CHALLENGES AND STRATEGY TO TACKLE THE EXTREME-SCALE FLUID SIMULATION FOR ENGINEERING PROCESS

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Smoky Mountains Conference 2014-09-04

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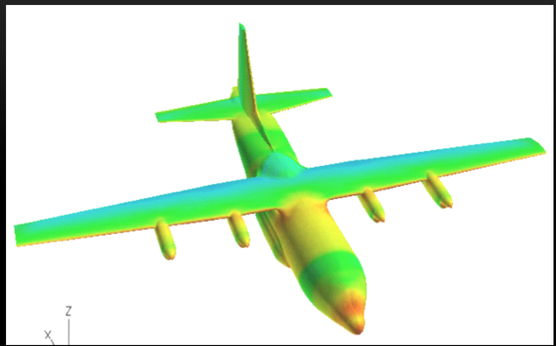
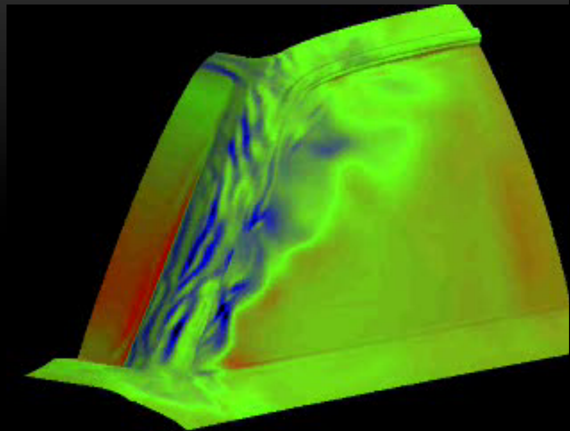
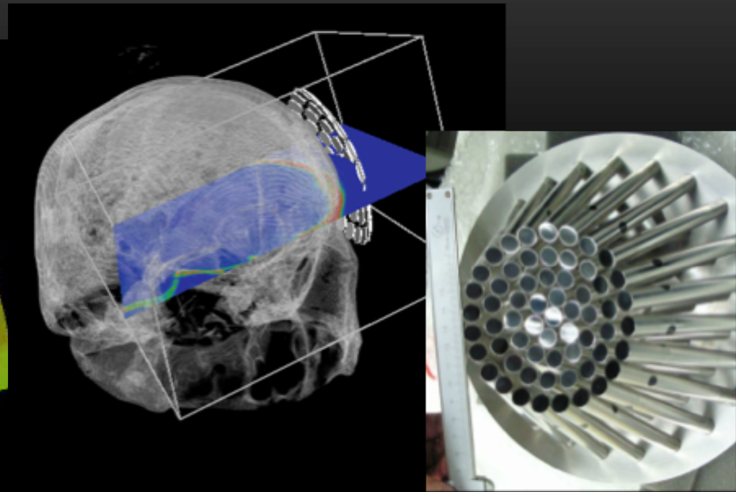
INDUSTRIAL APPLICATIONS



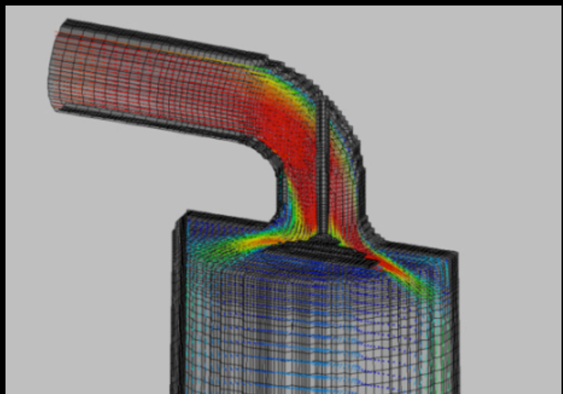
Aircraft
(Nakahashi, Tohoku Univ.)



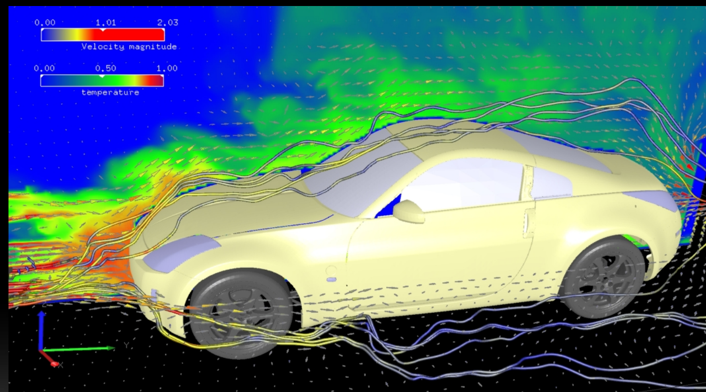
Wind Noise Prediction
(Ono, Nissan)



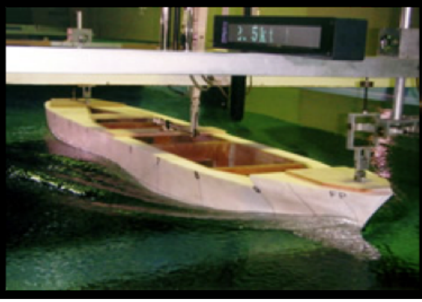
Tumor Surgery by HIFU
(Okita, Nihon Univ.)

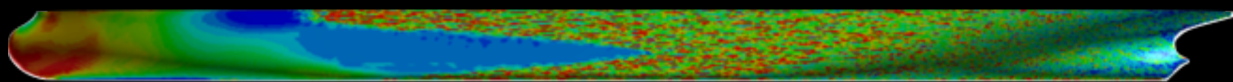


Flow inside Engine Cylinder



Vehicle Aerodynamics (Ono, Nissan)



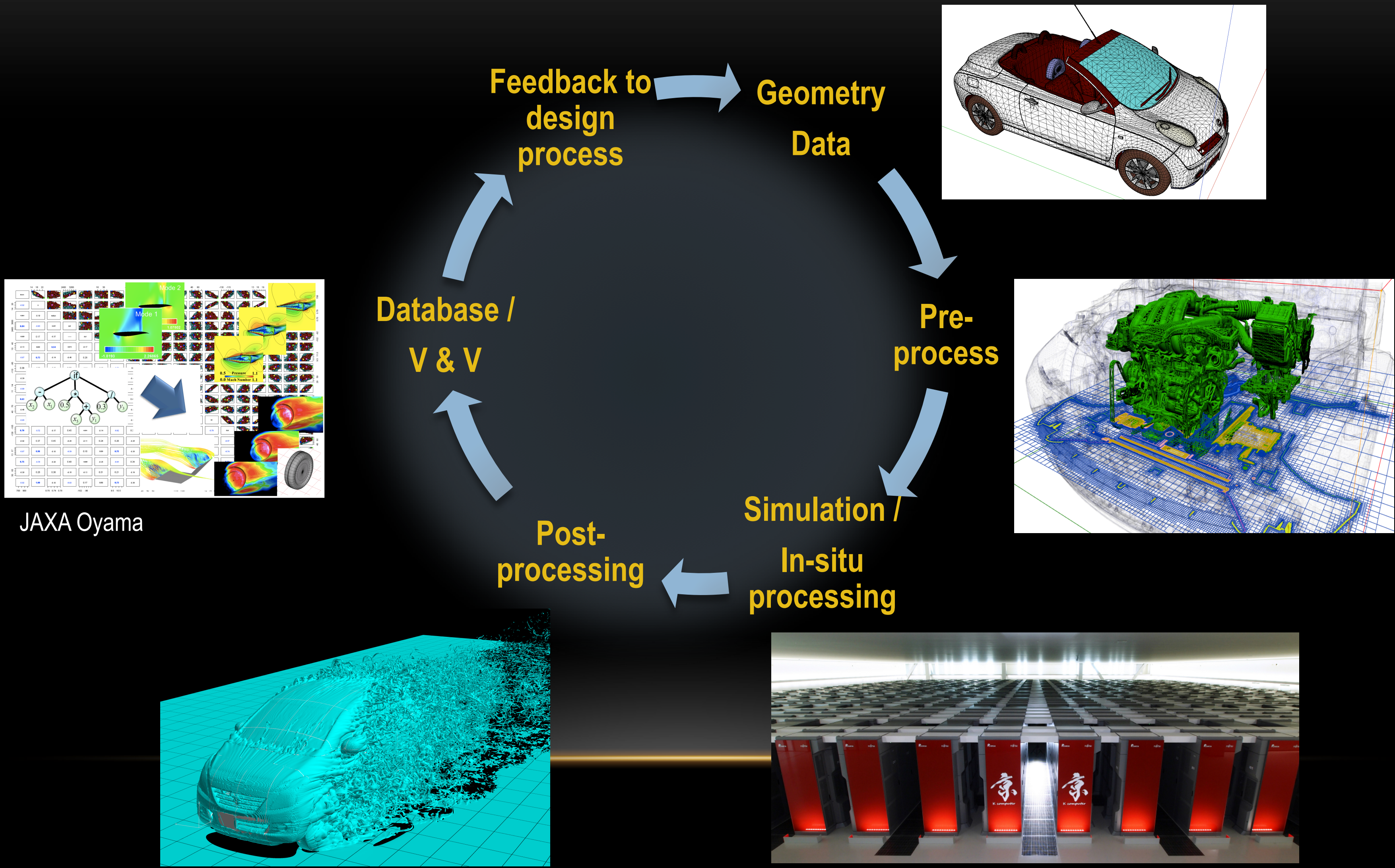


Vorticity distribution on ship surface (Kato, UTokyo)

IMPACT OF HPC FOR PRODUCT DESIGN

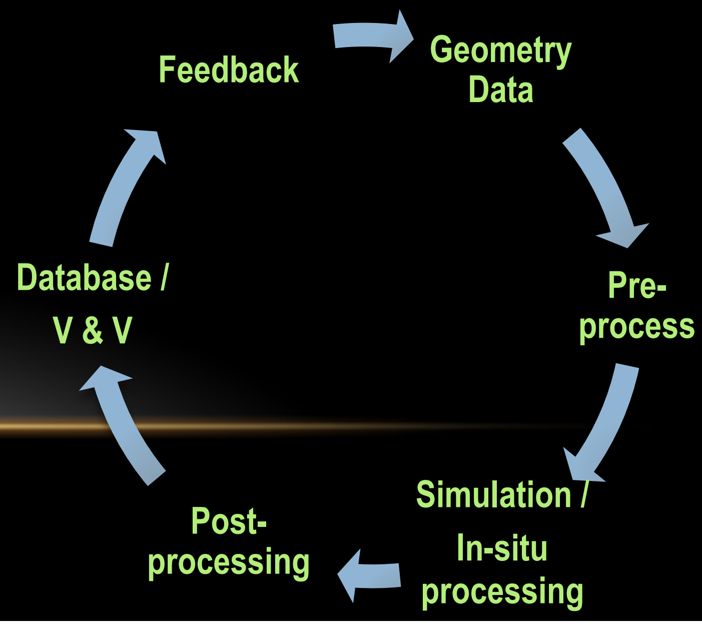
- HPC will change a style of product design
  - Reduce time cost
    - A solution in a short period of time
    - Many trials in shot turnaround time
      - Parametric study with details becomes feasible > MOO
  - Increase reliability
    - Reliability becomes higher as the resolution increases with LES.
  - Tackle complicated phenomena
    - More physics

SIMULATION PROCESS IN INDUSTRIAL APPLICATION



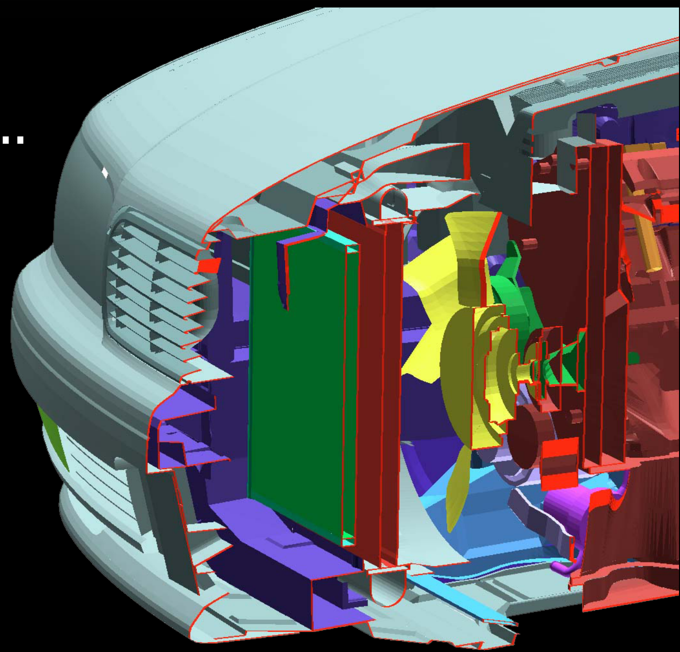
ISSUES TO BE ADDRESSED FOR LARGE-SCALE CFD

- Analysis model
  - Grid generation of 10G-100G range, file based method is distant
- Parallel computation
  - Performance, load balancing
- Post-processing
  - Parallel visualization and data exploration for large-scale dataset
  - Data re-use
- Other keys
  - File handling and file I/O performance
  - Automation by workflow
  - Database



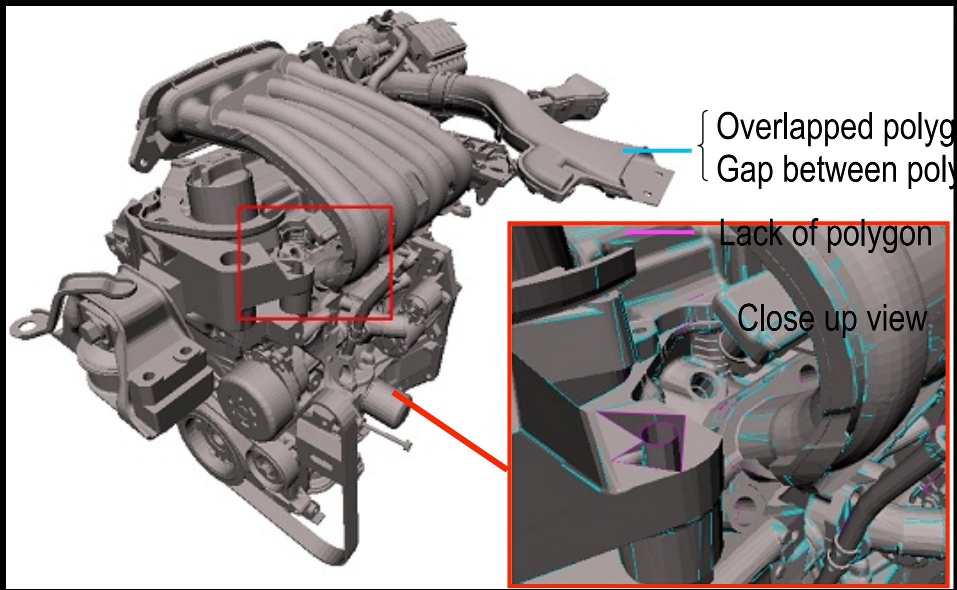
ISSUES OF LARGE-SCALE GRID GENERATION FOR COMPLEX GEOMETRY

- Conventional method >> Interactive
  - is operated on PC
    - Limited memory, CPU power, disk size,…
  - File size becomes huge
    - File IO cost
    - Data transfer time



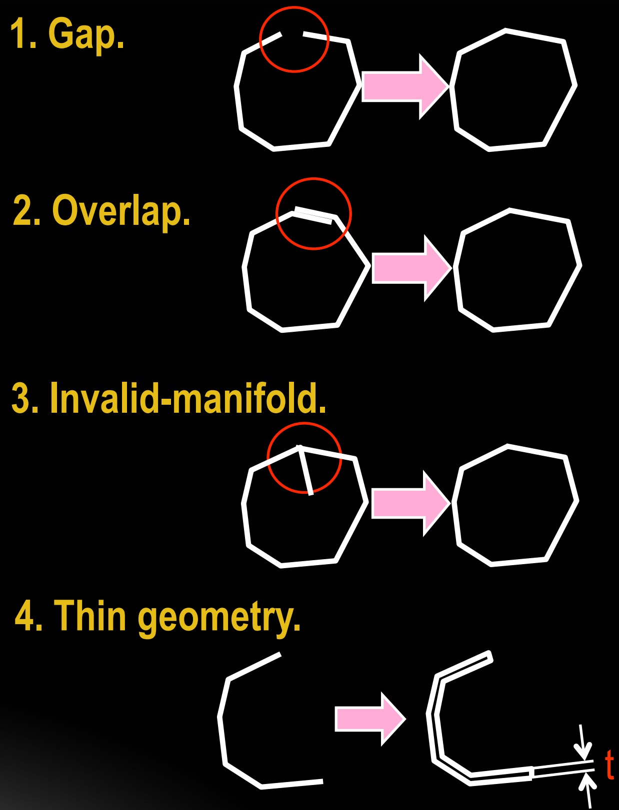
- Change paradigm
  - Not generate a grid system
  - Instead, transfer information to a background Cartesian mesh

DIRTY GEOMETRY ISSUE



Incomplete polygon data of an automotive engine.

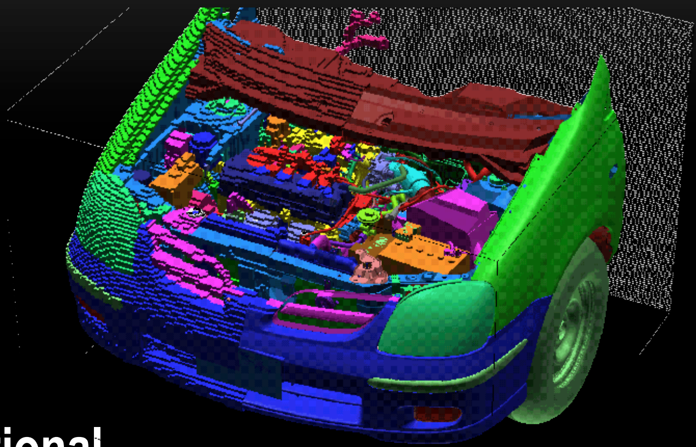
Water tightness is required to generate a grid system.



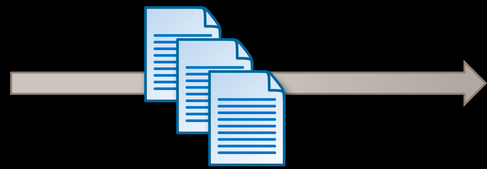
Typical examples of repaired polygons.

FROM PRE-PROCESS TO ON THE FLY

- Generate grid before computation
- Quality depends on operators
- Need time to transfer files



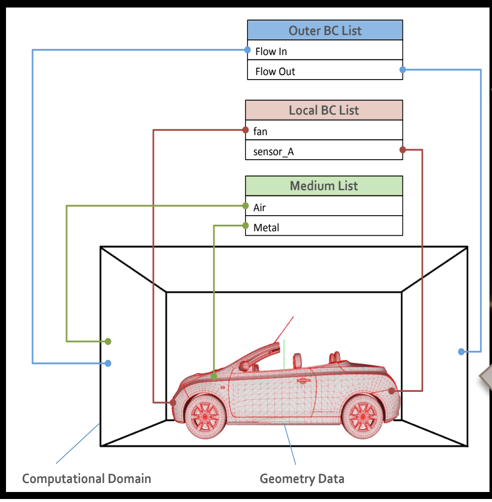
Conventional



Prepare decomposed grid file for a specific number of divisions

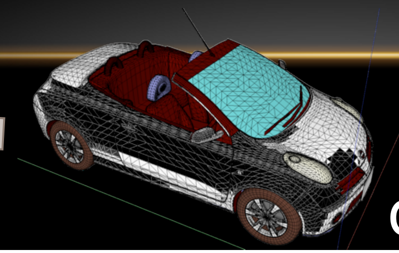
Parallel Computation

Automatic grid generation




```
DomainInfo {
  Global_origin   = (-0.5, -0.5, -0.5   )
  Global_region   = (1.0,  1.0,  1.0    )
  Global_voxel    = (64   , 64   , 64   )
  Global_division = (1    , 1    , 1    )
  ActiveSubDomain_File = "hoge"
}
```

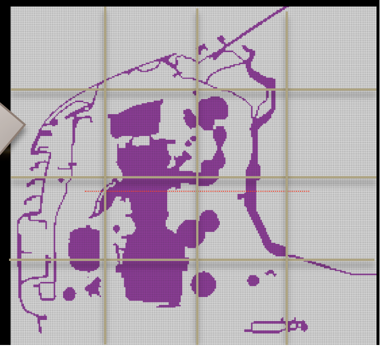
Domain information & BC (Ascii)



Geometry

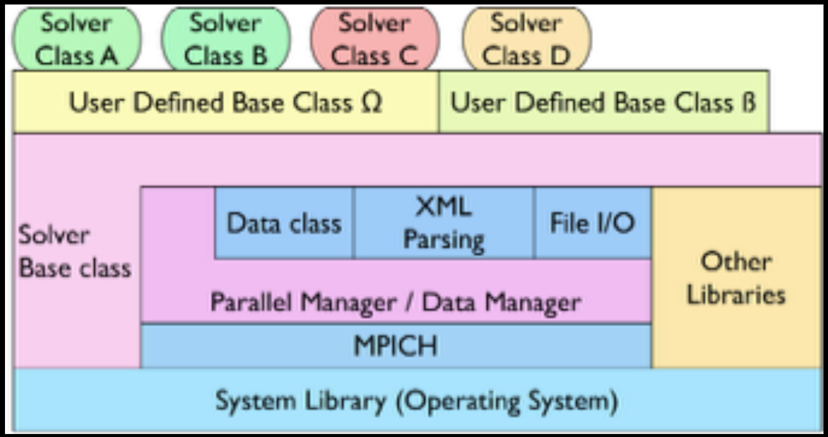
Parallel Computation

Robust Algorithm

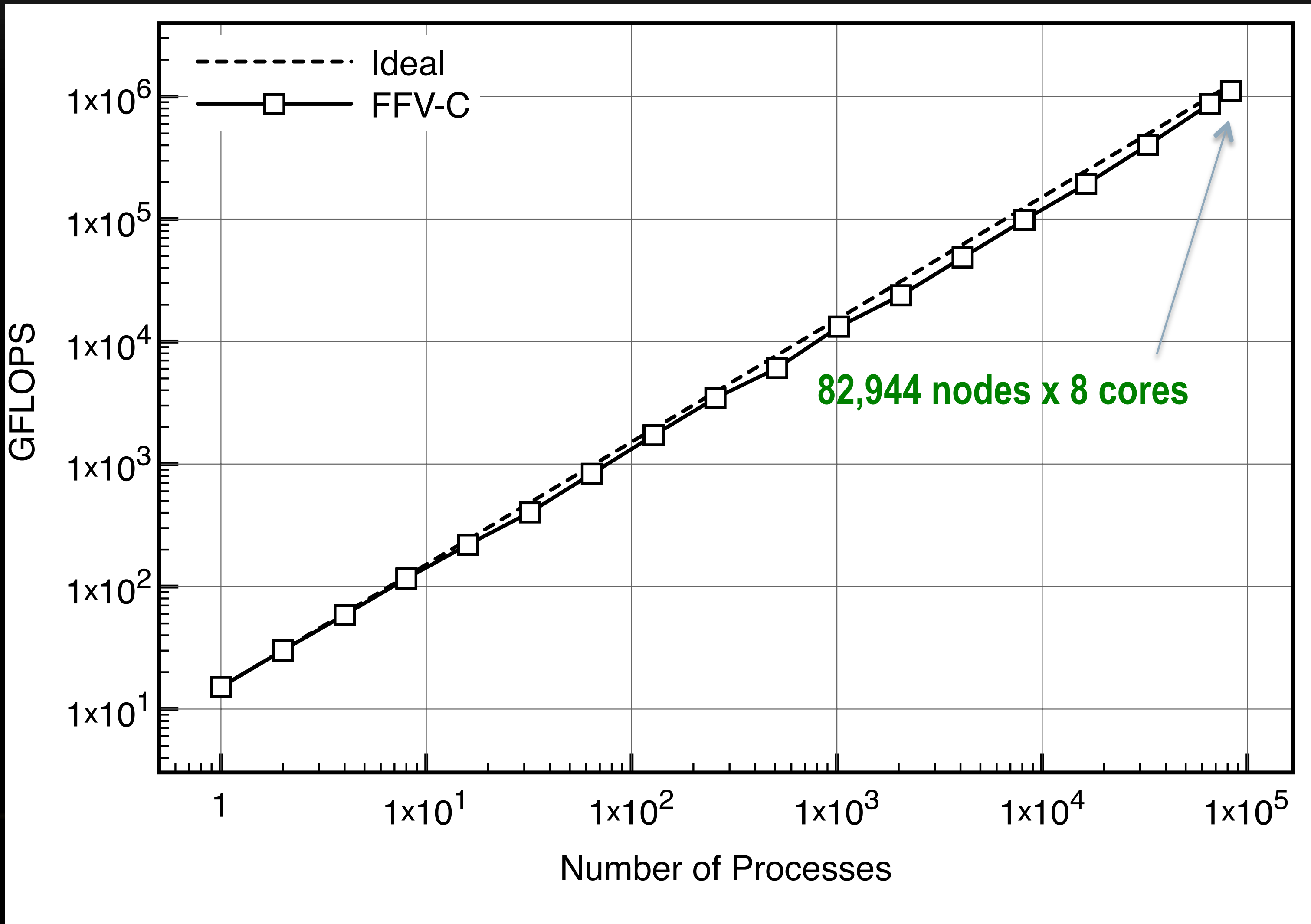


HYBRID PARALLEL COMPUTING FRAMEWORK

- Domain specific framework
  - Domain decomposition for Cartesian data structure
  - Hybrid parallel computation
  - Object-oriented tech.
- Excellent scalability on K computer
  - 90% at 82,944 processes
- File management of distributed files
  - Compression aware
  - Streaming

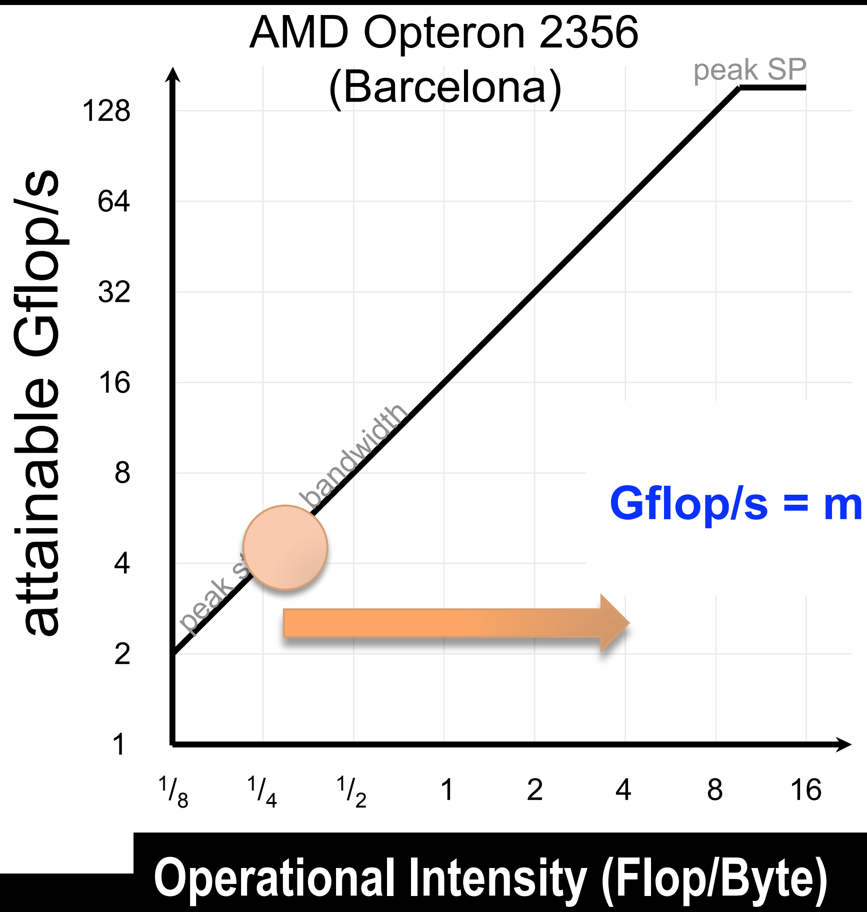


HYBRID PARALLEL PERFORMANCE



HOW TO MAXIMIZE PERFORMANCE?

- Roofline Model [Williams, Commn. ACM. **52**(4), 2009.]



- Peak roofline performance
- based on manual for **single precision peak**
- and a hand tuned stream read for bandwidth

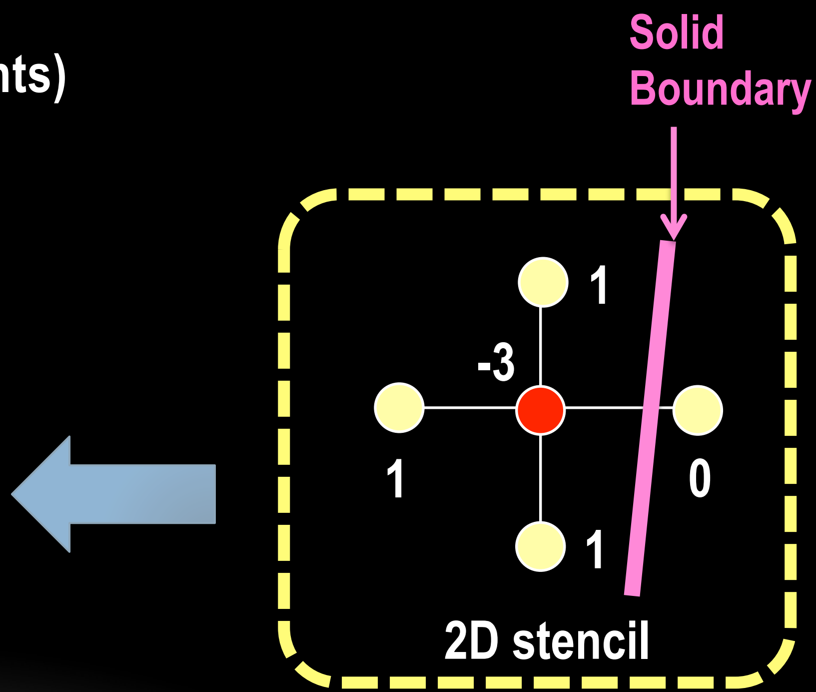
Gflop/s = min { Peak Gflop/s ; Stream BW * actual flop:byte ratio }

To increase OI, i.e., Flop/Byte in a loop

SIMPLE IDEA

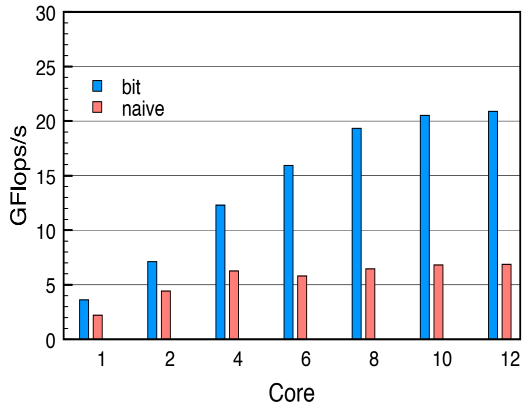
- Elements in coefficient matrix are small figures, which can be expressed by fewer bits
    - ‘0’ or ‘1’ >> 1 bit (non-diagonal elements)
    - ‘0-6’ >> 3 bits (diagonal element)
- Reduce the amount of data transfer

```
| -4  1              1      |
|  1 -4  1              1   |
|     1 -3  0              1|
|        1 -4  1            |
|  1        1 -4  1         |
|     1       ...           |
```

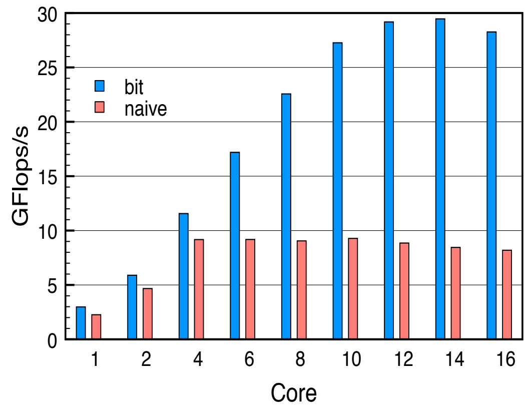


K. Ono, VECPAR 2014

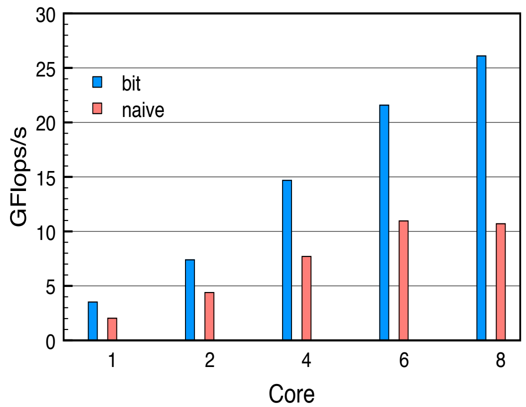
PERFORMANCE (NAÏVE VS BIT-REPS)



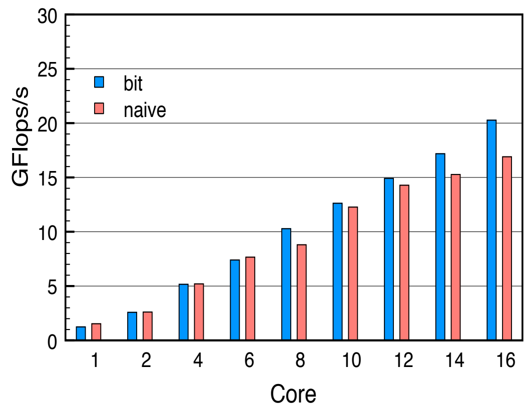
(a) Intel Westmere X5650.



(b) Intel SandyBridge E5-2670.



(c) Fujitsu Sparc Venus VIIIfx.

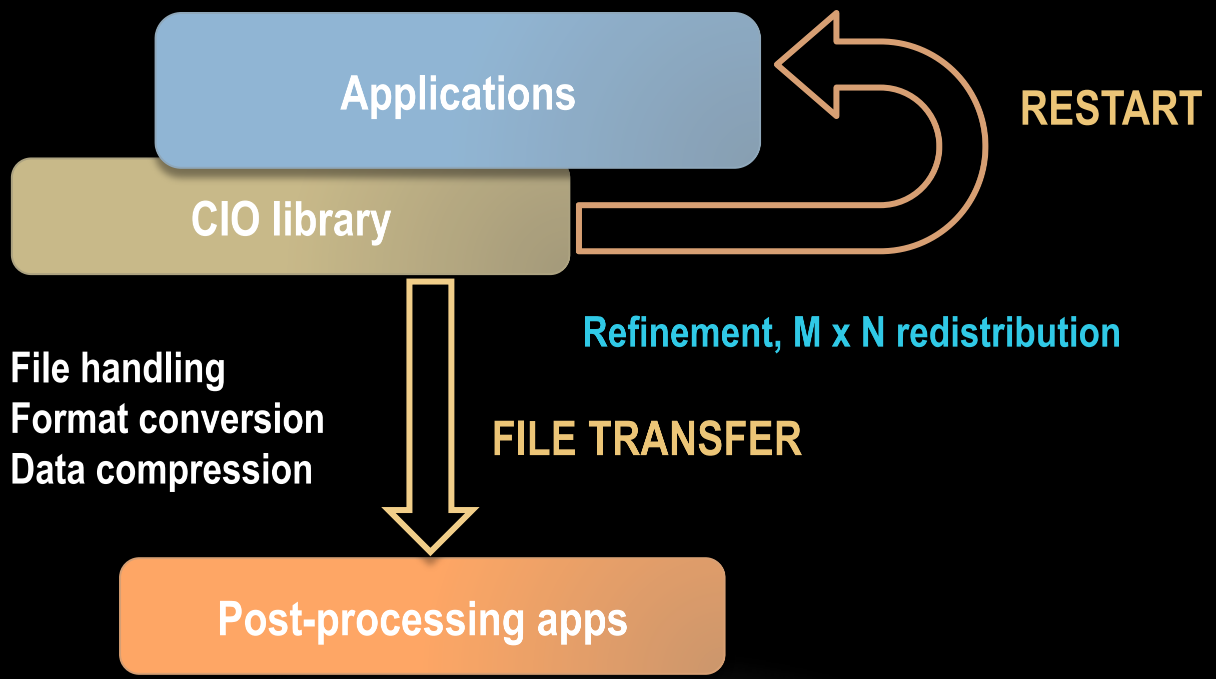


(d) Fujitsu Sparc Venus IXfx.

Fig. 4: Comparison of thread parallel performance of each machine. The problem size is chosen to 256^3 so that the data resides in main memory.

I/O ISSUE

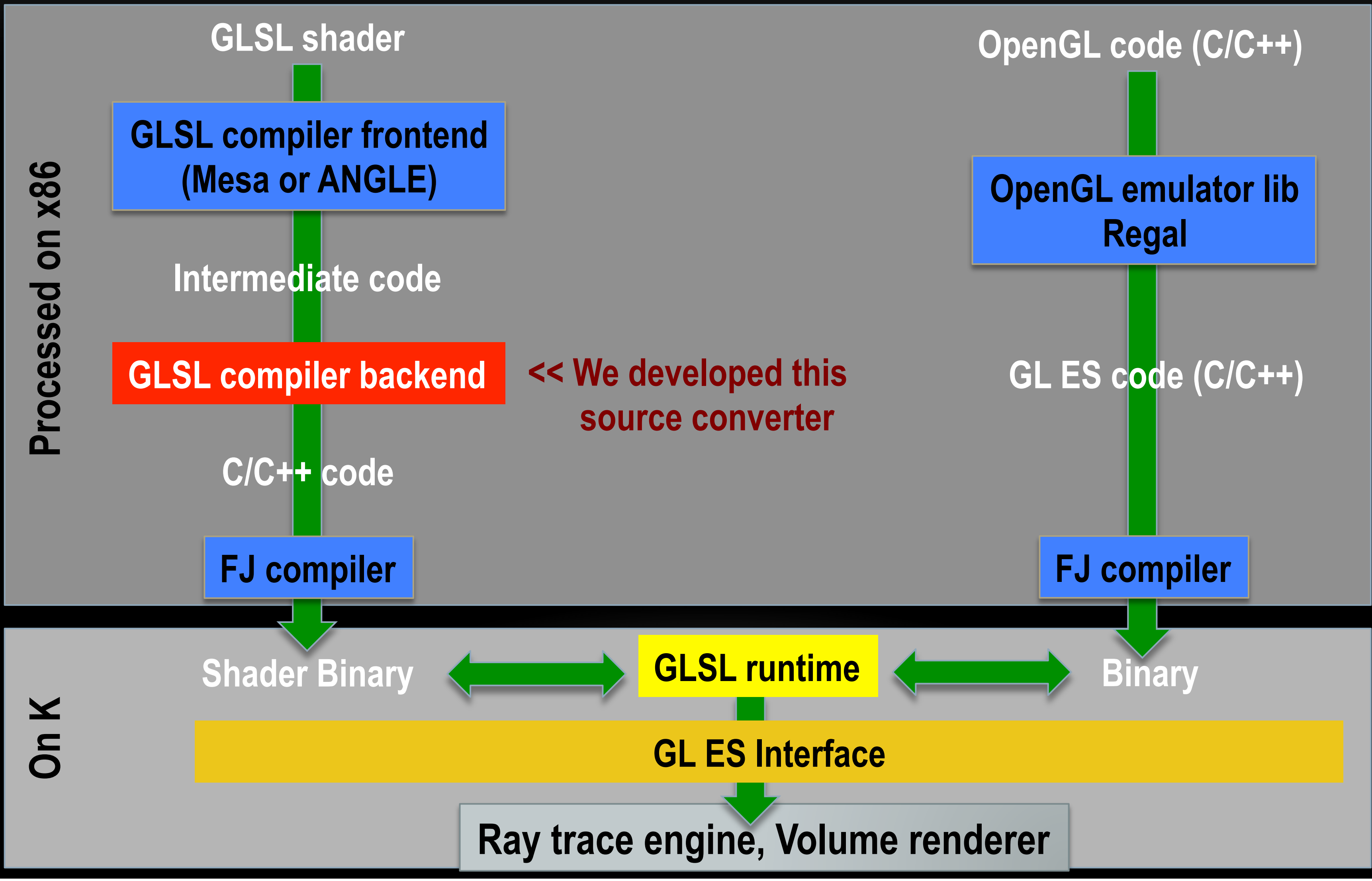
File management function for Cartesian data structure on distributed parallel environment



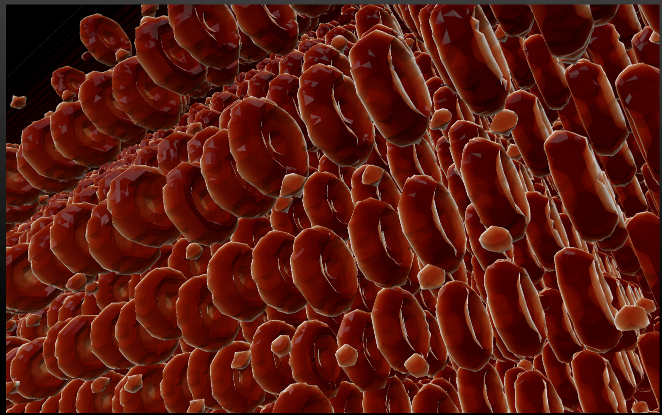
ISSUES FOR LARGE-SCALE DATASET IN POST-PROCESSING

- Data size is large and numerous files
- Data operation becomes costly
- Data can not be moved !
- Visualization must be processed on the machine where data exists.
- We need a renderer that works on K computer

SURFACE – SCALABLE & UBIQUITOUS RENDERING FRAMEWORK FOR ADVANCED COMPUTING ENVIRONMENTS

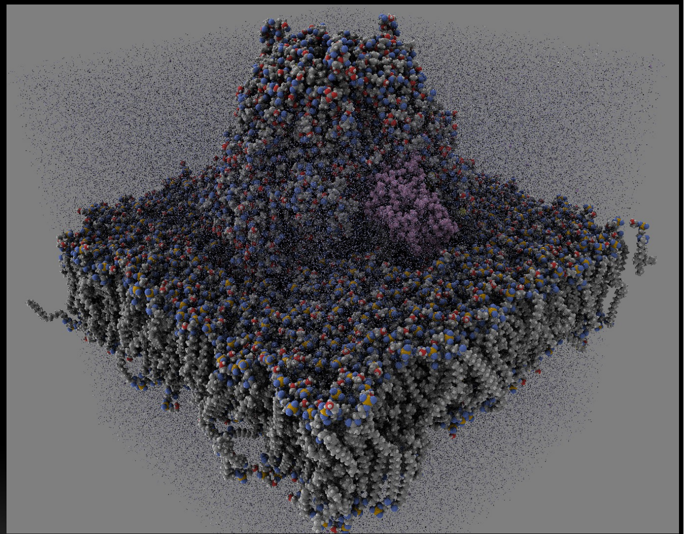


VIS. SYSTEM ON K-COMPUTER



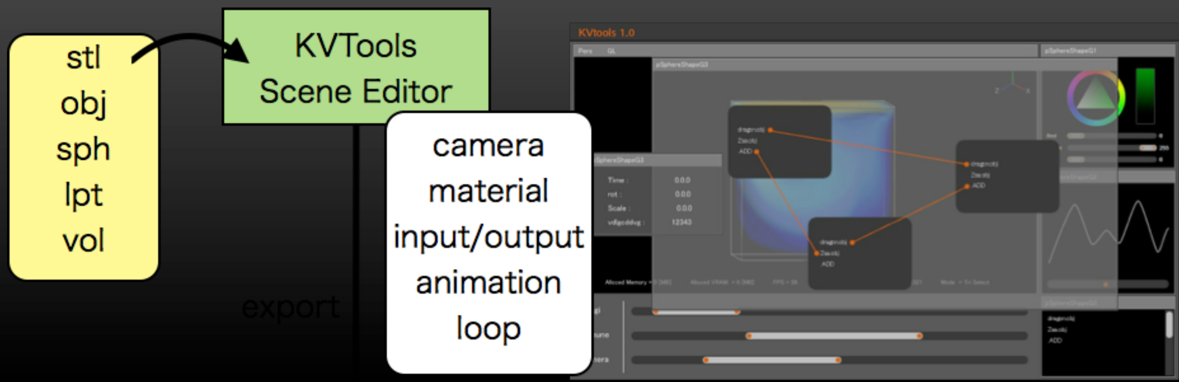
- Handle large-scale distributed data files
  - CIO library
- Direct rendering on K
  - Common rendering core for both on PC (/w GPU) and on K >> GLSL/GLES API, not OpenGL
  - Ray tracer and Volume renderer

Rasterlizer -> O(N)
Ray tracer -> O(logN)

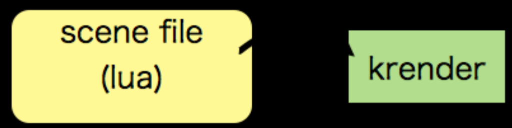


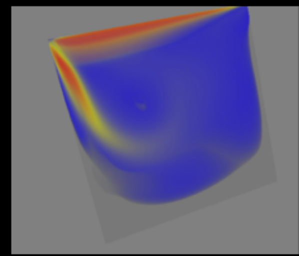
  - Sort-last type parallel renderer
  - For Cartesian, UNS, particles data structure
  - Currently, batch and interactive(x86 /w GPU)
  - Bring exascale into view

HIVE

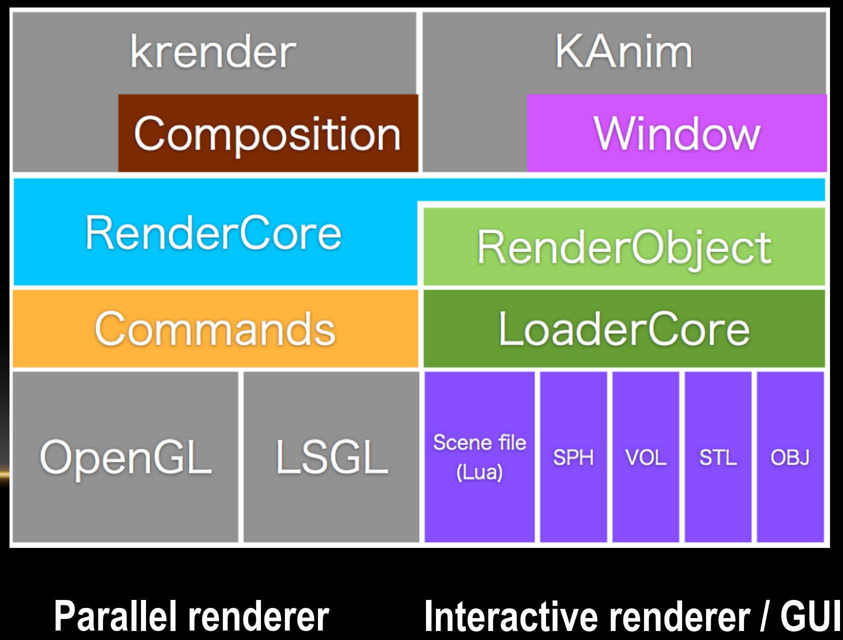


- **Heterogeneously Integrated Visualization Environment**





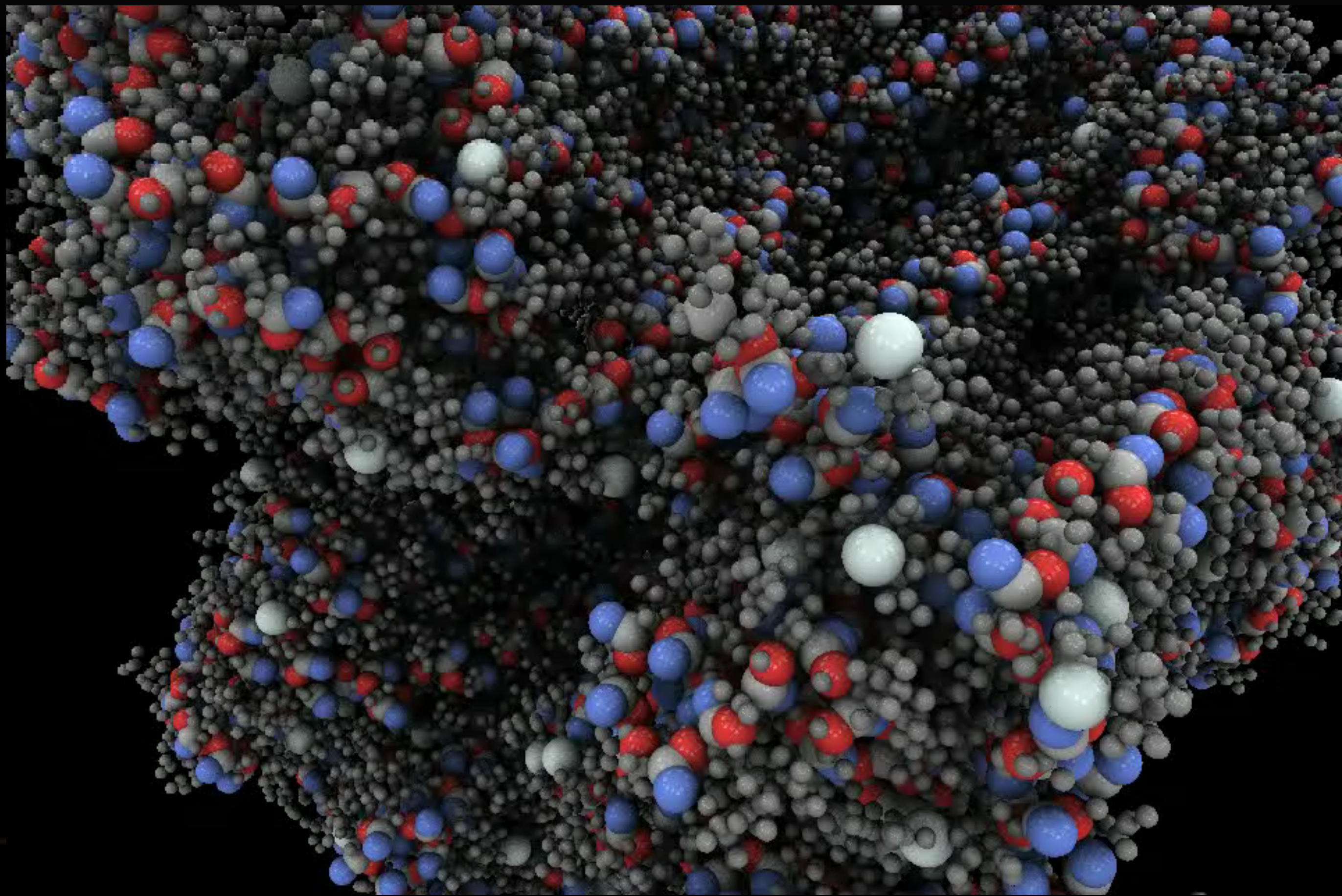
- **Parallel visualization system in AICS**
    - **Scene Editor for visualization scenario**
    - **krender : image generation**
    - **Can be operated on local or remote machines**
    - **Batch job with visualization scenario**



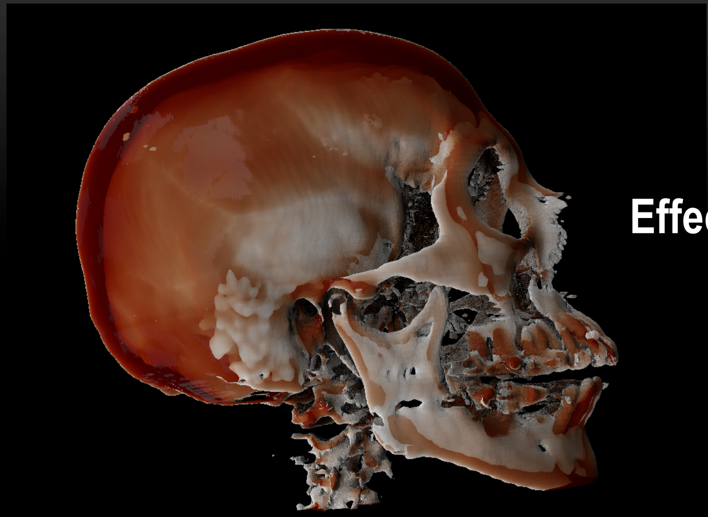
Performance of Volume renderer on K

32k Parallel, 8192^3 volume, 16k x 8k image
>> 6 min / image

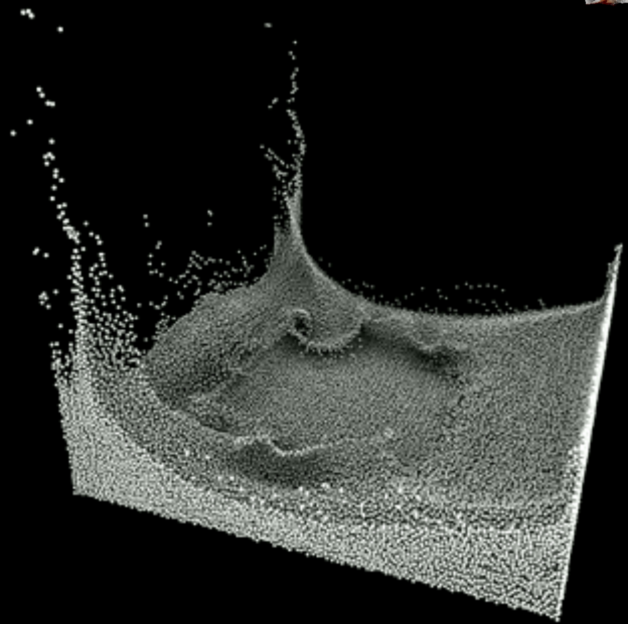
HIGH RES. RENDERING IMAGE



EXAMPLES



Effect of sub-surface scattering



Resolution of 4096 x 4096 pixels, Asian Dragon

FLOW WITH DEFORMED RBC

ZZ-EFSI

Prof. Takaki & Sugiyama @UT

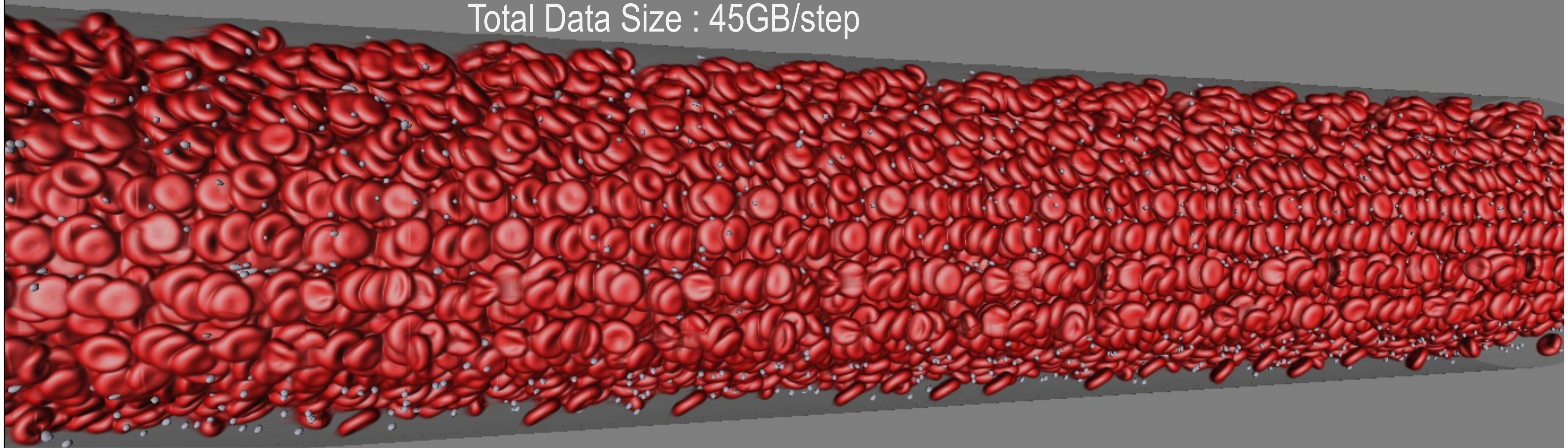
70,000 Step

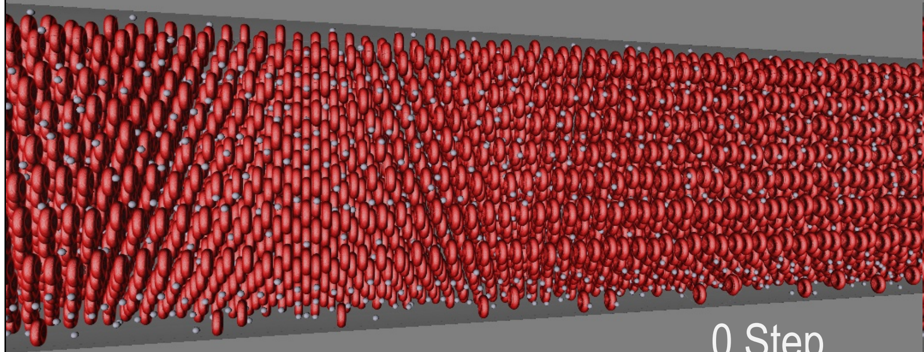
Voxels per Domain : 66 x 66 x 66

Num of Domain : 4,800

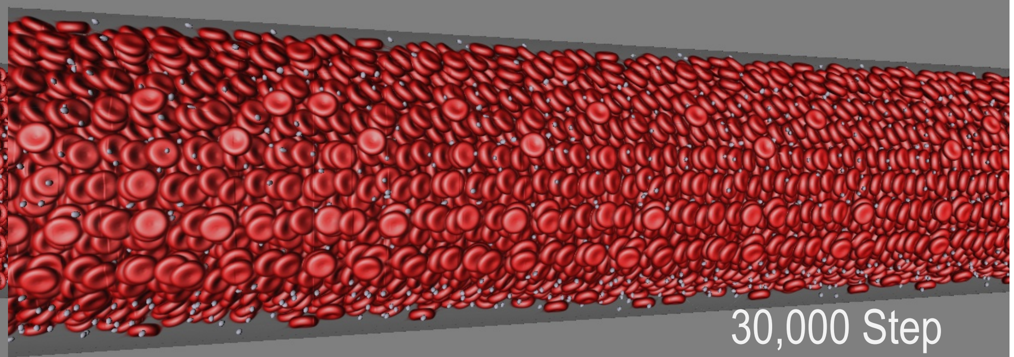
Num of Data : Scalar X 3(Red Blood Cell, Platelet, Blood Vessel Wall)

Total Data Size : 45GB/step



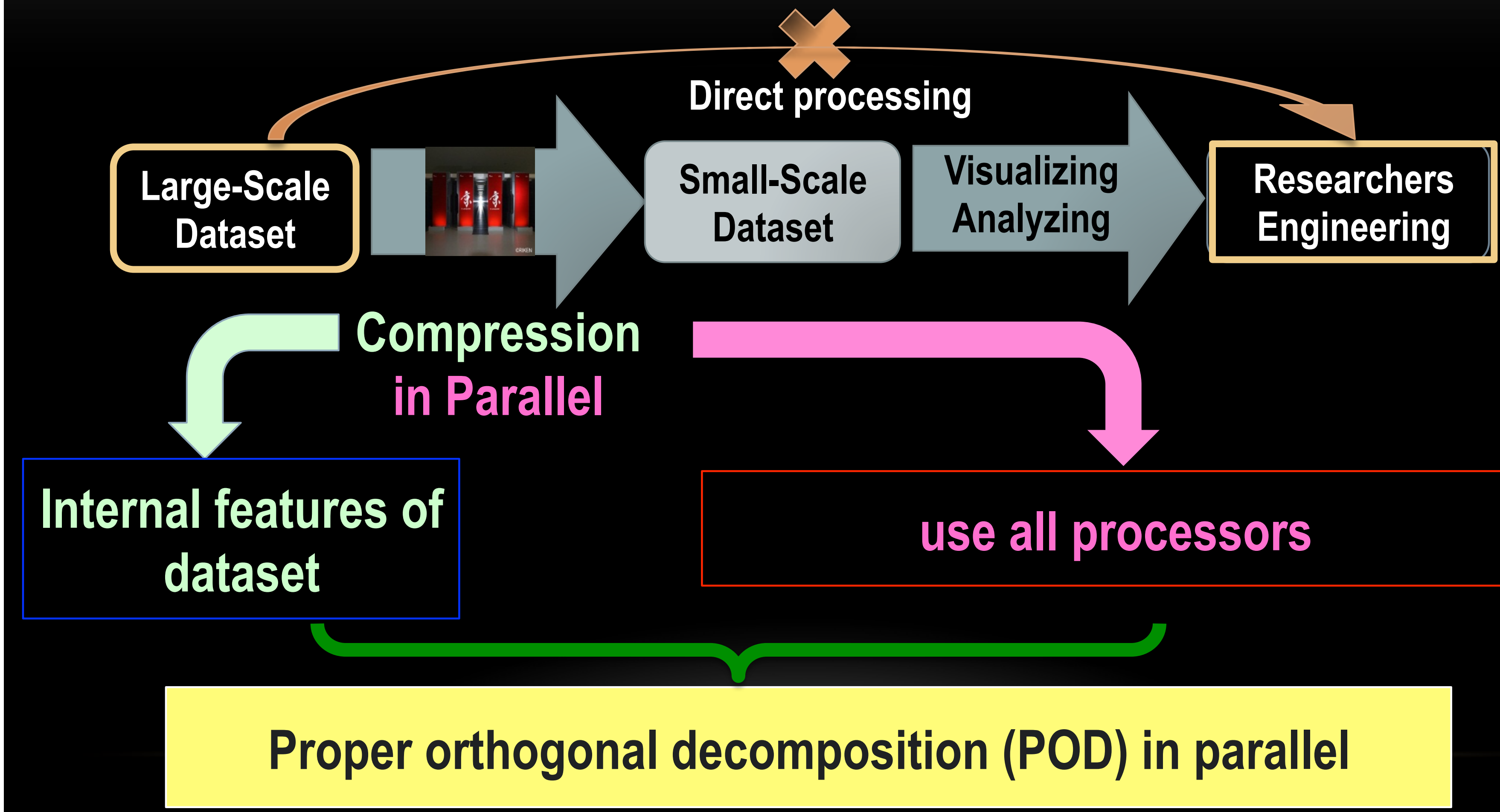


0 Step

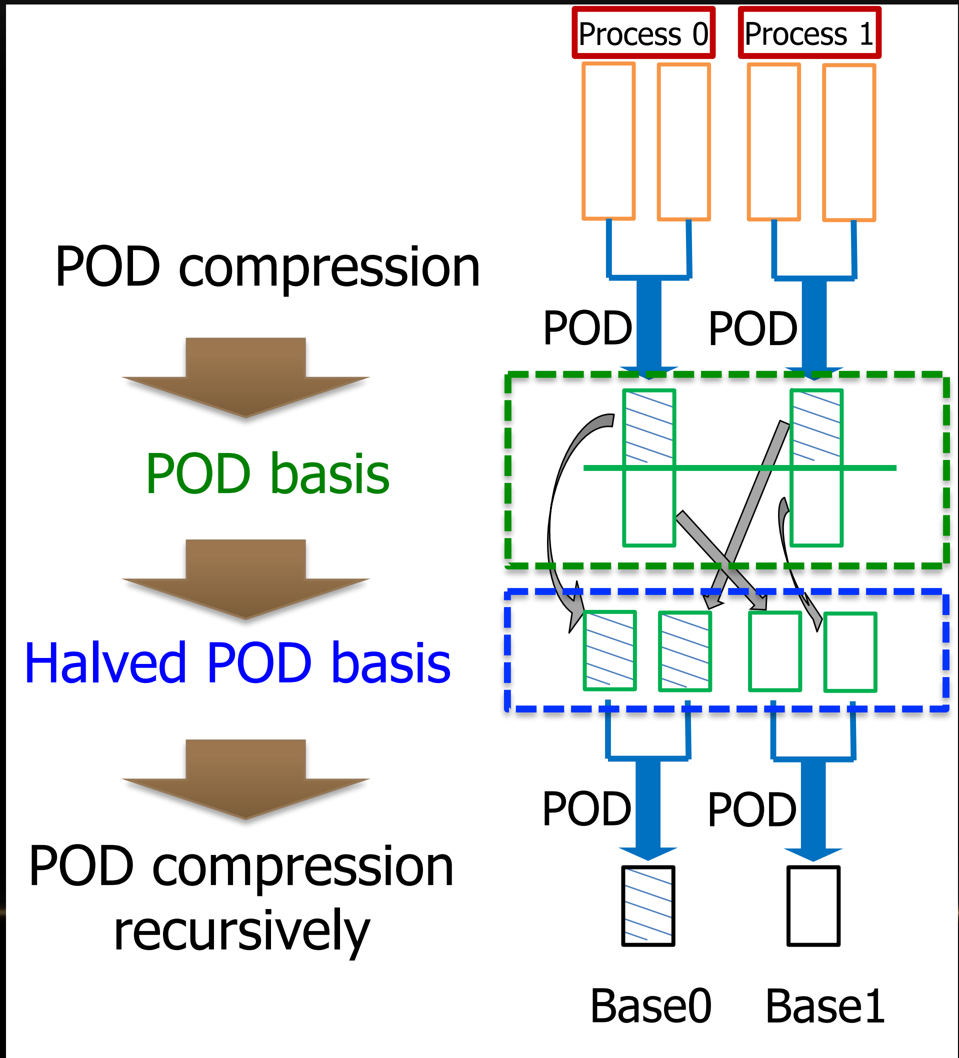


30,000 Step

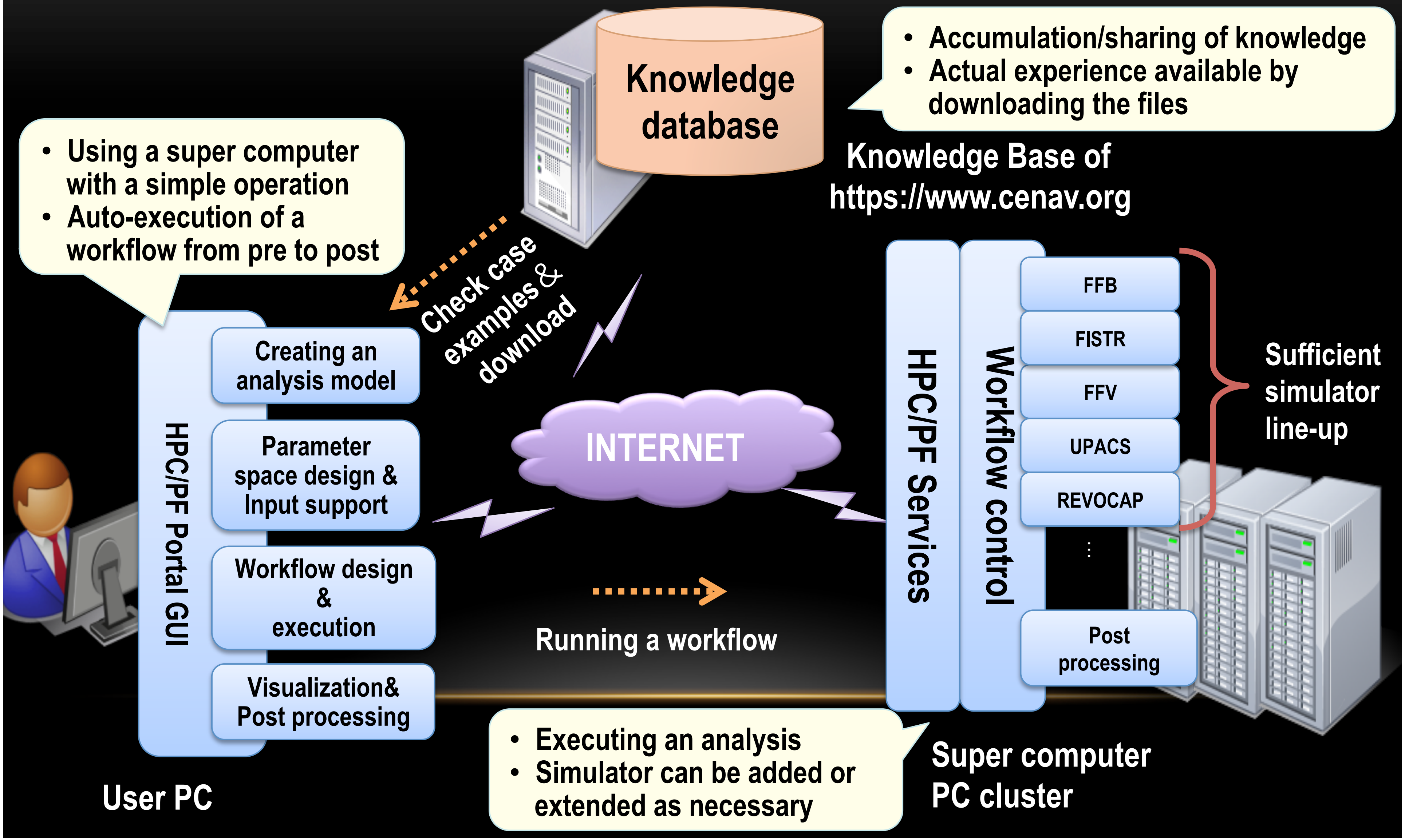
TEMPORAL DATA COMPRESSION



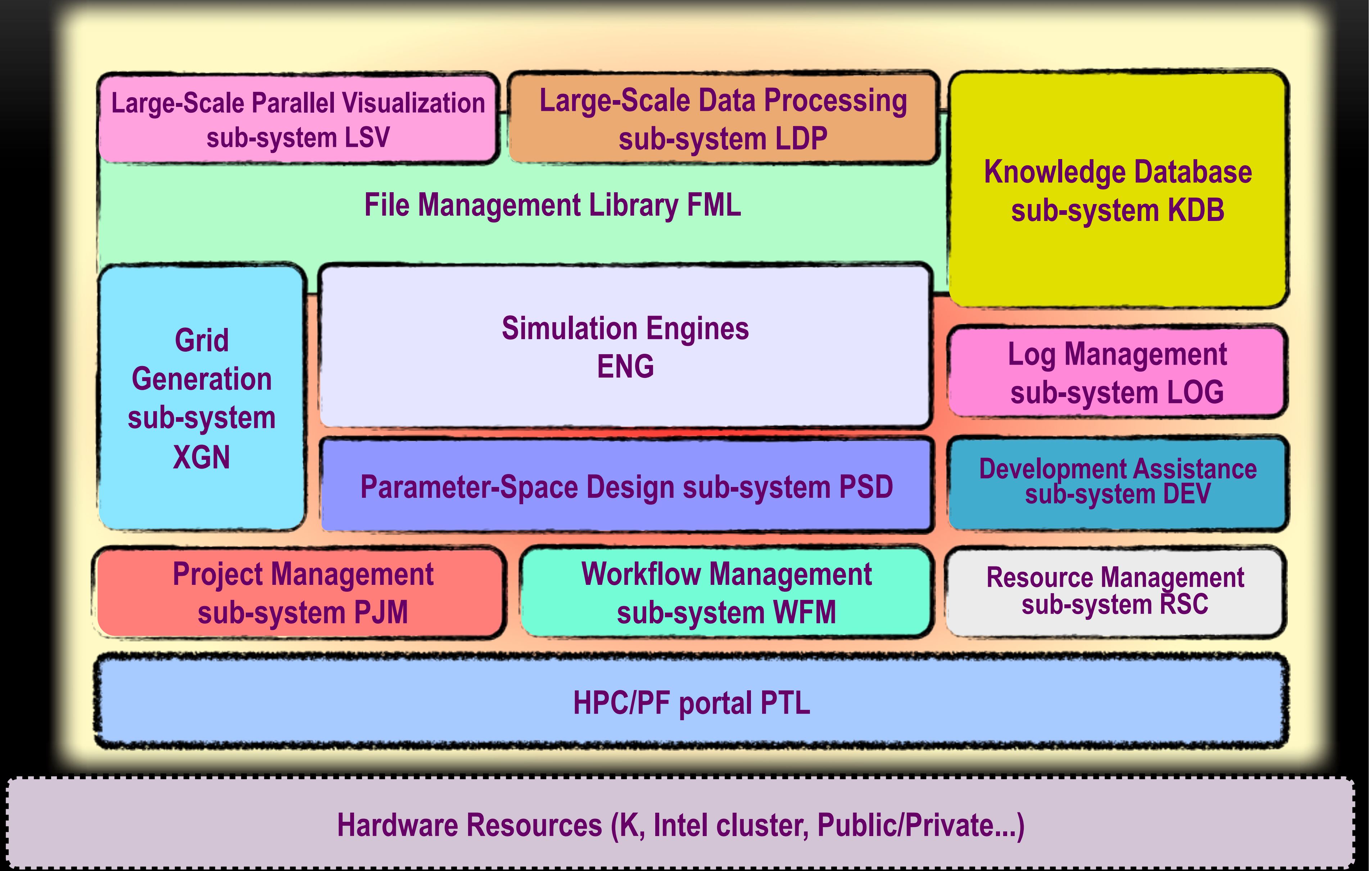
POD COMPRESSION IN PARALLEL



EXECUTION ENVIRONMENT IN HPC

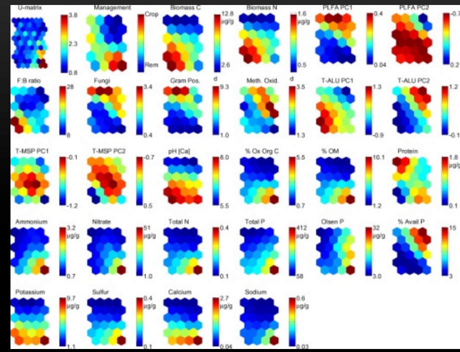


COMPONENTS OF EXECUTION ENVIRONMENT

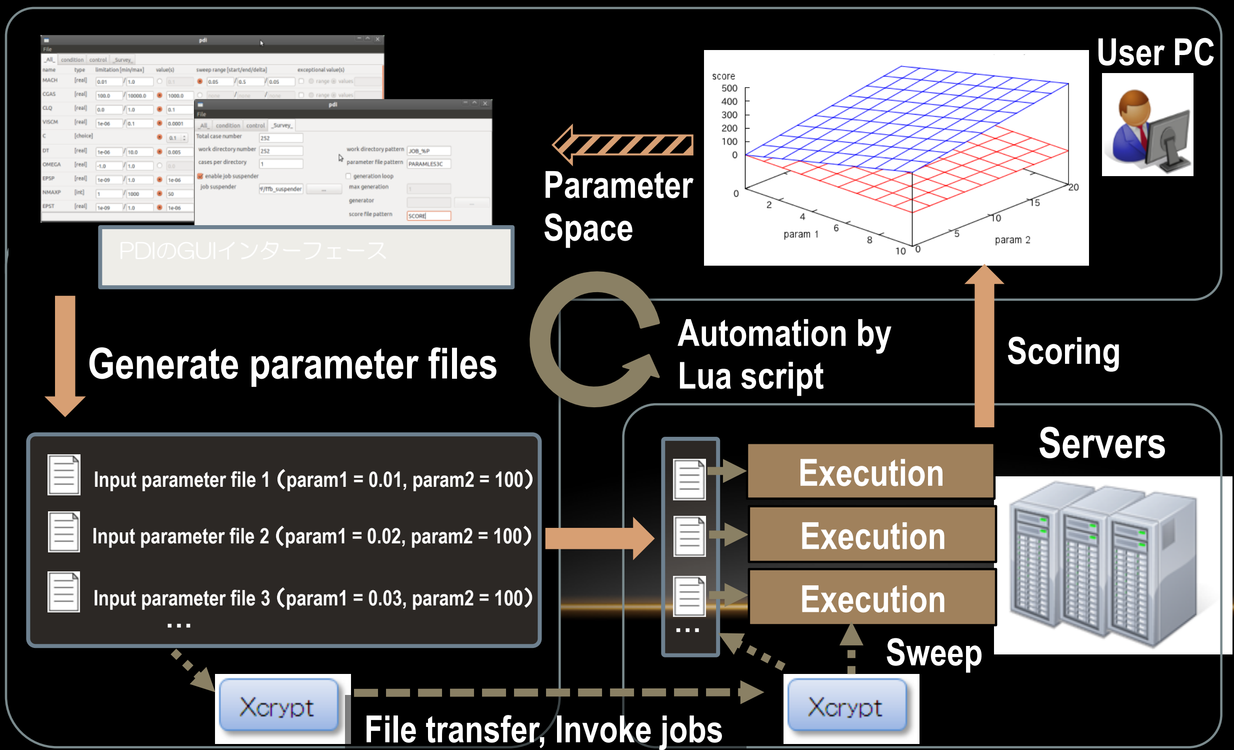


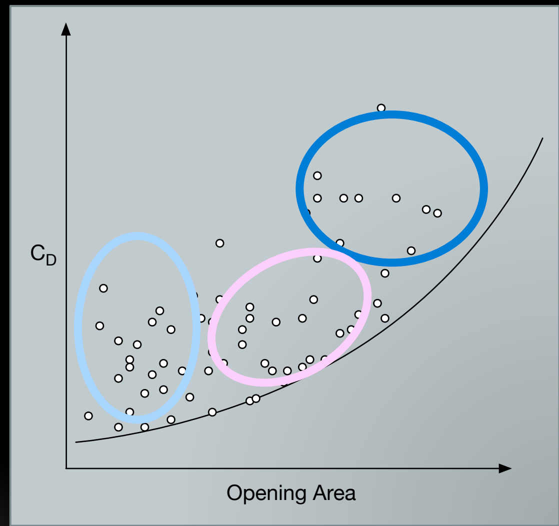
GRID SEARCH

- Optimization
- Many calculations for different parameters against design variables
- Search optimal parameters in the parameter space



Sensitivity Map





Clustering Analysis

CONCLUDING REMARKS

- For engineering
  - A useful execution environment will be required for practical problems.
  - It is a key to exploit HPC effectively at the upstream of manufacturing process.
  - Data management and workflow plays an important role than ever.
- Performance
  - Cooperation of physics and computer science push exascale apps.
- Open Challenges
  - Scalable Analytic framework that combines visualization system.
  - In-situ and interactive post-processing in a massively parallel environment.