The Roles of High Performance Computing in Heavy Industry

IHI

SCAsia2019

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SUNTEC SINGAPORE CONVENTION & EXHIBITION CENTRE

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Research Laboratory
IHI Corporation

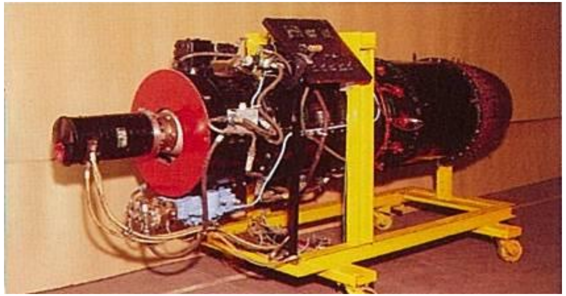
Profile of IHI Group

■IHI Corporation (IHI=Ishikawajima-Harima Heavy Industry)

- Founded : 1853 (End of Edo Era)
- Capital : 107 billion JPY
- Consolidated Net Sales : 1,486 billion JPY
- Employees : 29,659
- Works : 7
- Branches and Sales Offices in Japan : 16
- Overseas Sales Offices : 13

As of March 31,2017

Ship “Tsu-un-maru”



Turbojet engien, Ishikawajima Ne-20

Computational & Mathematical Engineering Department

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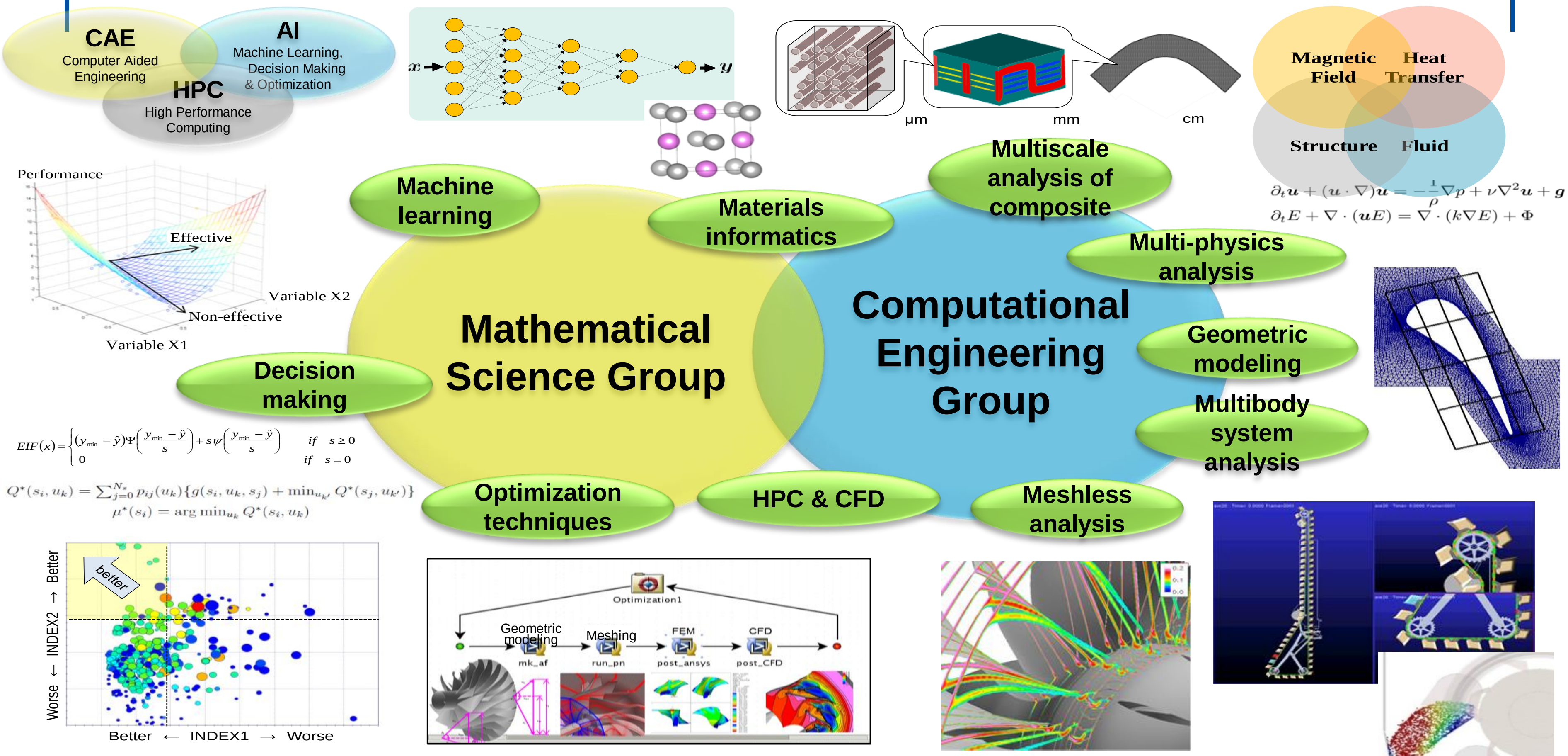

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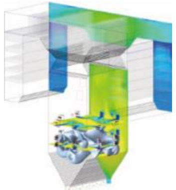
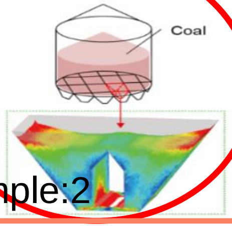
CAE is essential to develop and design products in all of our business area.

Resource, Energy & Environment

・Combustion analysis for coal-fired USC boiler



・Bulk material analysis for coal storage facilities

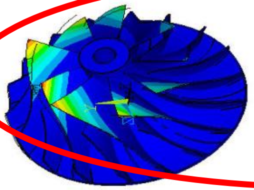


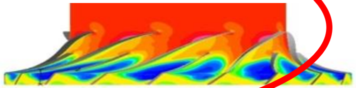
Example:2

Industrial Systems and General-purpose Machinery

・Structural & Fluid analysis for compressor blade

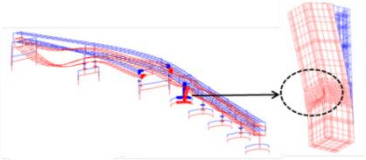
Example:1



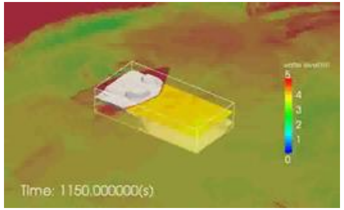


Social Infrastructure and Offshore Structure

・Seismic response analysis for bridge

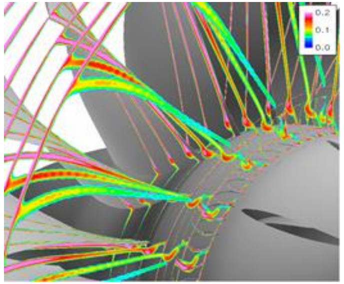


・Tsunami analysis for coastal structure

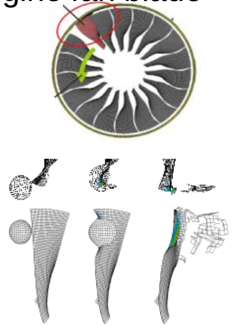


Aero Engine, Space and Defense

・Fluid analysis for engine fan blade



・Bird strike analysis for engine fan blade



Source : IHI R&D Activities, Journal of IHI Technologies 1998, 2013, IHI Engineering Review 2017

HPC in our work

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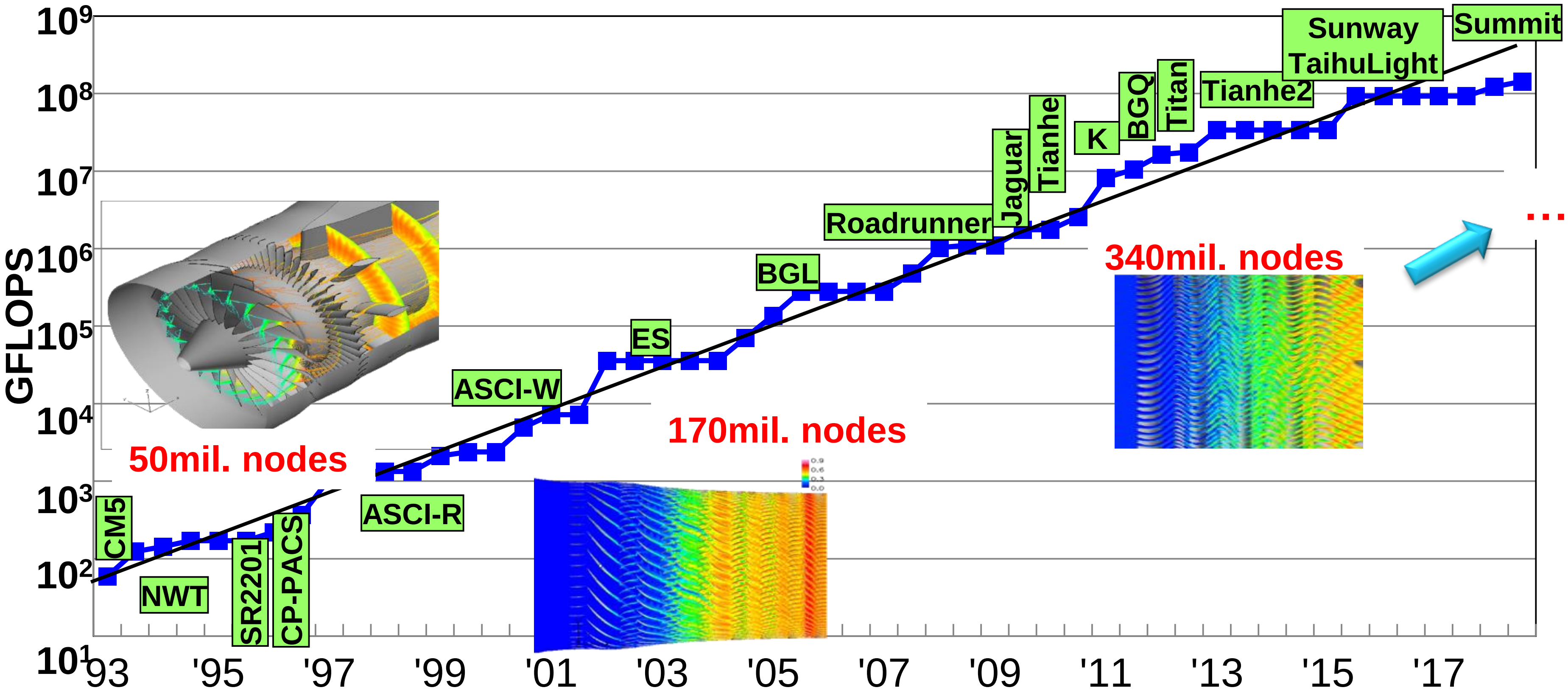
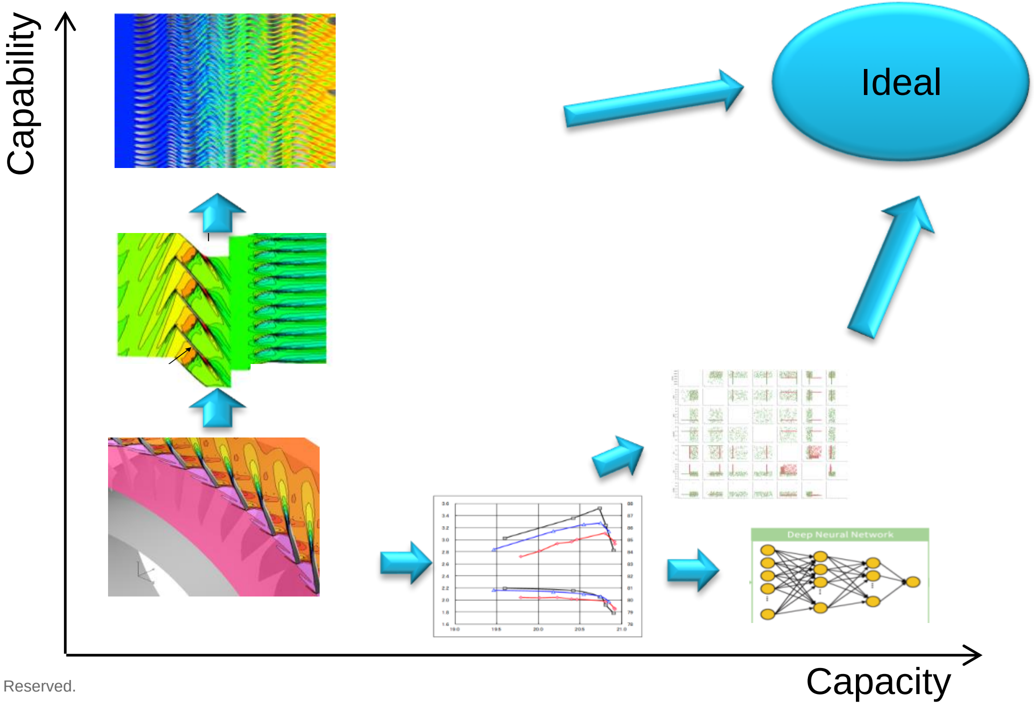
Scale of most precise computation also increases following the trend in the world.



HPC takes two roles in our works

- Capability computing: to analyze large scale / precise phenomenon
- Capacity computing: to evaluate a great number of cases in shorter time

Both roles are important and ideal situation is to satisfy both !



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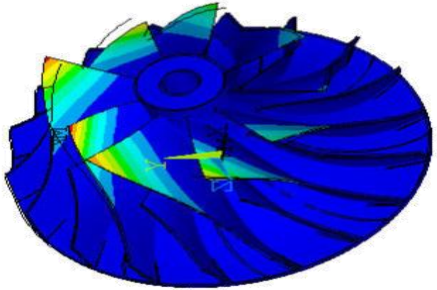
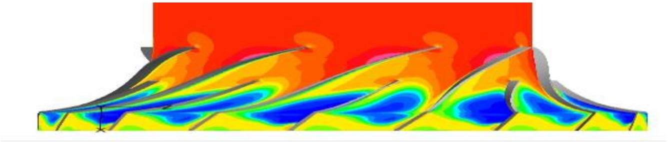
Optimize performance of centrifugal compressor by FEM, CFD and GA*

*GA: Genetic Algorithm





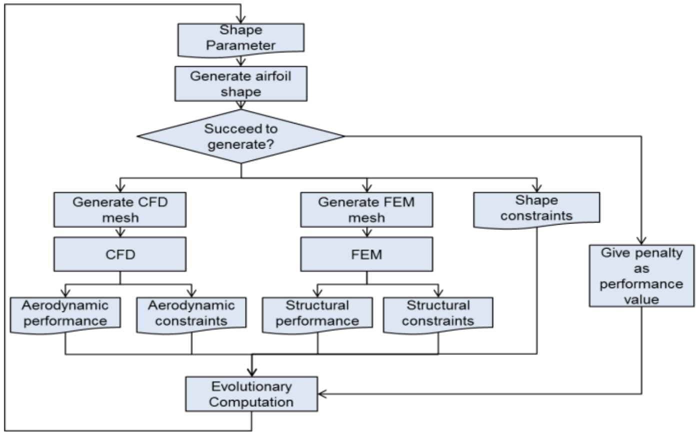
Centrifugal impeller, installed in turbocharger, etc.

- Objectives
  - ✓ Maximize isentropic efficiency
  - ✓ Maximize frequency detuning
- Variables (shape parameters)
  - ✓ Distribution of blade angle, thickness
  - ✓ Lean angle
  - ✓ L/E position of half blade
- Constraints
  - ✓ Shape smoothness
  - ✓ Maximum centrifugal stress
  - ✓ CFD stability

Optimization process

- For effective optimization, all of the CAE process should be automated.
- Computation time for each solution (design candidate) is not so long.
- However, Population (can be parallelized) 32 ,
  Generations(should be sequential)128 for GA

→ Over 3 days & 500 CPU cores are required.



		Computation time
For each solution	CFD	40min. x 16core
	FEM	15min. x 2 core
	Sum	40min. x 18 core (worst case)
x32 solutions x128 generations		3.6 days. x 576 core

Performed on in-house PC cluster

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Compare genetic algorithms (ranking and constraint handling technique)

✓Collaborative research with Dr. Oyama @ JAXA*)

*Japan Aerospace Exploration Agency

- Algorithm 1: NAGA-II[*1] + CD(Constraint-Domination principle)[*1]

  NSGA-II : Solutions are ranked by “Pareto Rank”

  CD : Treat constraint as top priority.

- Algorithm 2: CHEETAH[*2] + MCR(Multiple Constraint Ranking)[*3]

  CHEETAH : Originated by JAXA. Solutions are ranked based on “*Chebyshev Distance*”

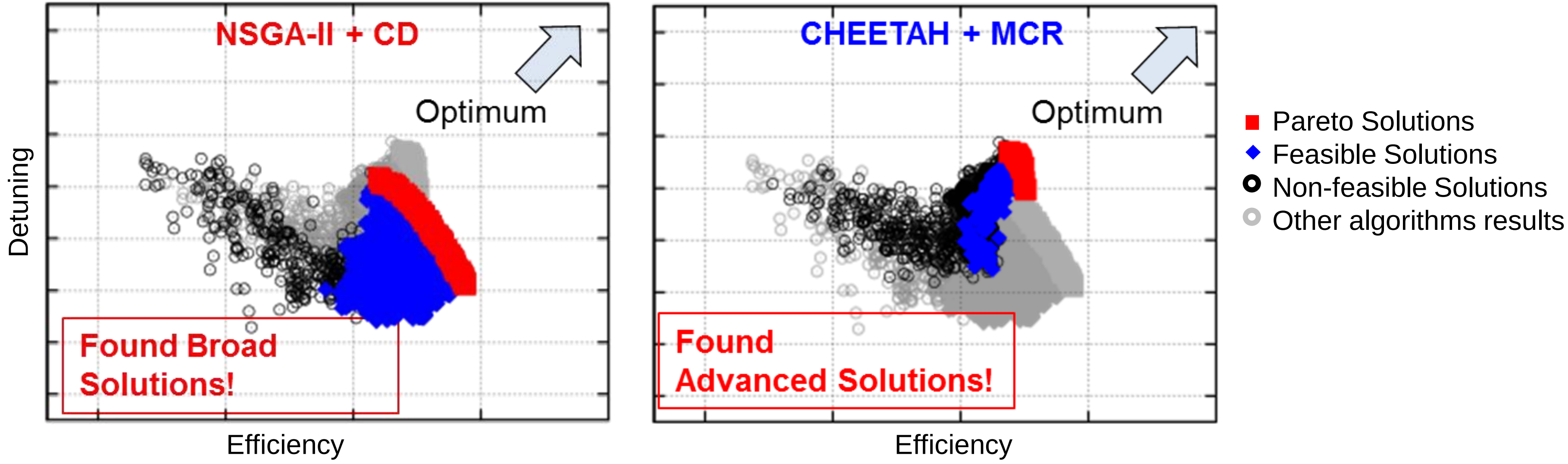
  MCR : Generate new rank by blending objective function value with number and amount of constraint violation.

*1:Deb, K., IEEE Trans. Evol. Comput., 2002. *2:Jaimes, A., IEEE CEC, 2015. *3:Garcia, R,, Computers and Structures, 2017.

Results (for same population and generation size)

- ✓ NSGA-II + CD finds broadly distributed solutions.
- ✓ CHEETAH + MCR finds narrower but more optimized solutions.

= High-speed convergence



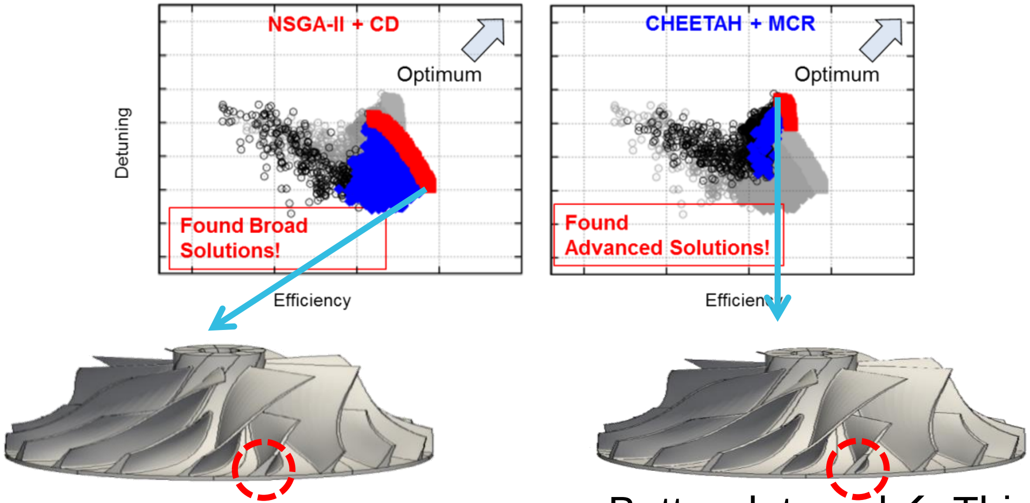
Resultant Solutions

Obtained solutions are depends on algorithms and initial solutions.

If there were enough large number of solutions, same ideal solution may be obtained…

Currently, we have to choose better designs from obtained solutions,

or manually modify by using knowledge from solutions.



Better efficiency ← Thin-tip blade

Better detuned ← Thick-tip blade

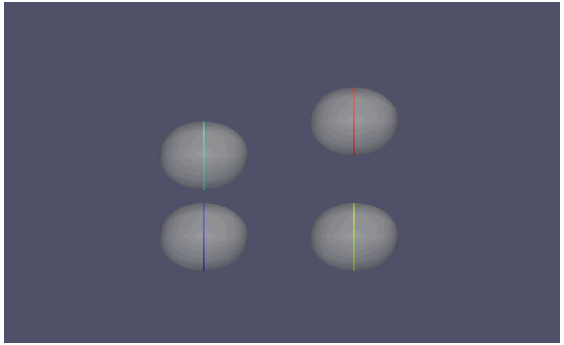
DEM（Discrete Element Method/Distinct Element Method）

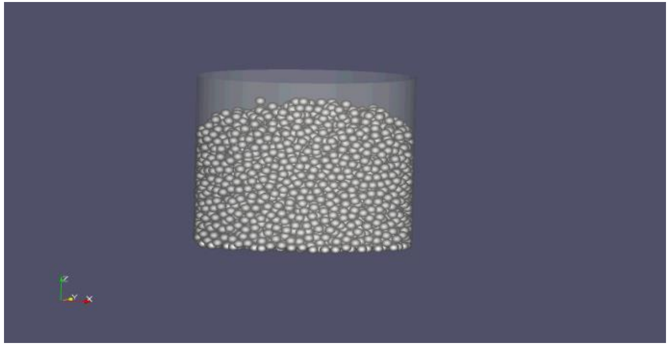
Numerical method for computing motion and interaction of a large number of small particles.

→ Effective to predict and represent bulk solid behavior.

We are attempting to use DEM for design bulk handling facilities.

hopper, conveyer, unloader, …





Estimate internal / wall pressure from bulk solids in the Silo*.

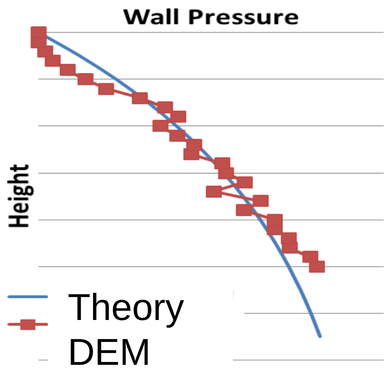
*A tower shape structure for storing bulk materials

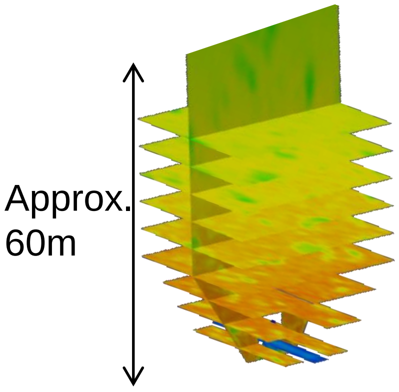
There is a theory for simple design of silo, but not universal.

→ Attempting to design by DEM (asymmetry, inside obstructs, feeder system, …)

Particle Diameter	50mm
Silo Height	60m
Number of Particles	60,000,000

⇨ 13 days x 128 CPU cores are required to compute behavior during only 120sec.





Parameter fitting is also a matter.

DEM requires properties of each particle and their interaction

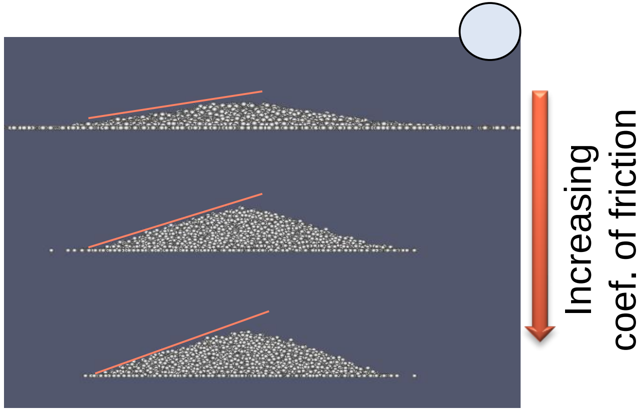
- Particle Shape (diameter, single sphere / cluster shape)
- Coefficient of restitution
- Coefficient of friction
- Cohesion model etc…

These are difficult to measure.

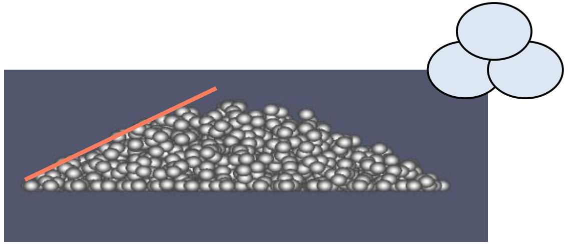
→ Measure MACRO behavior and fitting parameters.

Large number of combinations of parameters should be tested.

Single Particle



Cluster Particle



- **Overview and two examples of our HPC and CAE activities are introduced.**

- **The roles of HPC in our work are;**

✓ **to reveal physical phenomenon**
by computation with large number of nodes/elements.

✓ **to find out more sophisticated designs / parameters**
by computation with large number of design candidates.

◆ Nowadays, we are attempting to use simulation results as training data for AI.
→ More larger number of simulations are required !

We wish the appropriate HPC environment for not only capable computing,
but also capacity computing.

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Realize your dreams