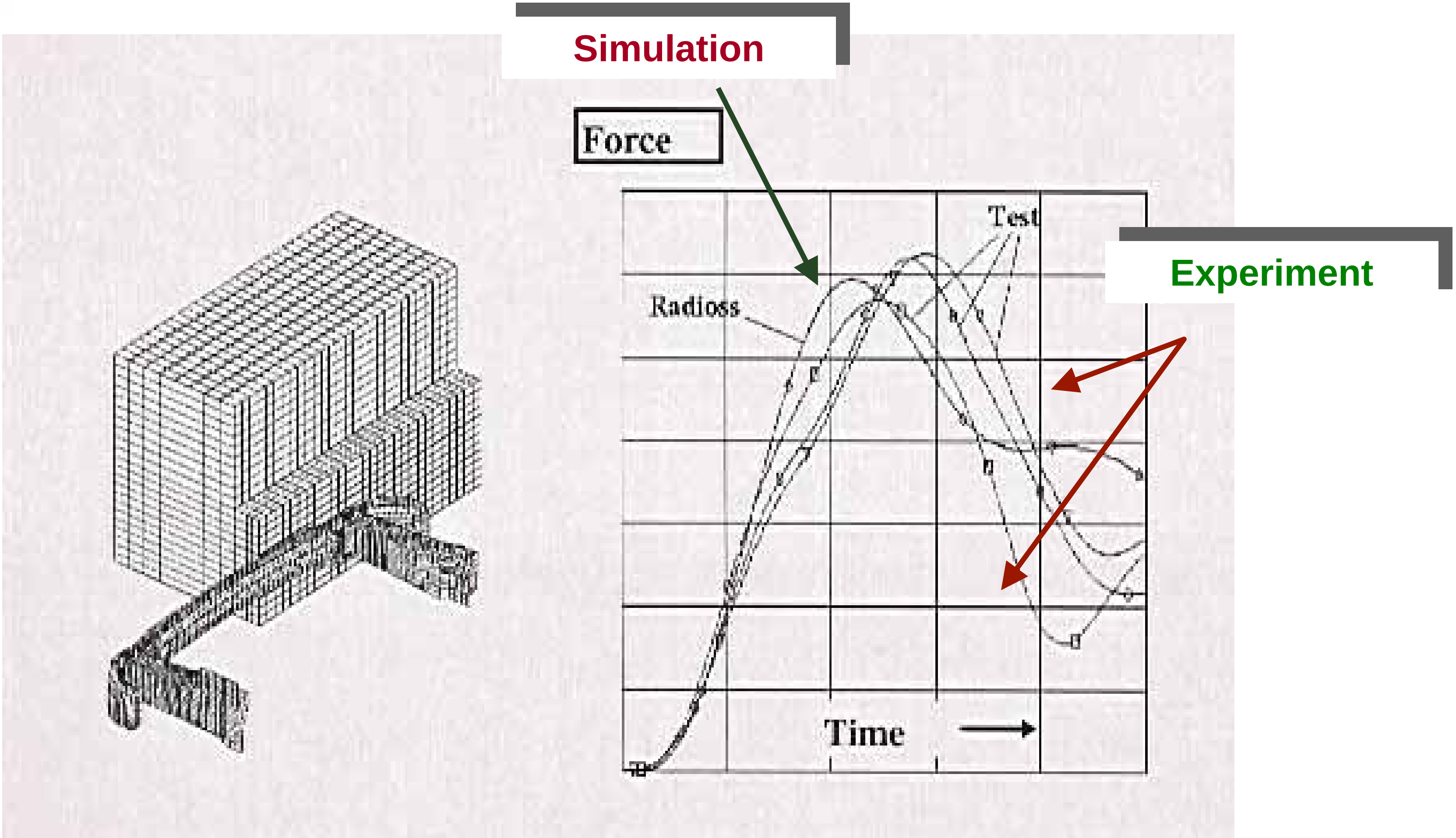
Obstacles in Advanced CAE Process

- Too Many Design Variables
- Influence of Each Design Variables are Unknown
- Trade-off Trends between Multiple Responses are Unknown
- No Time to Verify Possibility of better Design despite there might be
- Time is Consumed for Inter-Group adjustment for Target or Design Changes
- No Match with Experimental Results
- All the Software and Hardware Resources are Distributed on Global Network
  - Multiple Architectures and Operating Systems
  - Multiple Operational Environments ---Know-how can not be shared
  - Not Effective Use of All Computing Resources
  - Many Software Tools are Independently Existing
  - Very Low Connectivity and Interoperability among the products even from Same Vendors
  - Manual based Connection and Execution of Tools
  - Manual based Communication and Data Exchange
- Not Easy to Apply PC-Clusters and UNIX Servers by Efficient Manner
- Grid Computing?????

Experimental Results & Simulation Result



Barrier Model vs. Barrier Force

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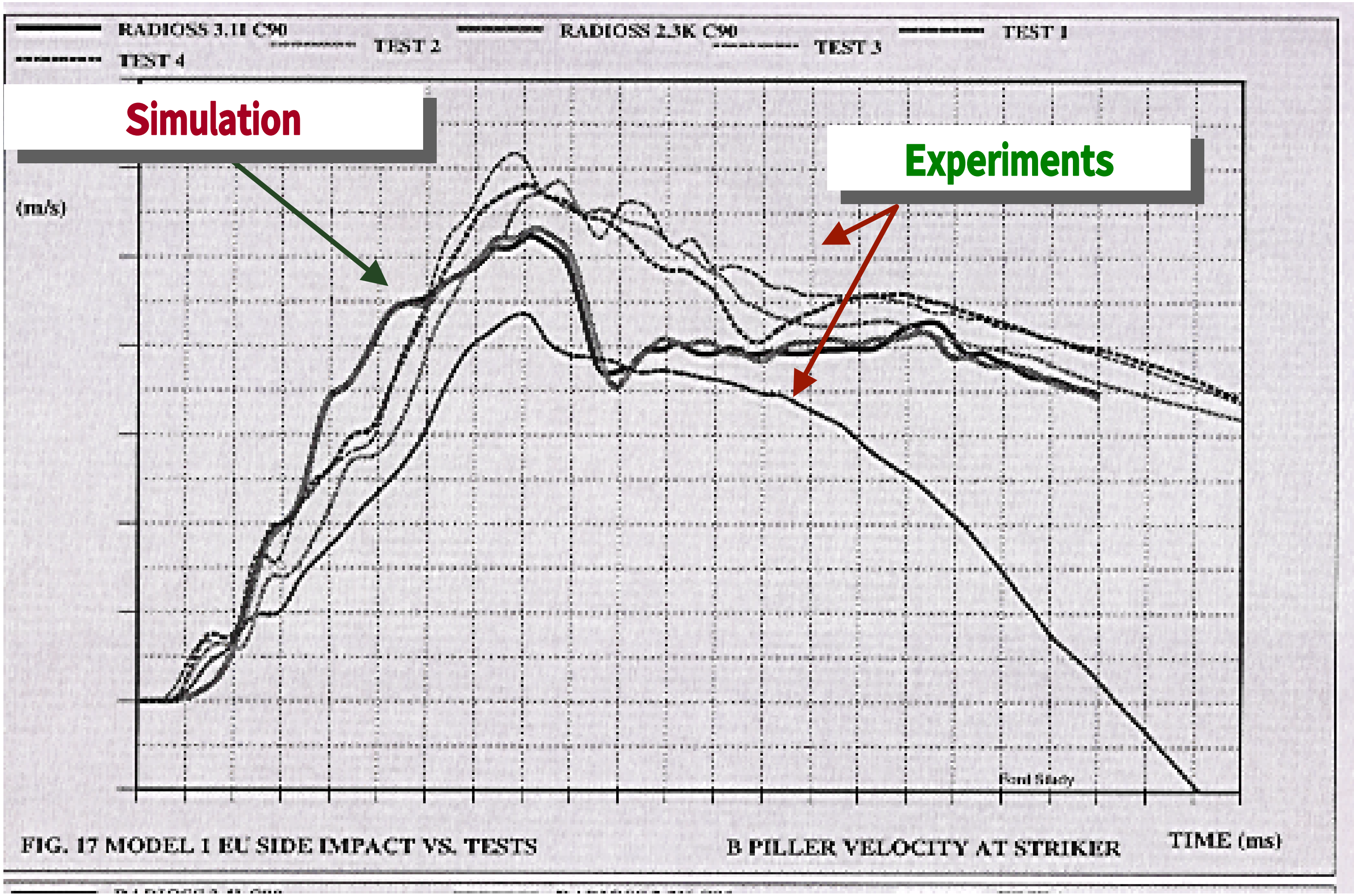
Experimental Results & Simulation Result



B-Pillar Velocity in Side-Impact

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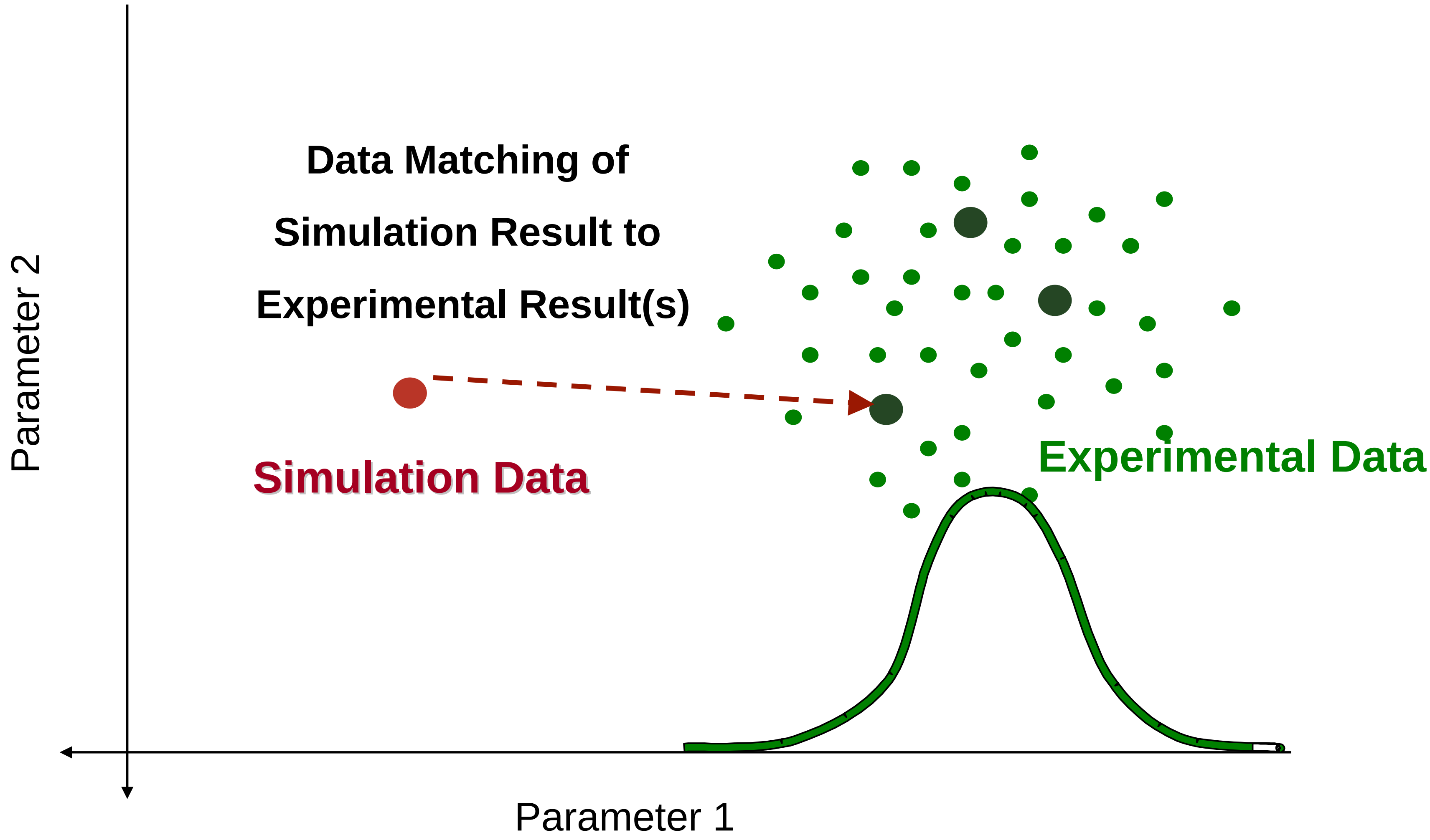
Sources of Variability = Uncertainty

- **Manufacturing related**
  - Forming processes
  - Machining processes
  - Assembly processes
- **Material related**
  - Material properties
  - Thickness
- **Test conditions**
  - Environments
  - Initial Conditions
  - Loading Conditions
  - Boundary Conditions
- **Human Factors**
  - Beginner or Expeienced
  - Careless Mistake

- **Constitutive Models**
  (Governing Equations)
- **Shape Definition**
  (CAD Representation)
- **Modeling Techniques**
  (Discretization – FEM, FDM, BEM)
- **Material Models**
- **Numerical Algorithms**
  (Integration, Matrix Solving)
- **Computer Architecture**
  (64bit, 32bit, Numerical Libraries)

Experiments vs. Simulations



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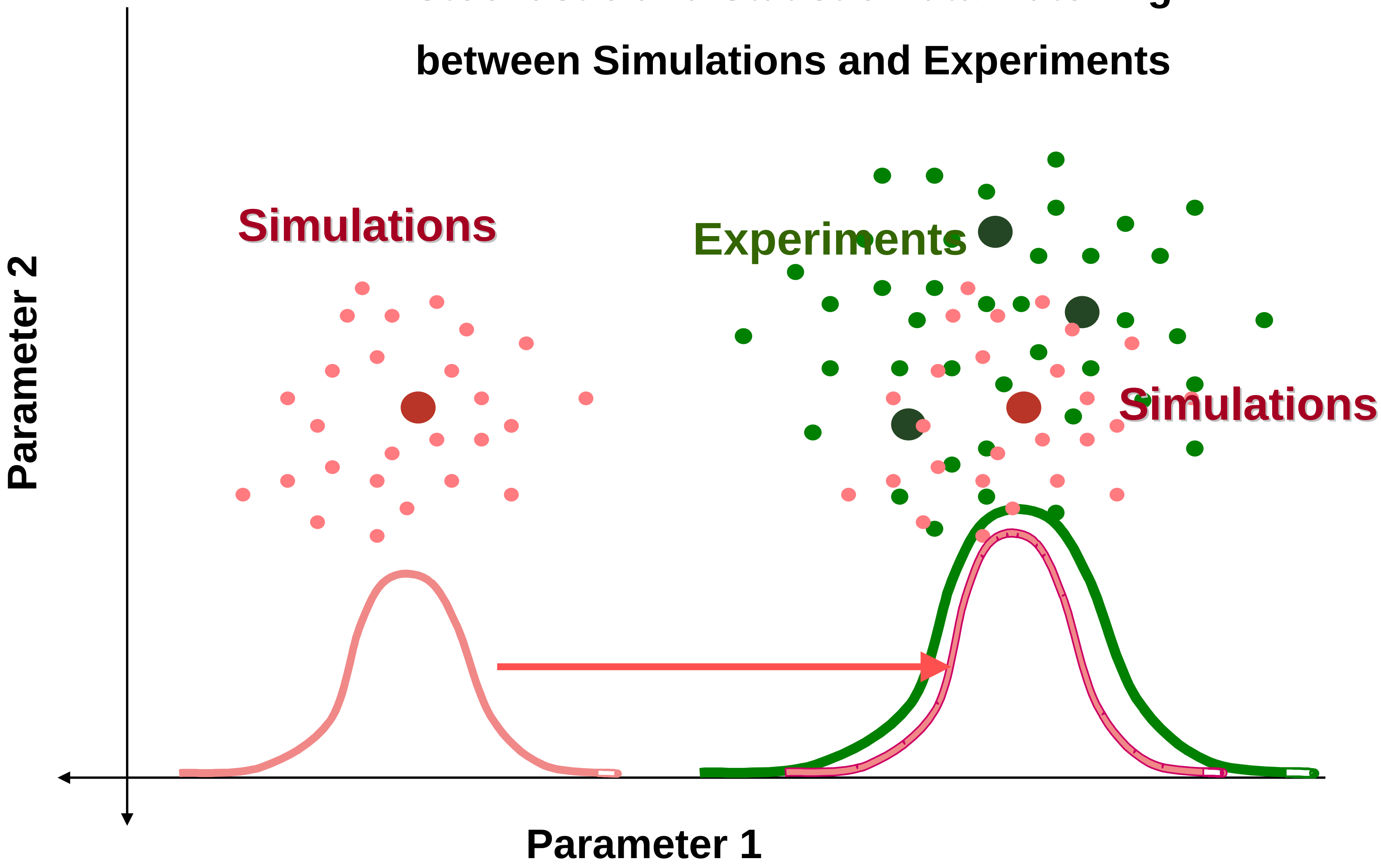
Experiments vs. Simulations

Stochastic and Statistic Data Matching

between Simulations and Experiments



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If You have 100 X More Powerful Computers?

- **If you are Scientists/Researchers:**

  → Solving 100 Times Higher Fidelity Problems
  - Solving Problems which could not be solved before
  - Chasing Problem Size and Preciseness of Numerical Models

- **If you are CAE Engineers:**

  → Solving 10 Times Higher Fidelity Problems by 10 Iterations
  - Improving Accuracy by increasing number of mesh (x 10)
  - Comparing multiple cases for Improving Design (x 10)

- **If you are Design Engineers:**

  → Solving 100 Cases as Parameter Study
  - Statistical Analysis
  - Trade-off Analysis
  - Robust Design

Physical Phenomena are all Stochastic! Why not on Computer Simulations?

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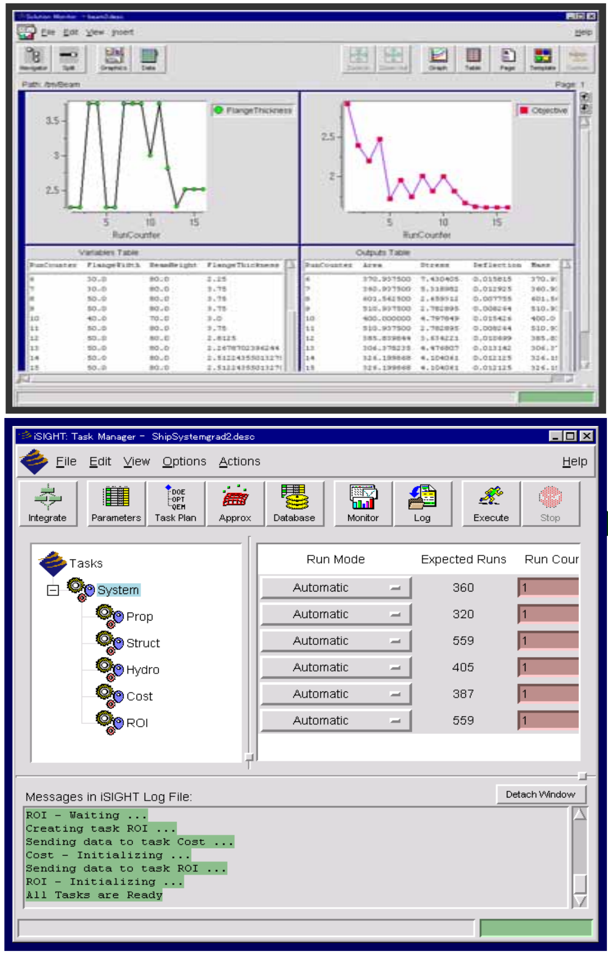
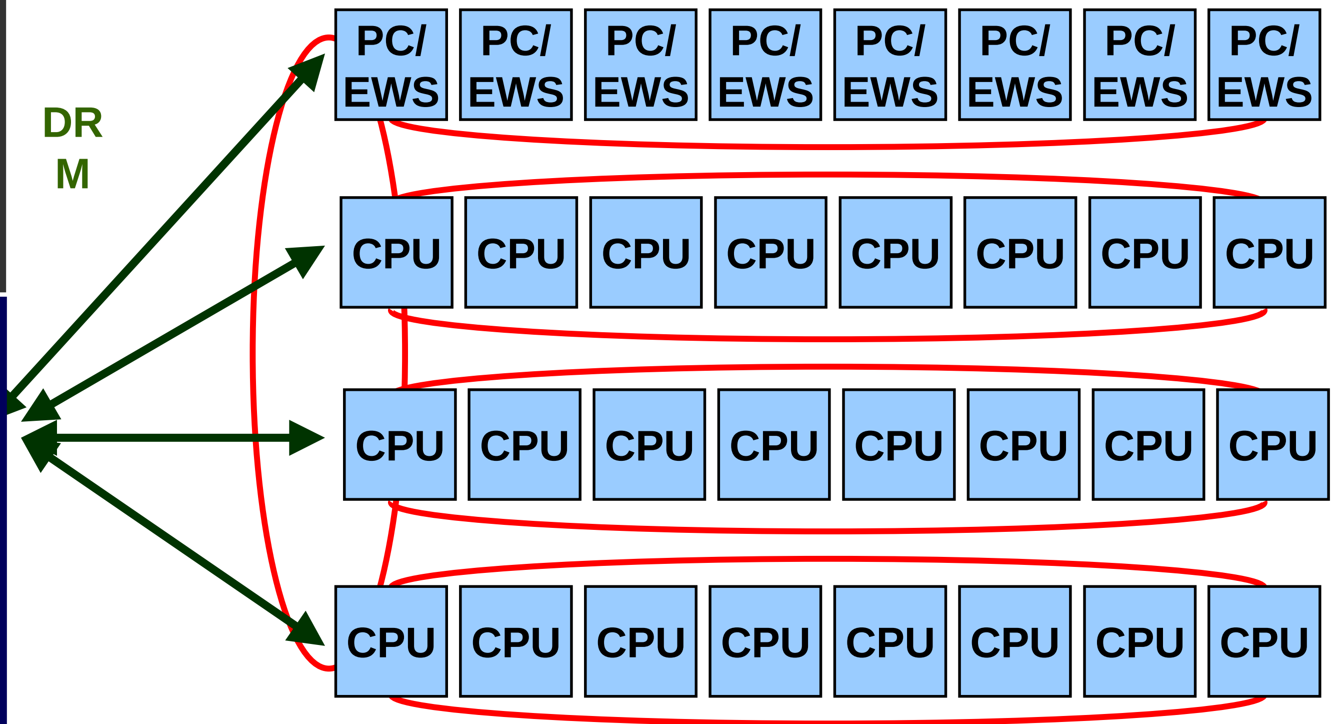
Parameter Studies by Parallel Distributed Computing System

- Automatic Execution of Tasks
- Load Balancing and Resource Management
- Automatic Gathering of Computed Results
- Automatic Statistic Analysis

Parallel Task Submission





Heterogeneous HPC Network (Supercomputers, Servers, Clusters, Grids)

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Parallel System as Parameter Study Engine

- Effective Use of Large Scale Parallel Processing Systems
  - Performance Improvement of Single Processor
  - Limitation in Parallelization, Granularity and Scalability
  - Bottleneck in Data Transfer between Distributed Memories
- Ways to Improve System Efficiency
  - From Deterministic Simulation to Stochastic/Statistical Simulations
  - Effective Combination of Parallelism of Single Job and Parallel Parameter Study
  - Automatic Data Exploration
    - Simultaneous Parallel Executions of Multiple Parametric Samplings
    - Combination of Multiple Sampling and Exploration Methods suitable to Problem Characteristic
- Grid Computing
  - Automatic Data Gathering and Statistic Analysis from Just Job Execution

From Verification of Design by Singe Large Scale Model Execution

Toward Clarification of Uncertain Elements by Parameter Study

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Parameter Variation - Terminology

- **Random Variable:**
  - Input design parameter that will fluctuate about it nominal, mean value, perhaps following a probability distribution
    - ***Pure Random Variable*** – fixed nominal / mean + variation

      Example: Material Properties (Young's Modulus, density)
    - ***Random Design Variable*** – nominal / mean value is design variable, variation around that nominal / mean

      Example: Material Thicknesses
- **Performance Variation:**
  - Fluctuation in performance (output) parameters due to random variable variation
- **Design Quality:**
  - Ensuring, to a specific probability, designs will not fail
  - Reducing, controlling performance variation

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Parallel Processing Parameter Studies

- GA(Genetic Algorithm) (1000 Parallel)
  - All the process in Single Generation
- MonteCarlo Method (100 to 10000 Parallel)
  - Number of Sampling Points
- DOE (Design of Experiments) (10 to 1000 Parallel)
  - Number of Sampling Points based on DOE formulation
- Taguchi Method (8 to 1000 Parallel)
  - Number of Sampling Points based on Orthogonal Arrays
- Sensitivity Different Analysis (10 – 1000 Parallel)
  - Number of Design Variables
- Approximation Methods (10 –1000 Parallel)
  - Sampling Calculations for RSM or Taylor Approximations

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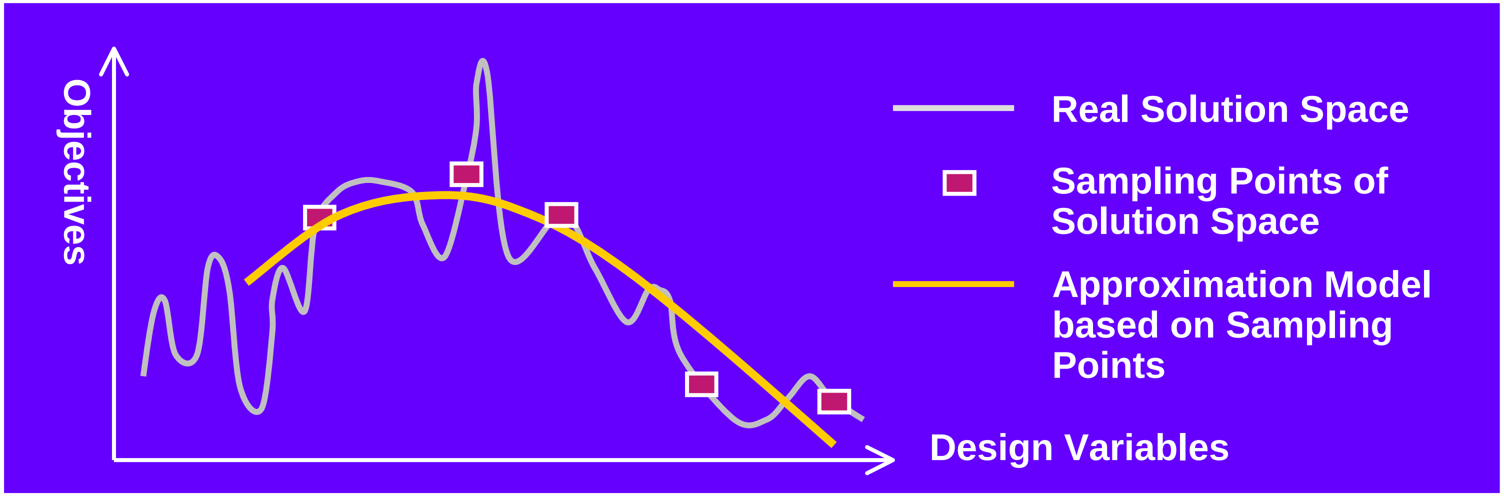
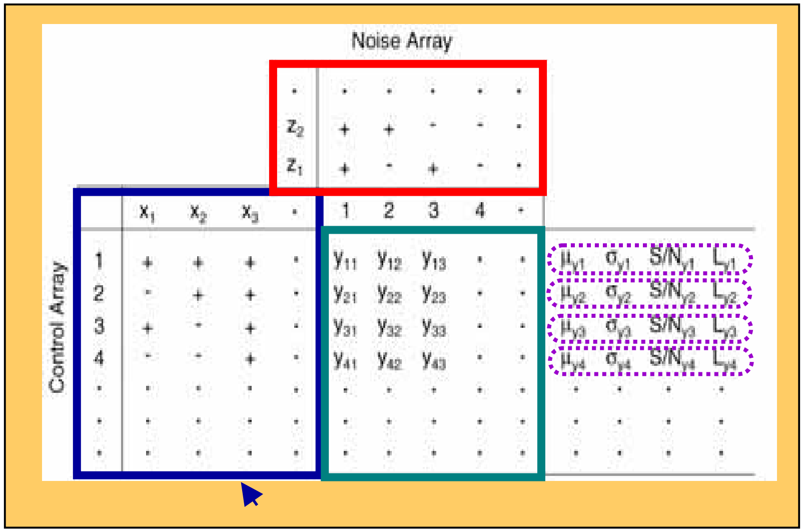
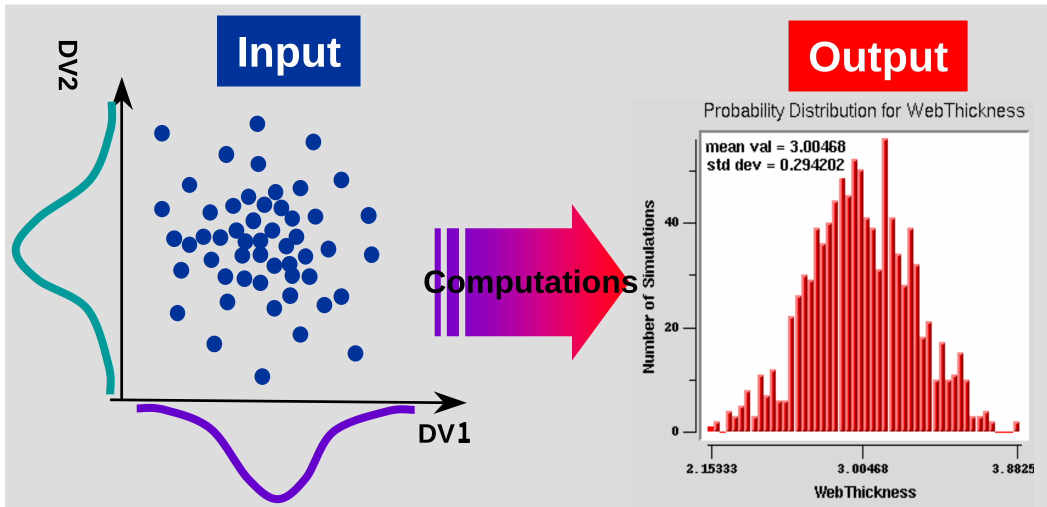
Sampling Methods

Sampling for Approximations





Taguchi Method Sampling



MonteCarlo Sampling

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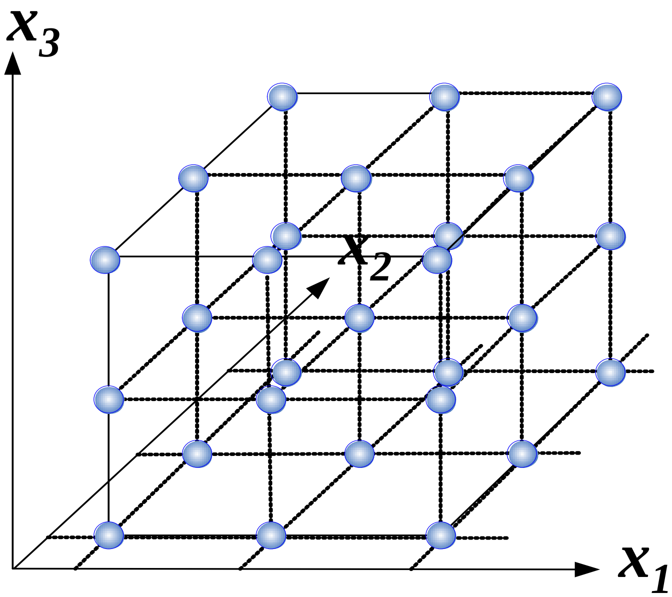
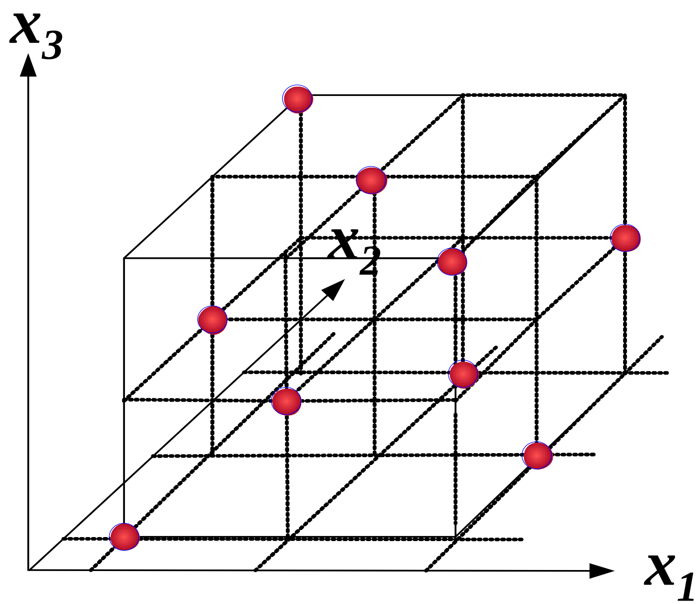
Design of Experiment

- Define a designed sampling around a baseline design examined
- Two to four factor levels are used typically, though it can have more levels
- Each levels is separated equally (Equal interval)
- Better for small size sampling, but needs preliminary information about the object system



Three level full factorial design



Three level orthogonal design (L9)

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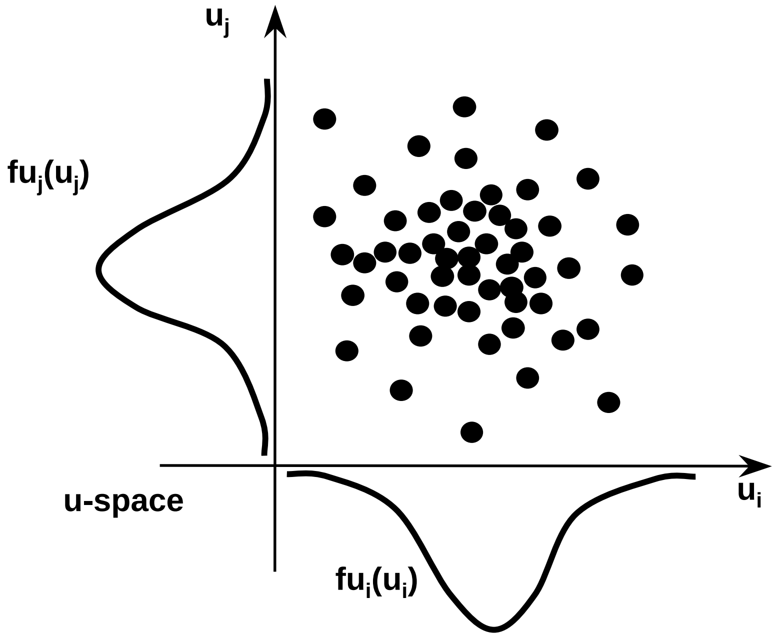
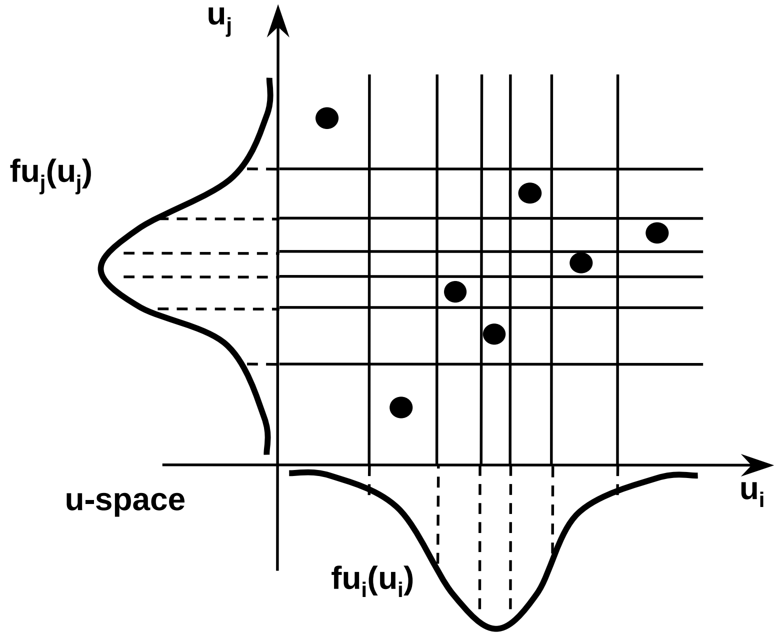
Monte Carlo Sampling Techniques

- Large number of sampling points often required
- Use of “variance reduction technique” can lead to reduced points

Standard MCS:
Simple Random Sampling



Variance Reduction Technique:
Descriptive Sampling



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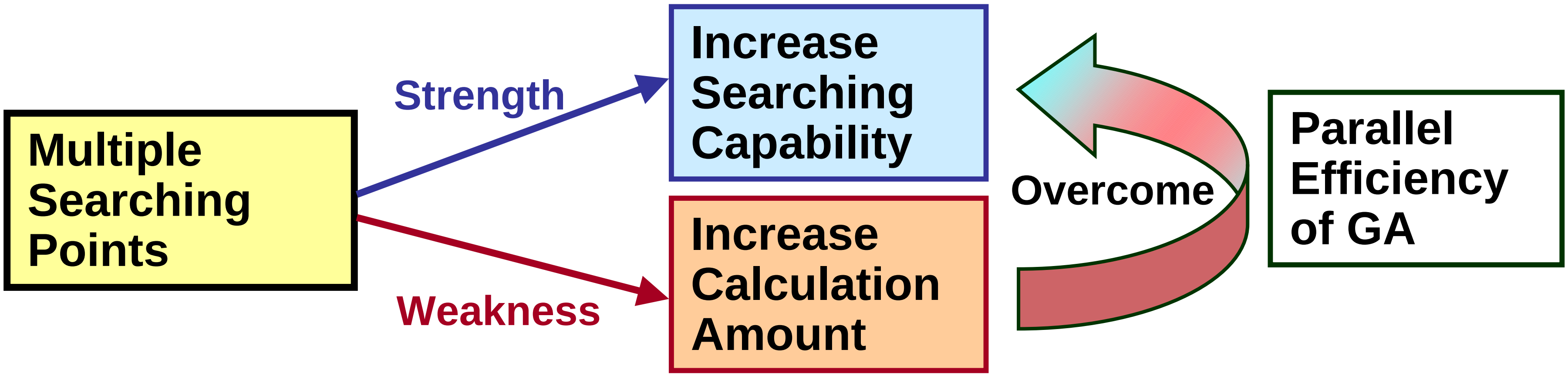
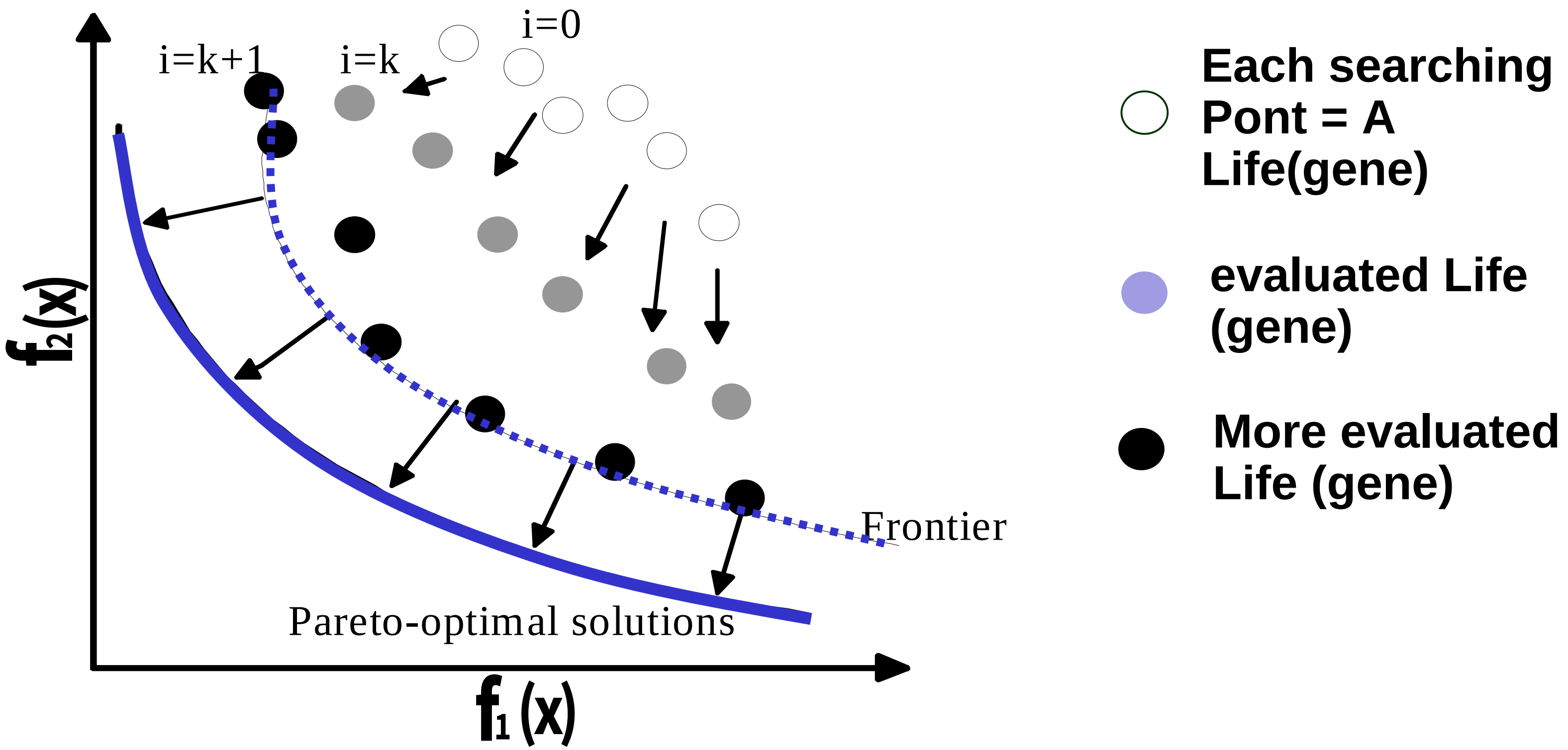
Multi-Objective Genetic Algorithm

- How to get the Pareto curve
  - One Approach: Genetic Algorithm
- Genetic Algorithm:
  - Stochastic search algorithm based on evolution mechanism of life(genes)
  - Multiple search points move solution space independently and simultaneously.
  - Needs numbers of calculations

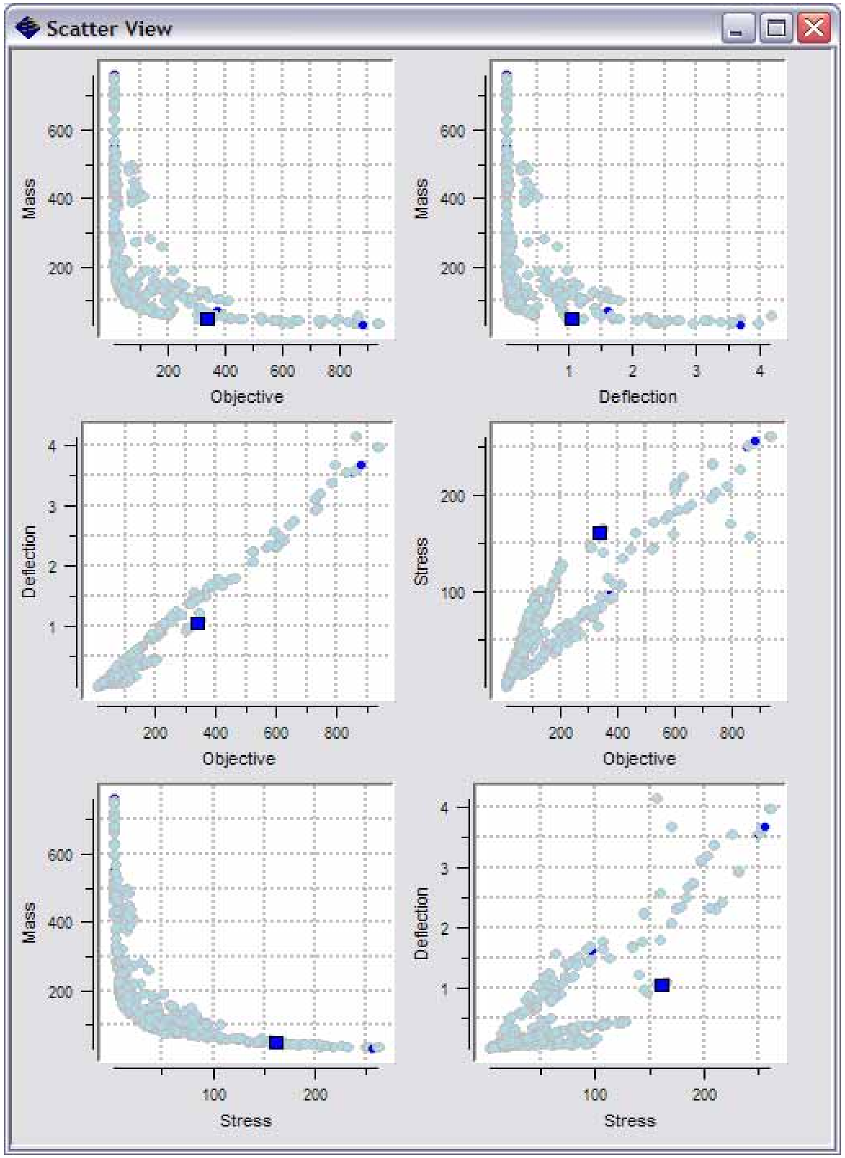


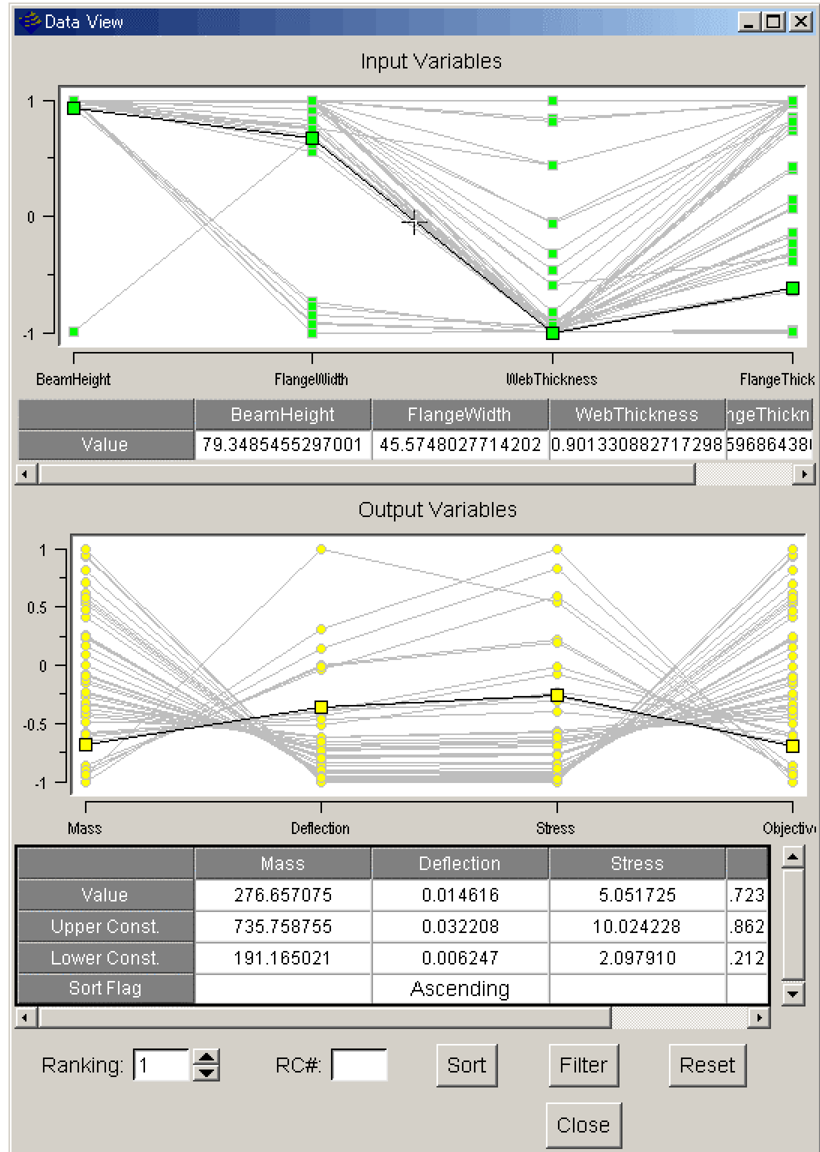
Multi-Objective Genetic Algorithm

- MOGA (Multiple Objective Genetic Algorithm)

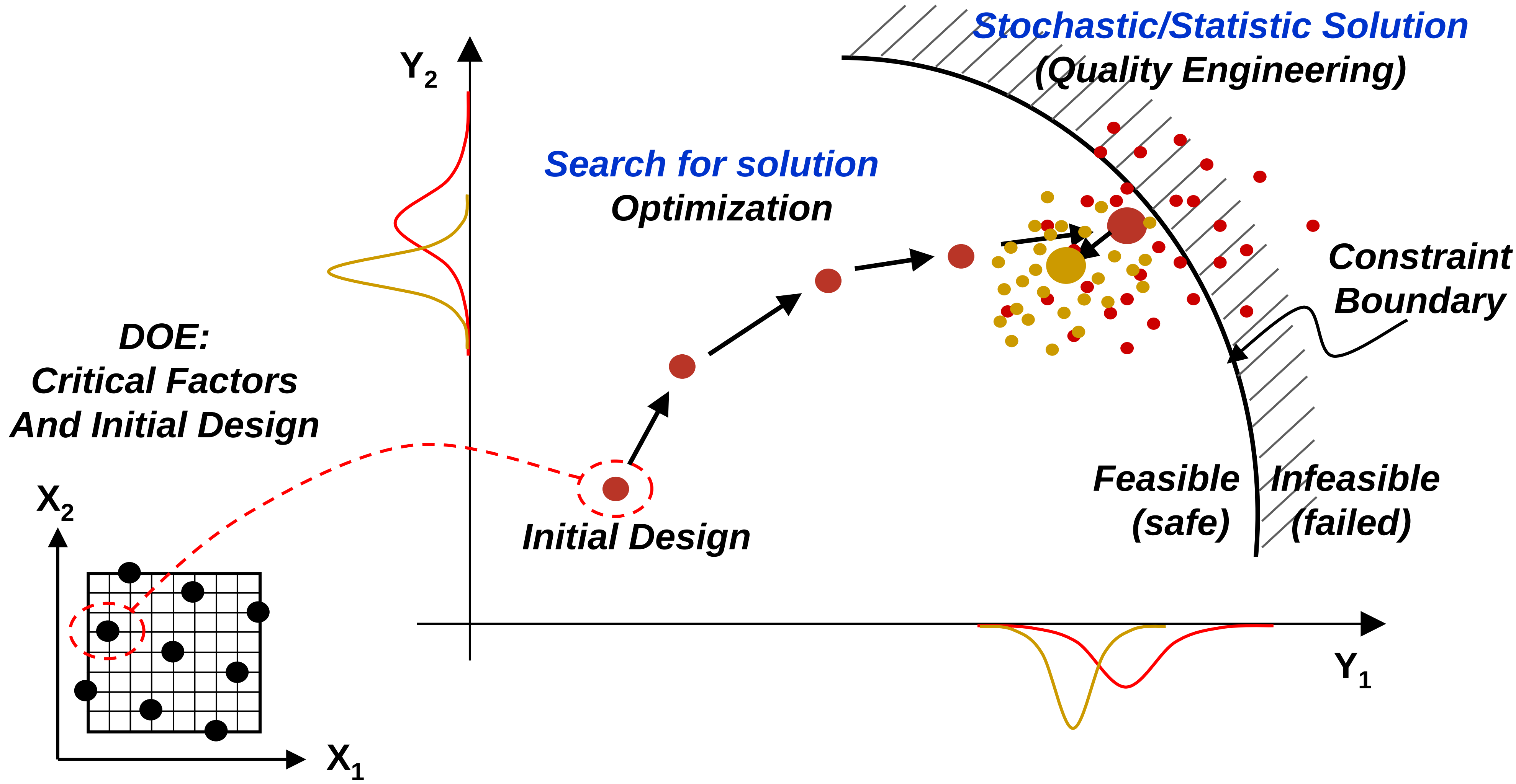


Engineering Data Mining for Multi-Objective Analysis





From Deterministic Simulation to Stochastic/Statistic Simulations



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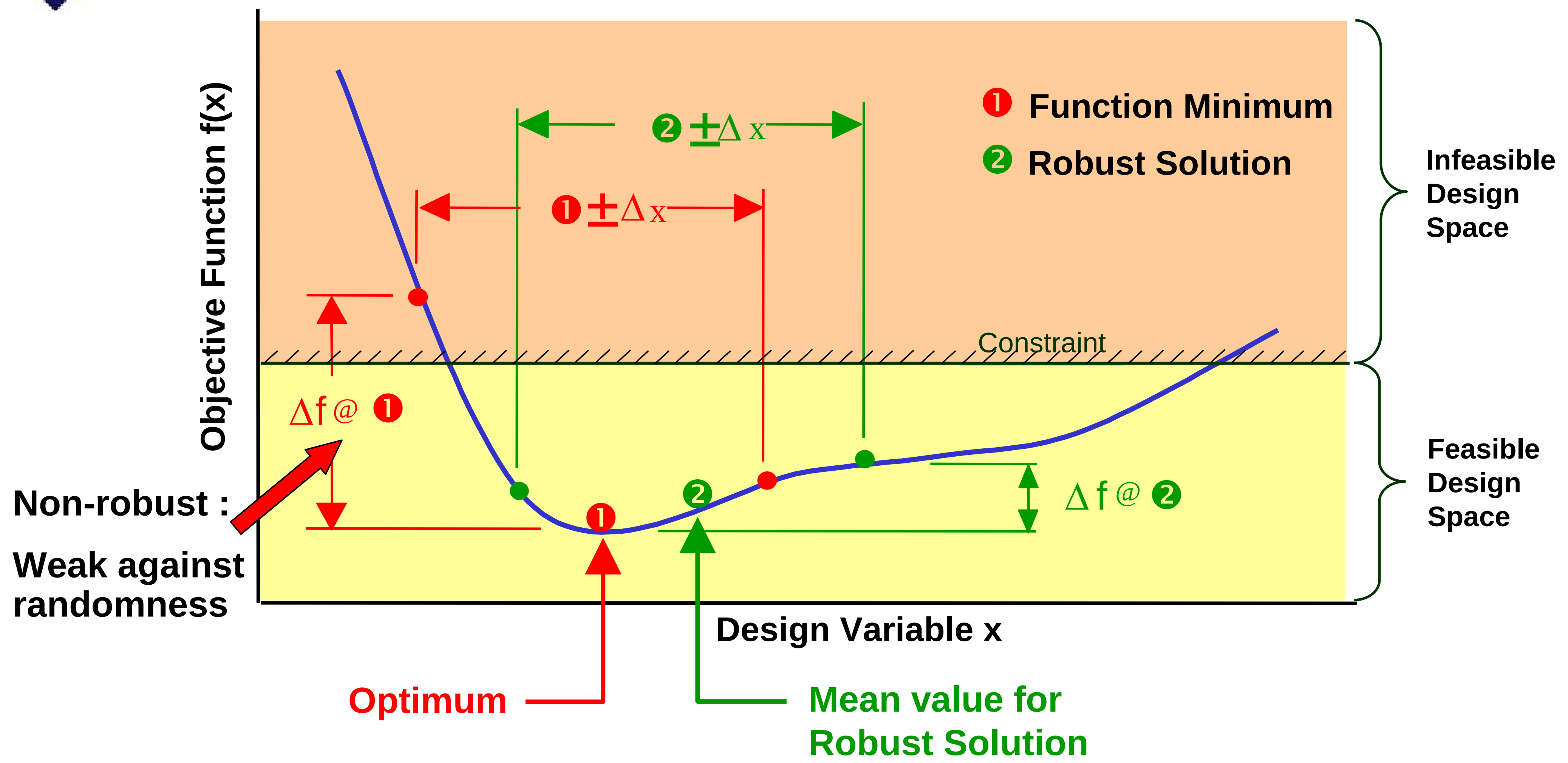
From Optimal Design to Robust Design



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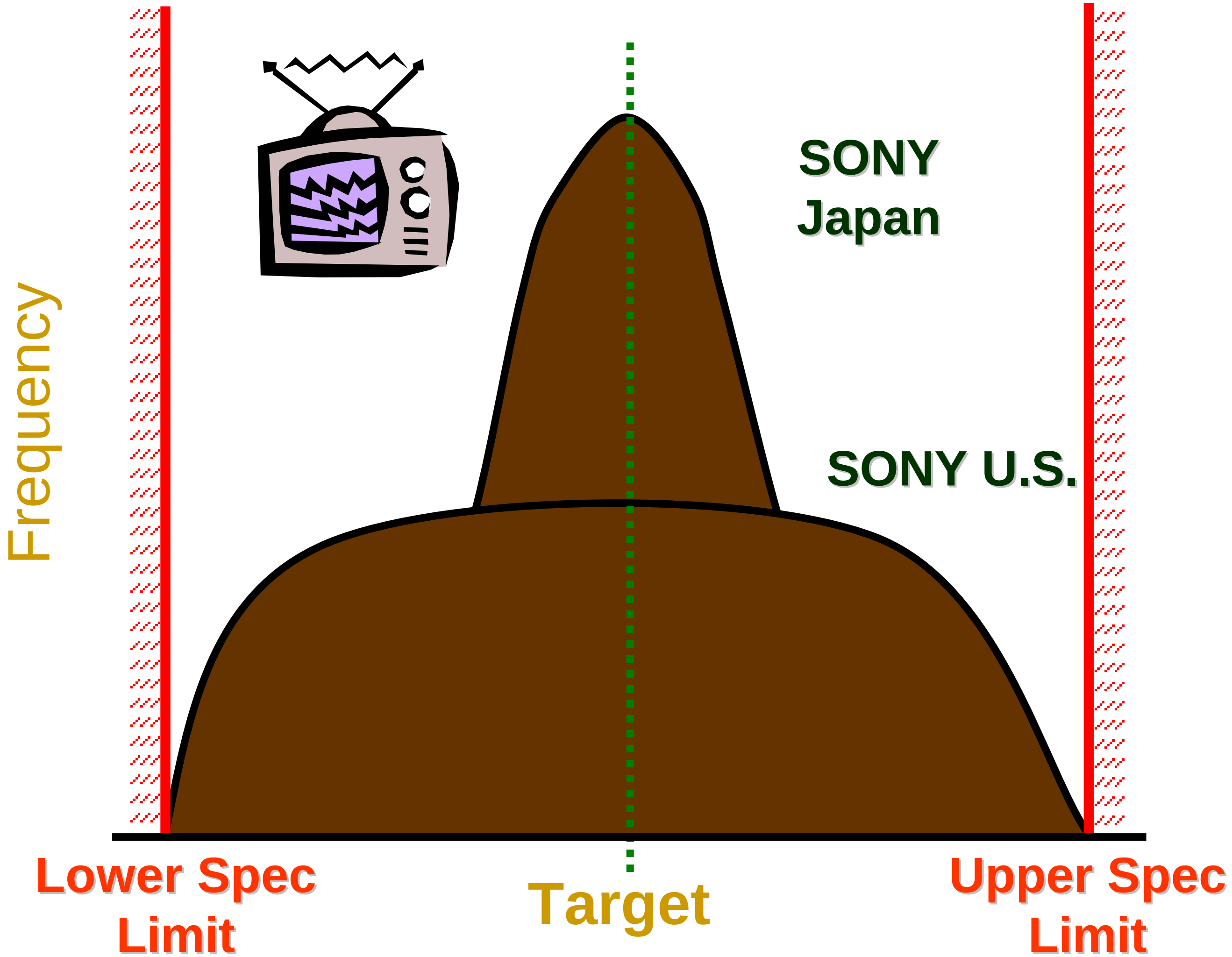
Quality Loss – A Case Study - SONY

- American consumers consistently preferred overseas sets
- TVs had identical system design and tolerances
- No out of tolerance sets shipped to any consumer

- US sets built to a flat distribution
- QUALITY IS MORE THAN JUST STAYING WITHIN LIMITS
- MUST GET CLOSE TO TARGET WHILE MINIMIZING DEVIATION



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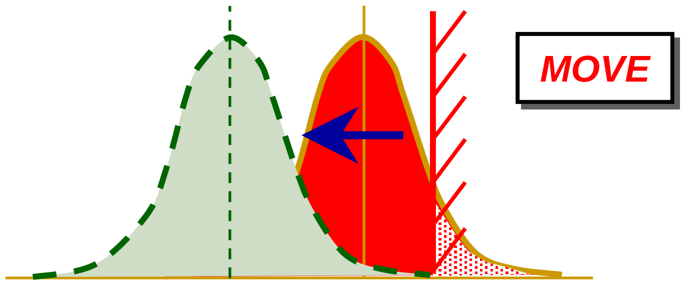
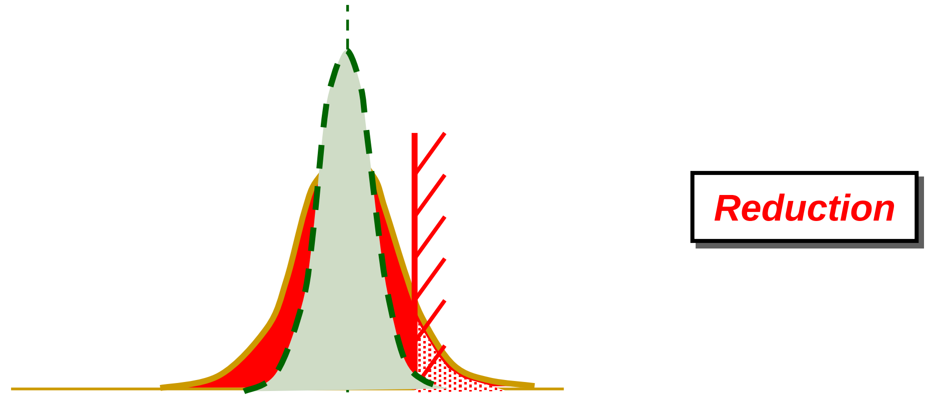
QEM Approaches

Design Variables
*+ Stochastic Variables (*Variability depend on Physical Phenomenon*)*

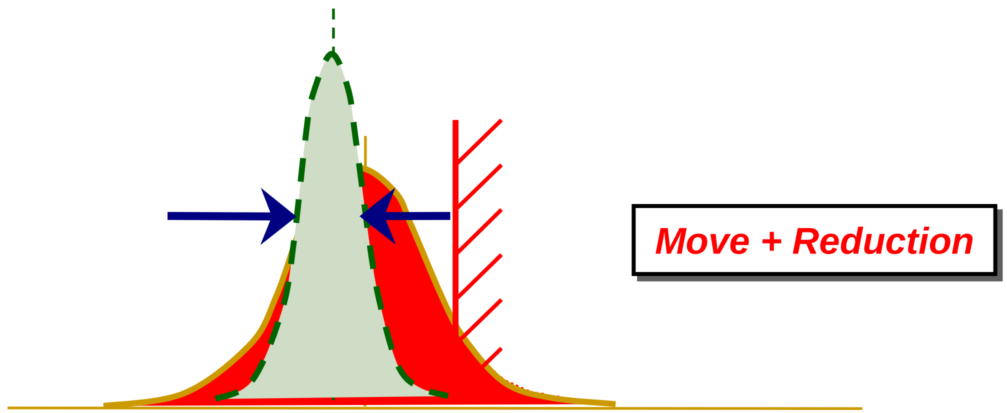
- **Reliability Optimization:** Satisfying Constrain



- **Robust Design:** Minimizing Variance (Taguchi)



- **Robust Optimization:** Satisfying Constrain & Minimizing Variance (DFSS)



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What is Design for Six Sigma?

- **Wider Meaning**

  Redesigning of Total Operation Process in order to realize Six Sigma Level Management Quality

- **Narrower Meaning**

  Innovative Product Design Process in order to realize Six Sigma Level Product Quality

A Structured, Disciplined, Repeatable Process That Will Deliver Near Perfect Products and Performance

Six Sigma Robust Design - Terminology

- **Sigma (s):**

  standard deviation of product or process performance - *a measure of performance variation*

- **Quality Level / Sigma Level:**

  Can be characterized as percent variation or defects per million:

	Sigma ± σ	Percent Variation	Defects per million	Defects per million (with 1.5s shift)
	1	68.26	317,400	697,700
	2	95.46	45,400	308,733
Former Engineering Target	3	99.73	2,700	66,803
	4	99.9937	63	6,200
	5	99.999943	0.57	233
New Philosophy	6	99.9999998	0.002	3.4

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Is 99% Near Perfection?

- 15 Minutes of Unsafe Drinking Water per Day
- Two Unsafe Landings per Day at O'Hare
- 20,000 Mailed Letters Lost Each Hour
- 5,000 Incorrect Surgeries Each Week
- No Electricity for Almost 7 Hours Each Month
- Watch off by 15 Minutes per Day

Source: controleng.com

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Six Sigma – Benchmarks

- IRS Phone-in Tax Advise — 2.2σ
- Prescription Writing — 2.9σ
- Average Company — 3.0σ
- Airline Baggage Handling — 3.2σ
- Best in Class Companies — 5.7σ
- Watch off by 2 Seconds in 31 years — 6.0σ
- Airline Industry Fatality Rate — 6.2σ

Source: controleng.com

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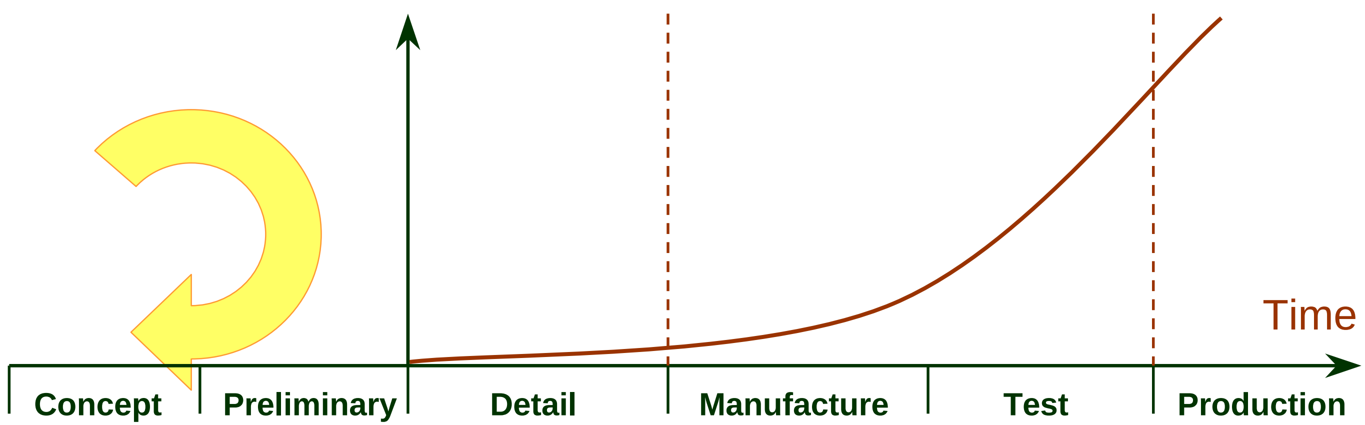
Why Six Sigma Robust Design?

- **Cost of Poor Quality**
  - **Internal – Scrap, Inspection, Rework, Increased Cycle Time**
  - **External – Customer Satisfaction, Warranty, Competitive**

Cost: (4σ＝25% of Revenue： 6σ＝1% of Revenue)

- **Cost of Change**
  - **Apply Six Sigma Early in the Design Phase**

Cost of Design Change ($)



Quality should be “designed, not inspected” Taguchi

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New Viewpoint and Methodology as Having Infinite Computing Resource

- **Past: Assuming Limited Computing Resource**
  - Requiring to learn from very limited Computational Results
  - Watching just Specific Trees without Scanning Wider Forest
- **Computing Environment is Revolutionary Improved !!**
  - Processor Performance & Multiple Processors (Cluster & Grid Computing)
  - Memory, Storage Space & Network (Broad Band Network/Internet)
  - Web, PDA, Cellular Phone
  - Middle Ware (DRM, Web Application Server, DB)
- **Future：Grid World**
  - Methodology to Execute as Many Calculations as Computing Resource and Time allow
  - How to draw Effective Information in Max from Many Parametric Studies
  - Obtaining Essence of Global Phenomena by Data Mining from Mass Computational Results
    - Engineering Data Mining (Understanding Characteristic of Global Phenomena)
  - Focusing on Specific Trees after Scanning All Forest
    - *Engineering Data Mining (Scanning All Phenomena)*
    - *Engineering Visualization (Looking at Specific Phenomenon)*

    → Visualization Grid (Deeply Watching One Specific Phenomenon by All)

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Theory of Constrains(TOC) and Optimization

- **Summation of Partial(Local) Optima may not be Global Optimum**
  - ➞ Partial Optimum may be disturbing Global Optimum *(Eliyahu M. Goldratt)*
  - ➞ Troubles will be concentrated on Bottlenecks(Constrains)

- **Removing Bottlenecks**
  - ➞ Removing Over/Under Specification and Variances
  - ➞ Stabilizing Performance/Quality of All Parts and Materials
  - ➞ Multi-Objective/Multi-Discipline Parameter Study in Components Level
  - ➞ Multi-Objective/Multi-Discipline Parameter Study in Product Level
  - ➞ Optimum/Robust Design in Total Product Life Cycle
  - ➞ Optimum/Robust Process in All Relating Operations

- **Collaborations in System/Process Level**

(R&D ➞ Design ➞ Analysis ➞ Prototyping ➞ Testing ➞ Manufacturing ➞ Supply ➞ Maintenance ➞ Recycling)

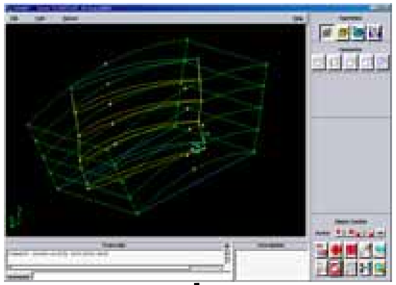
  - ➞ Dependency & Concurrency between Processes (Workflow Control)
  - ➞ Dependency & Communication between Organizations (Horizontal Operation)
  - ➞ Robust Optimization in Global Collaboration

Constructing Global Grid Environment

Turbine Blade Design

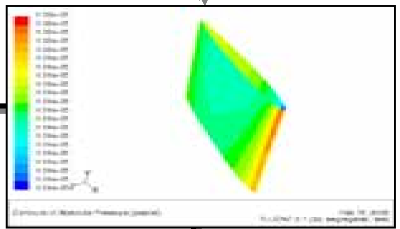
- Design Variables (circumferential and axial movement blade profile)
  - Angle(i)
  - Xposition(i)
  - Yposition(i) [i=1〜4]
- Objective:
  - Maximize Mass Flow Rate
- Constraints
  - VonMisesStress.
- Tools:
  - GAMBIT (CAD&Mesh)
  - Fluent (CFD)
  - Nastran (FEM)

Design Variables



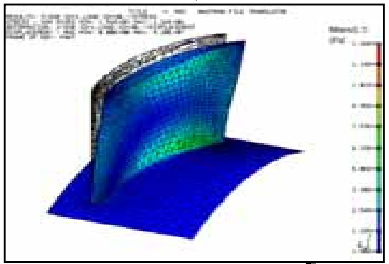
GAMBIT generates shape-geometry and mesh.

Mesh file



FLUENT calculates MassFlowRate and output pressure distribution on dynamic rotor.

Nastran Bulk data＆Pressure Force



Nastran calculates VonMisesStress

MassFlow Rate

VonMisesStress

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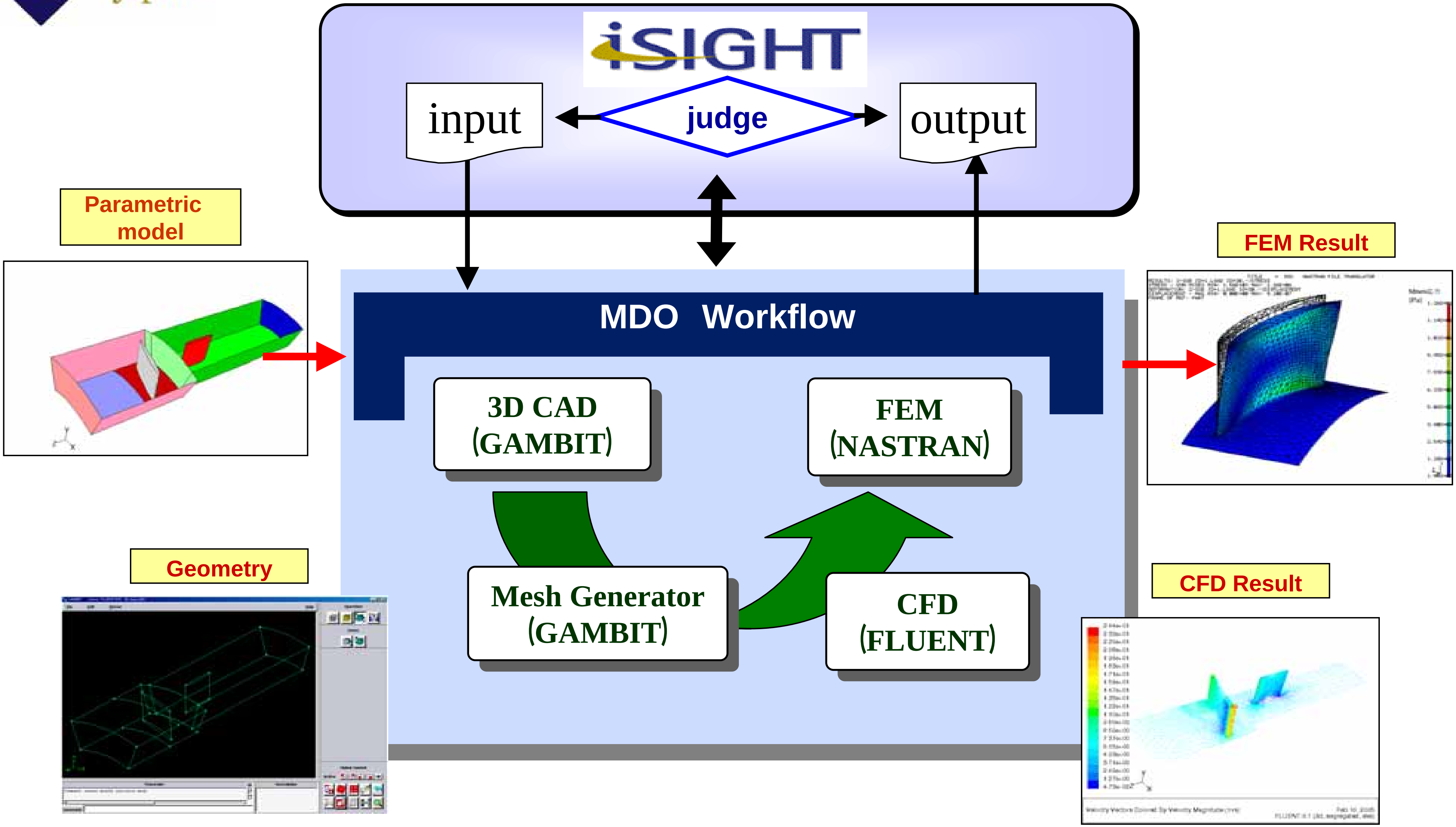
Turbine Blade Design Automated Workflow



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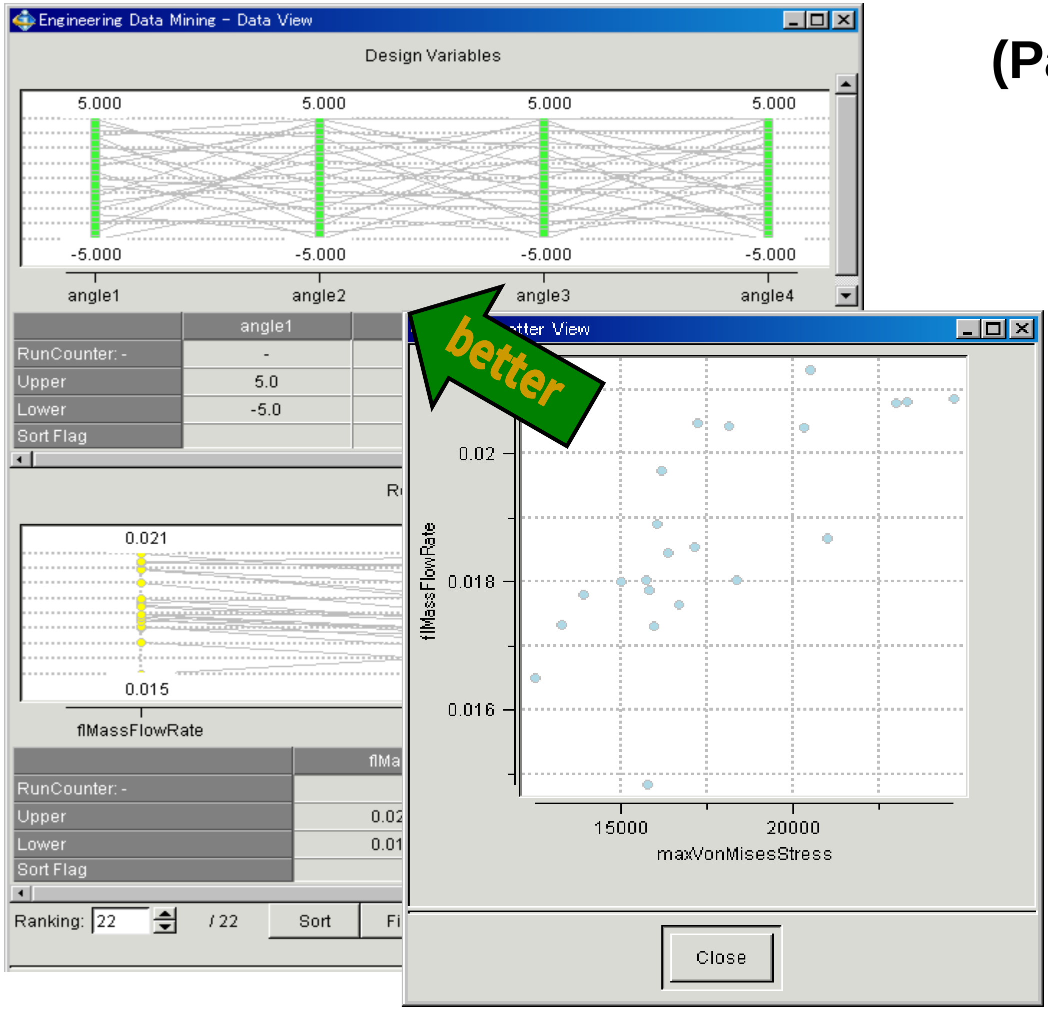
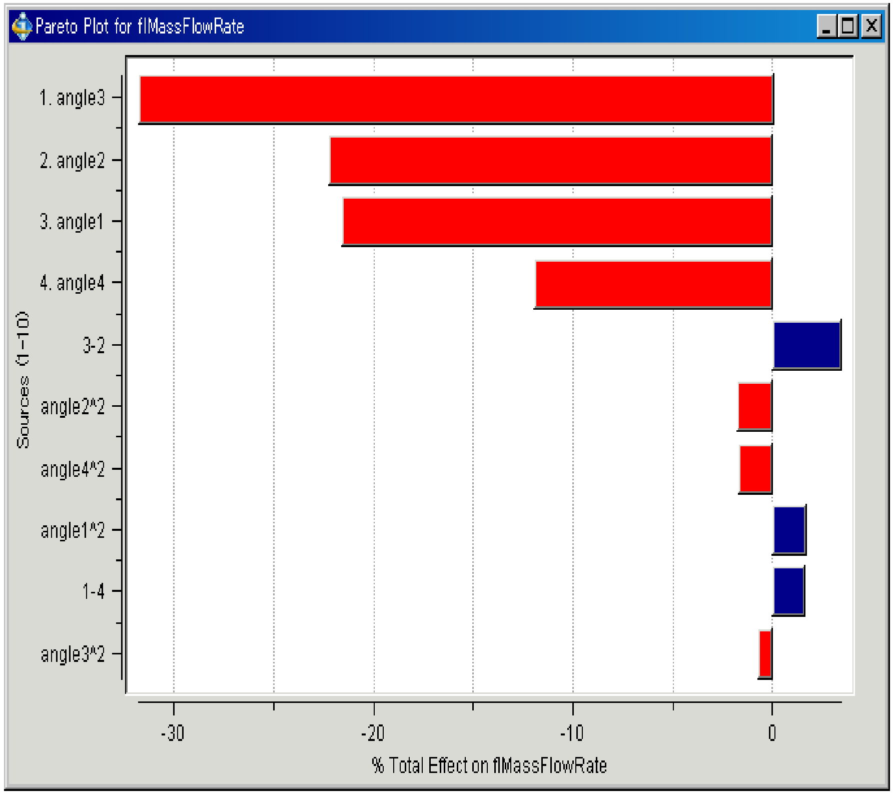
Parallel DOE Results (1)

- View Results Through EDM



- DOE Post

(Pareto plot for Mass Flow Rate)



Parallel DOE Results (2)

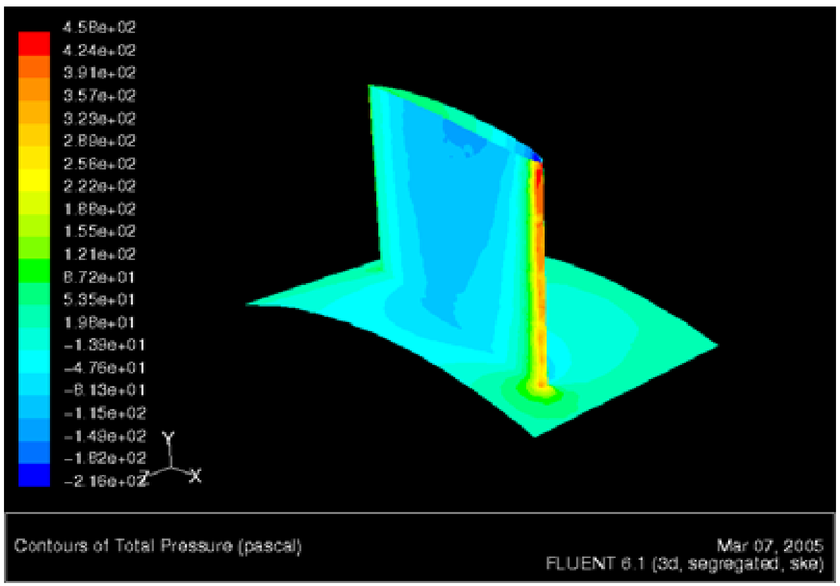
Initial Design

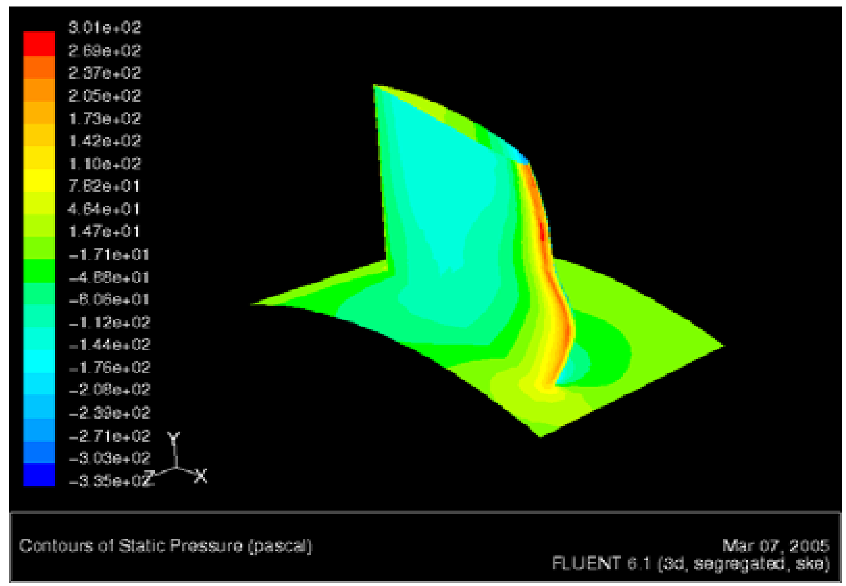
- **Objective:**
  - **Mass Flow Rate =0.0189 (kg/s)**
- **Constraints**
  - **VonMisesStress =16855.54 (Pa)**

Parallel DOE + Grid Computer

DOE Best Design

- **Objective:**
  - **Mass Flow Rate =0.0205(kg/s)**
- **Constraints**
  - **VonMisesStress = 17249.03 (Pa)**





1D Engine Performance Parameter Study

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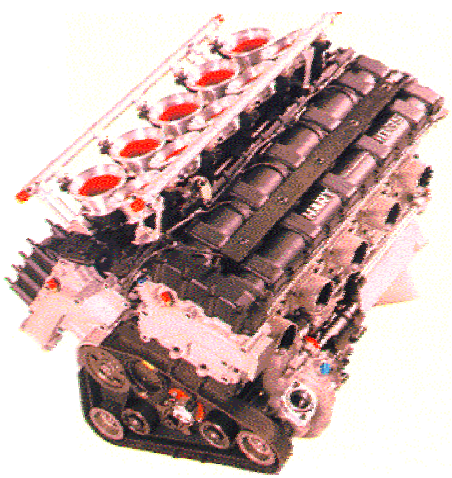
Design Variables

- Intake Valve Open Timing
  :IVO
- Exhaust Valve Open Timing
  : EVO
- Intake Valve Open Duration
  :DURi
- Exhaust Valve Open Duration
  :DURe

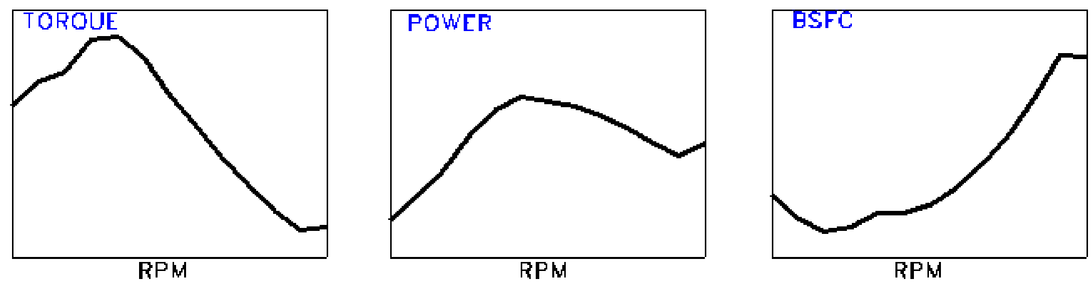


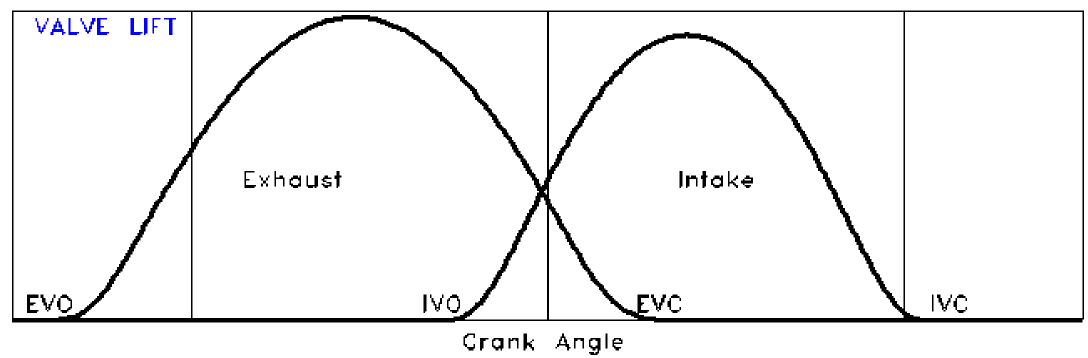
Objective Functions

Fuel Economy :BSFCSI

Volumetric Efficiency :VOLEFD

Brake Torque :TORQUE





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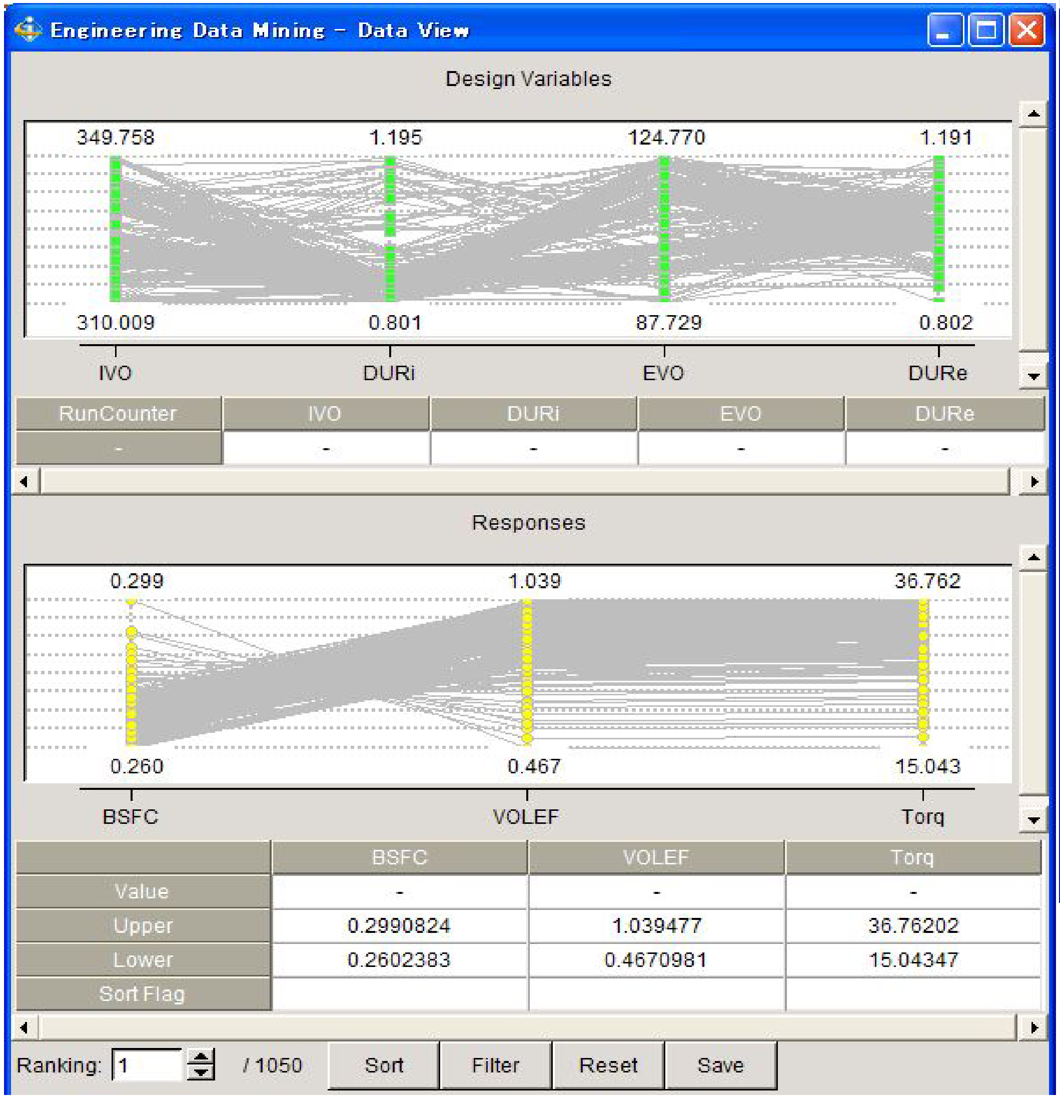
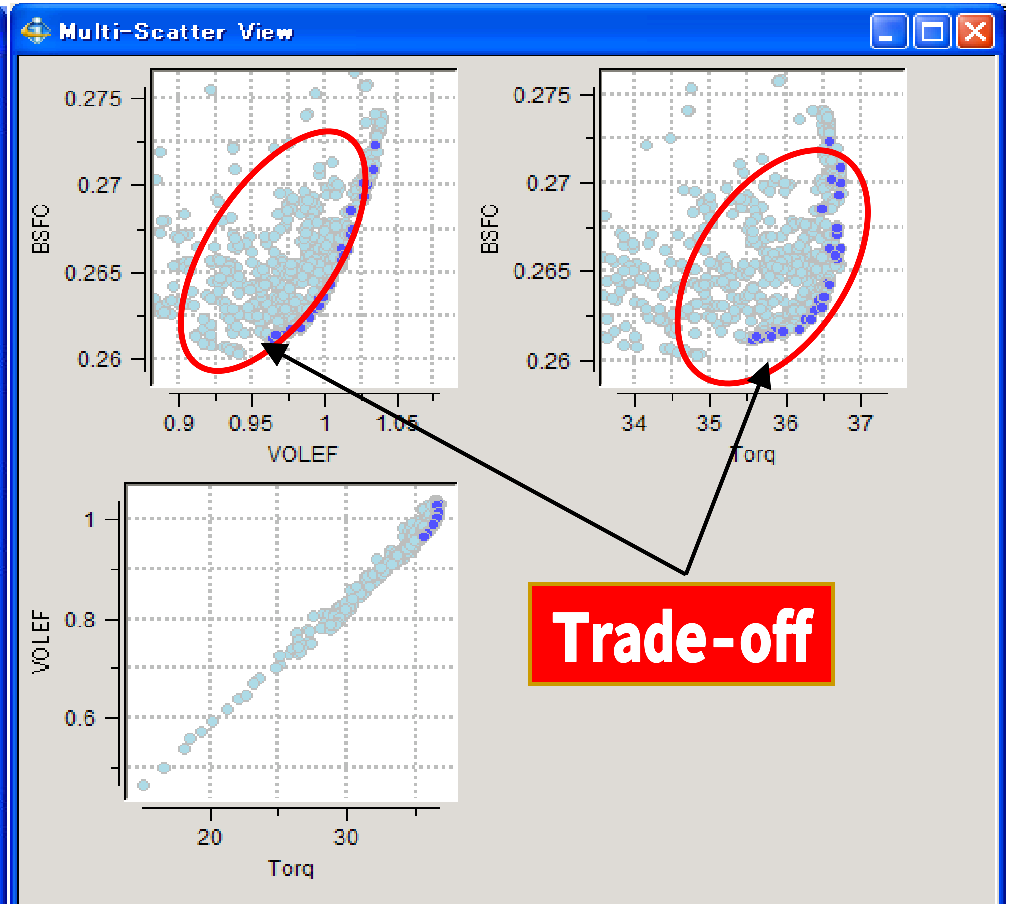
1D Engine Performance Parameter Study
(Multi-Objective GA with Engineering Data Mining)

20 Populations * 50 Generations=1000 Iterations





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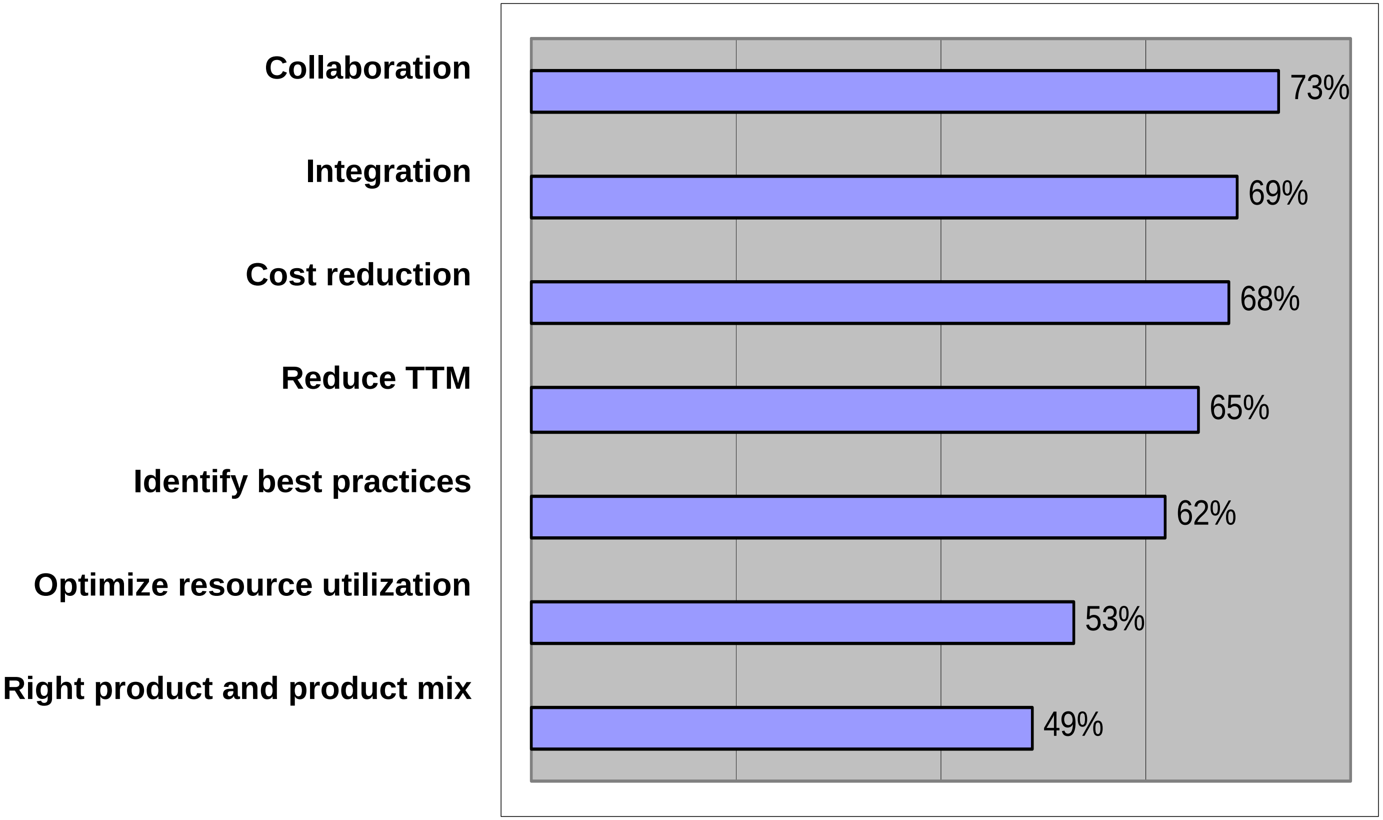
Collaboration and Integration: Top Issues in Executives' Minds

Key Customer Pain Points in the PLM Space



Source: Mercer Consulting Study

GridWorld/GGF15
Boston,2005

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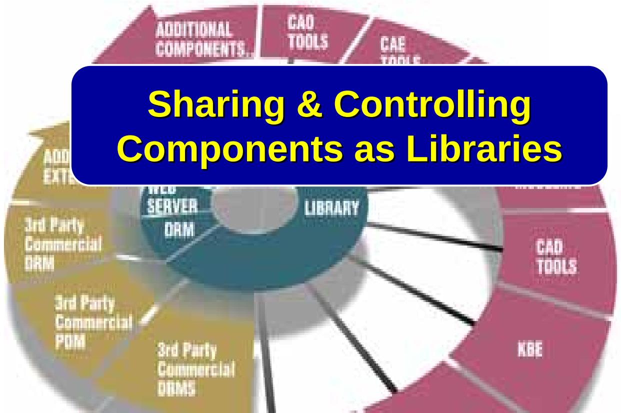
Building, Executing and Managing Collaborative Engineering Process

GUI for Components Development

Java Wrapped Components



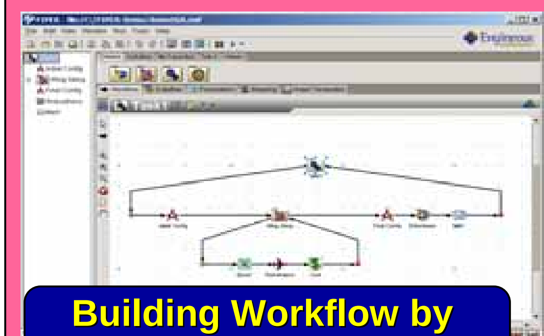
Sharing & Controlling Components as Libraries

Distributed Process Environment with Efficient IT Resource

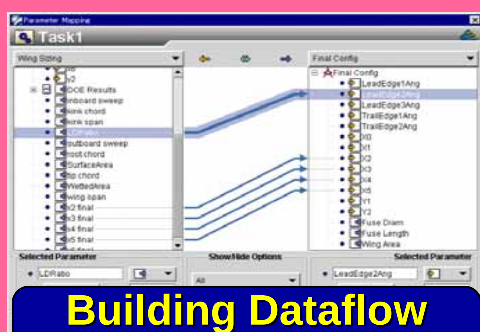
GUI for System Management

System Mgmt. & Monitoring

GUI for Building Workflow

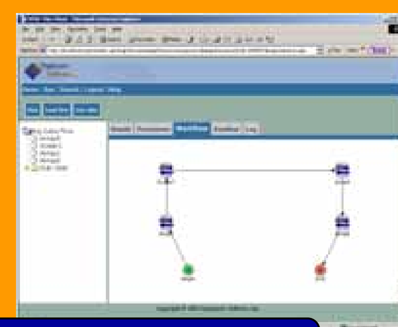


Building Workflow by Drag and Drop



Building Dataflow by Data Mapping

GUI for Process Execution



Access to Libraries

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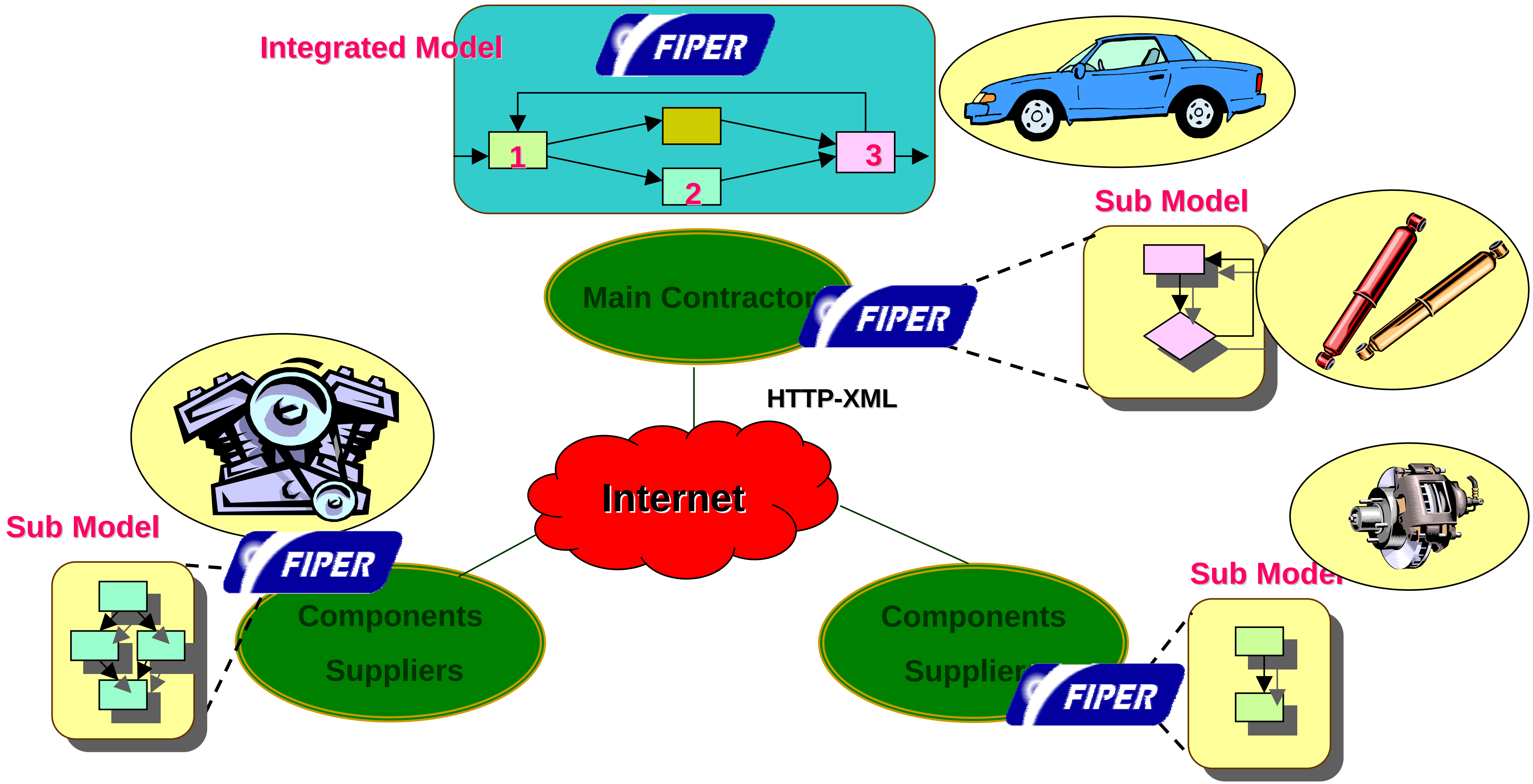
Collaborative Parameter Study & Robust Design

Design Study and Real-Time Information Exchange by Sharing and Integrating Models developed by Multiple Organizations



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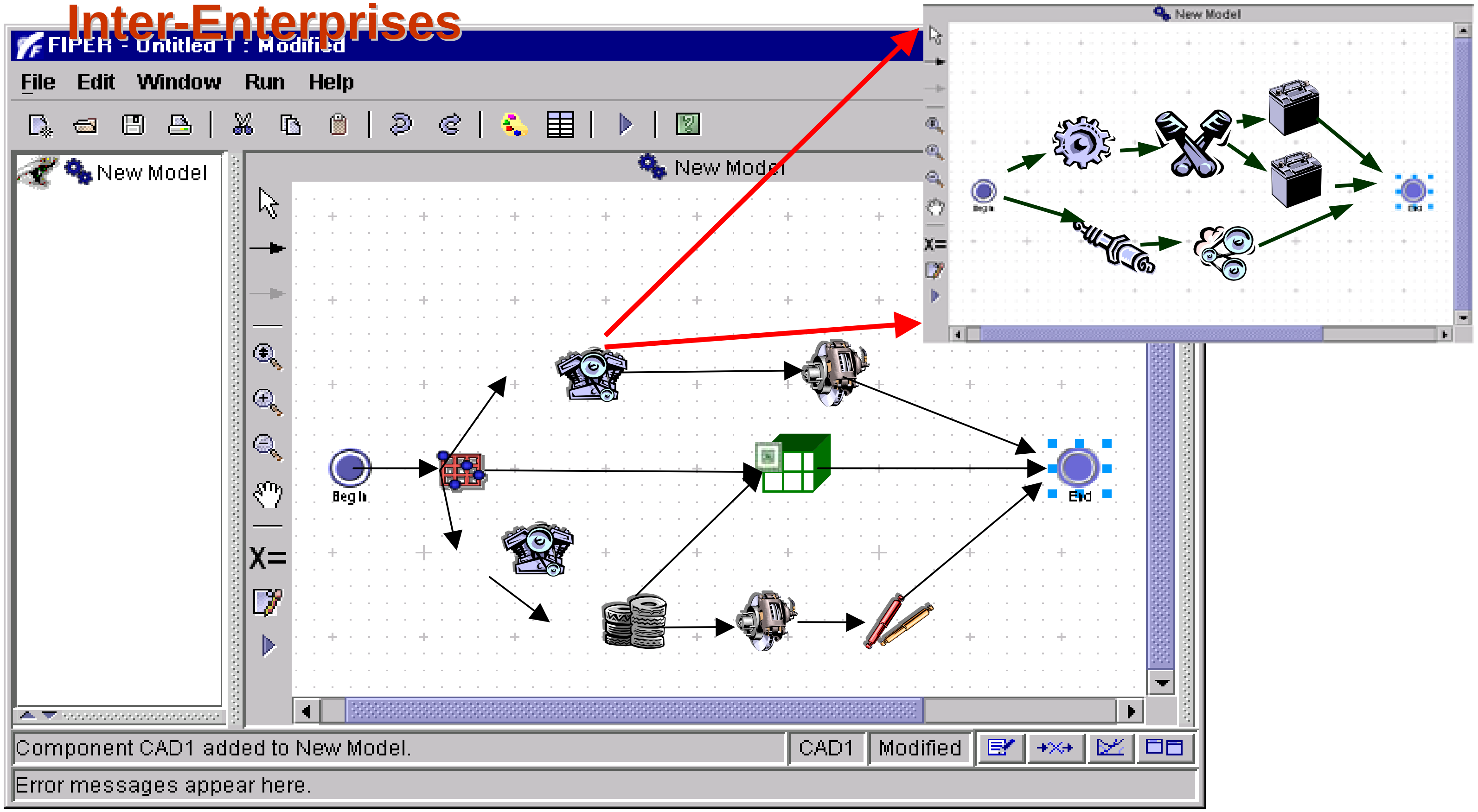
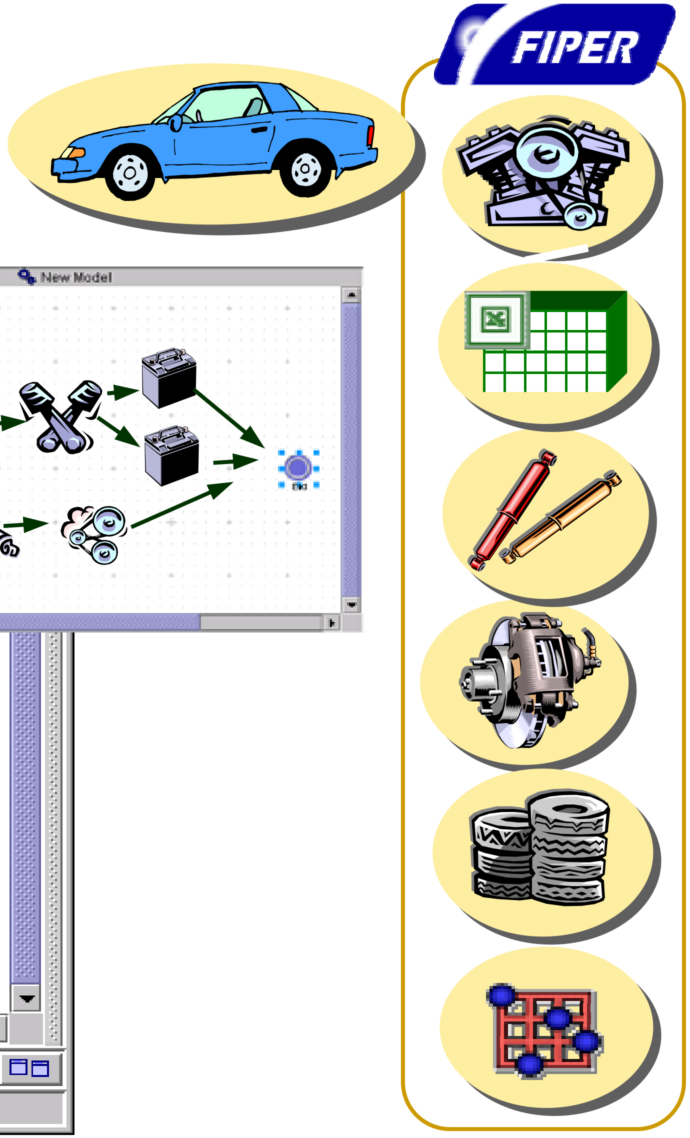
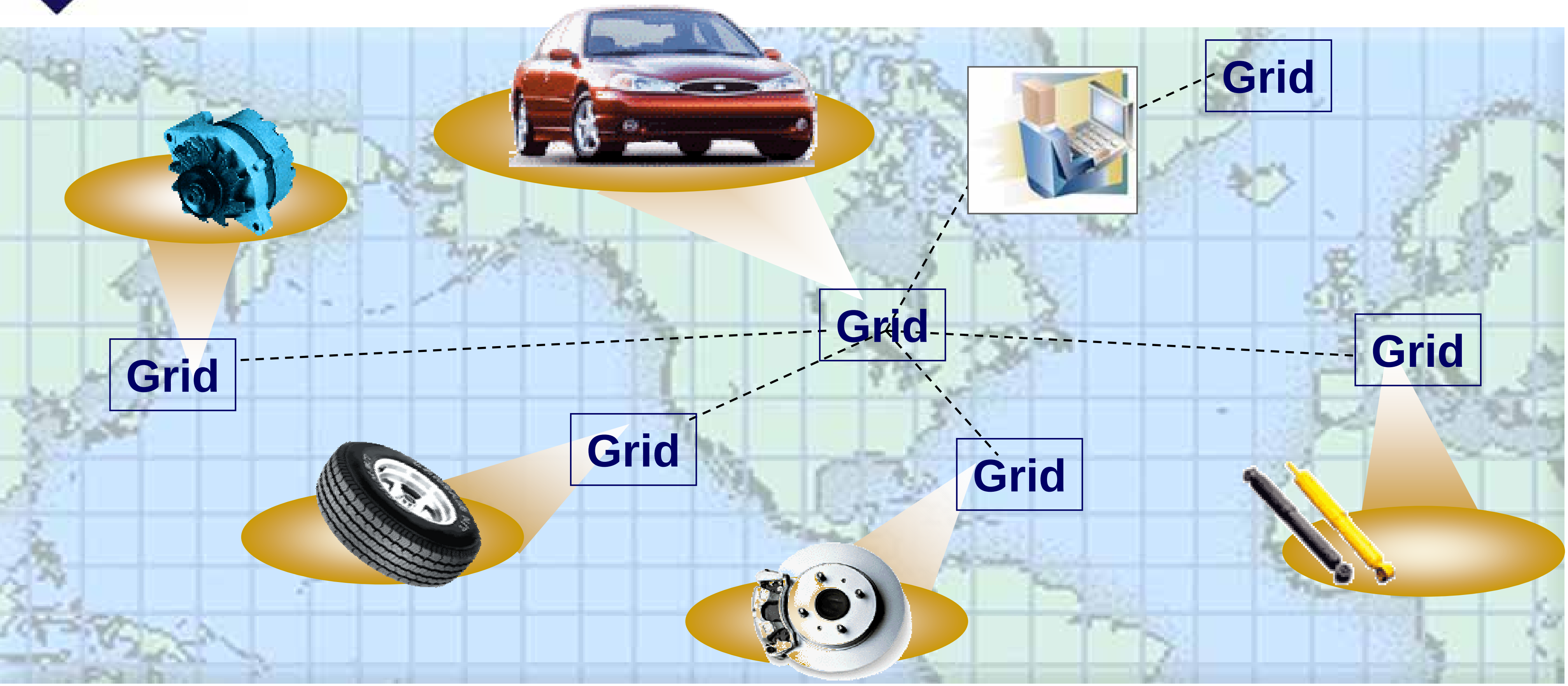
Collaborative Parameter Study & Robust Design

Multi-Objective & Multi-Disciplinary Robust Design with Process Sharing and Workflow Control /Automation/Integration by Inter-Divisions & Inter-Enterprises





Grid Solutions for Collaboration



Centralized product development and optimization environment that enables design collaboration with globally dispersed design teams, organizations, and suppliers

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Parameter Study System as Grid Enabler

- Current Status of Grid
  - Many Middleware such as Globus, LSF, Grid Engine, PBS-Pro
  - Considering Mainly Job Dispatching but not Computational Results
  - Parallel Processing of Very Large Scale Simulation (Parallel Efficiency?)
  - Trying to Deliver Single Deterministic Optimum through Parameter Studies
  - Usage of Computer Resource is increased, but how about Design Efficiency?

- Realizing More Practical Grid
  - Applying Middleware as Distributed Resource Management (DRM)
  - Automatically Generating Multiple Parameter Combination and Input Data
  - Automatically and Concurrently Executing Multiple Simulations in Parallel Distributed Environment
  - Statistically Analyzing Computational Results in Automatic Manner
    - Trade-off Analysis and Approximation of Design Space
  - Automatically Executing the follow-on Simulations by applying Previous Results
  - Not only Improving Computing Resource Usage but also Design Efficiency
  - Global Grid for Collaborative Parameter Study/Knowledge Base System for Robust Design

The Importance is

to Statistically Analyze the Results

to Store as Knowledge Base and to Apply for the future