The “How” of Exascale

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June 28, 2011
MEXT Symposium Panel

DoE Exascale 性能指標

System attributes	**"2010"**		**"2015"**		**"2018-20"**	
System peak	2 PetaFlops		100-200 PetaFlops		1 ExaFlop	
Power	Jaguar 6 MW	TSUBAME 1.3 MW	15 MW		20 MW	
System Memory	0.3PB	0.1PB	5 PB		32-64PB	
Node Perf	125GF	1.6TF	0.5TF	7TF	1TF	10TF
Node Mem BW	25GB/s	0.5TB/s	0.1TB/s	1TB/s	0.4TB/s	4TB/s
Node Concurrency	12	O(1000)	O(100)	O(1000)	O(1000)	O(10000)
#Nodes	18,700	1442	50,000	5,000	1 million	100,000
Total Node Interconnect BW	1.5GB/s	8GB/s	20GB/s		200GB/s	
MTTI	O(days)		O(1 day)		O(1 day)	

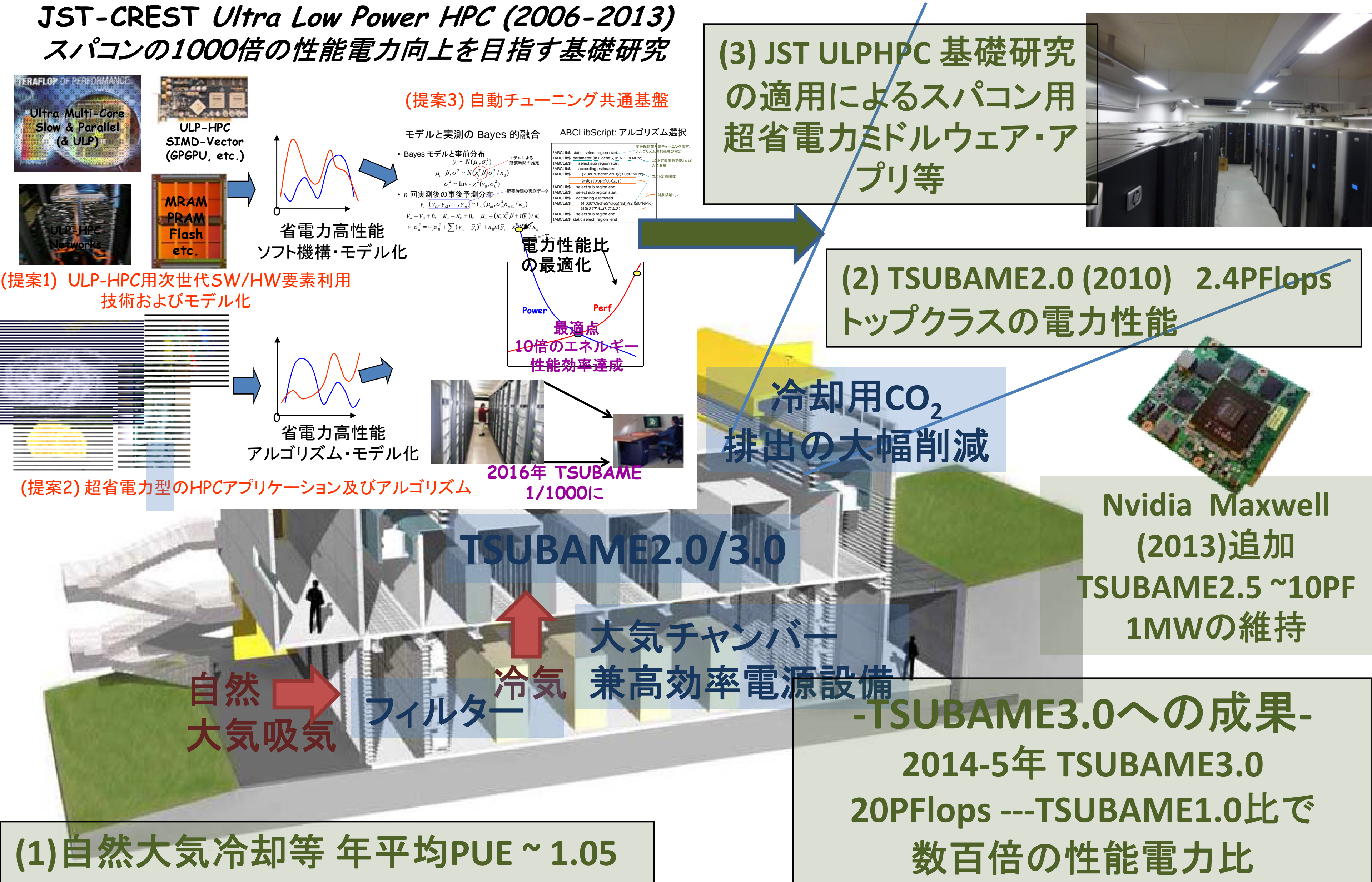
Important Strategy Towards Exascale

- ***Identify Key Application Areas (incl. Stakeholders)***
  - Disaster, Environment, Energy, Life/Medical, etc...
- ***Identify Technology Strength (of Japanese HPC)***
  - Device, Archiecture, Software, Applications
- ***Identify the Impediments and do Research***
  - Power, Resiliency, Programming, ...
- ***Learn from Existing Systems***
  - ES2, T2K, Tsubame2.0, K Computer ...
- ***Set Performance and other Metric Timelines***
  - 2010 1PetaFlop (done), 2012 10PetaFlops (to be done), 2015 100PetaFlops, 2018 ExaFlops, etc...

「エクサ10億並列へ」は勇ましいが。。。

- *電力・エネルギー (JST CREST ULPHPC + MEXT Green HPC)*
- (強)スケーリングの欠落 (Co-Design Center)
- *N^2 vs. N 問題により深まるメモリ階層*
  - *(ネットワークやI/O含む)*
  - *(レーテンシとバンド幅) (Device & Architecture)*
- 極端に低まる信頼性と実行不能性 (科研基盤S)
- *プログラミングや実行モデル (JST CREST Post Petascale)*

JST-CREST ULP-HPCの成果適用による スパコンのウルトラグリーン化(H23~概算要求)



ULP-HPC 遂行計画・マイルストーン

2007Q3

基礎開発

各種要素技術の研究開発
- マルチコア・アクセラレータ関係の種々の電力最適化アルゴリズム・プログラミング機構・コンパイラ等
- 新世代メモリ利用を含むプログラム
- VMベースのシステム全体の電力最適化
- 低消費電力・高性能ネットワークの設計活用
- 流体構造および分子科学における省電力高性能アプリケーションアルゴリズム
-上記の電力性能モデル化、自動チューニング適用
-電力性能自動チューニング基盤(理論・システム)

-各種テストベッドでの実際のソフトウェア機構開発・モデルの制定・自動チューニング
-モデルベースのシミュレーション遂行・大規模性能電力最適化シミュレーション
-一部HW小プロトタイプの開発

TSUBAME2.0の設計

2009Q1

第一次統合化

各種要素技術の連携・統合開始
- 各要素のモデルベースを統合化した自動チューニングシステムを開発
- 結果をTSUBAME2.0の設計に反映

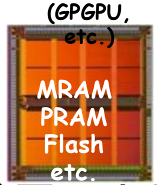
他の関連マシン

2010Q3

TSUBAME 2.0 完成・設置: 本研究の成果を用い<u>20倍以上の性能向上</u>を達成

新基盤上での更なる開発・最終統合化

ULP-HPC SIMD-Vector (GPGPU, etc.)

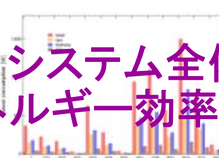


HWの要素活用によるポテンシャル x3~x30

アプリ最適化(x2)・
システム最適化 x2(平均)
冷却最適化 (x2)

2013Q4

自動チューニングで両ポテンシャル最大化・システム全体平均で10倍程度のエネルギー効率化



TSUBAME3.0の設計(2014年度完成)

Power Efficiency Compared

Machine	Power (incl. cooling)	Linpack Perf (PF)	Linpack Mflops/W	Factor	
Tsubame1.0 (2006Q1)	1.8MW	0.038	21	2368	
ORNL Jaguar (2009Q4)	~9MW	1.76	196	256	
Tsubame2.0 (2010Q4)	1.8MW	1.2	667	75	
K Computer (2011Q2)	~16MW	10	625	80	
BlueGene/Q (2012Q1)	~12MW?	17	1417	35.3	
Tsubame3.0 (2015Q1)	1.8MW	20	11000	4.6	
EXA (2018Q4)?	20MW	1000	50000	1	

Next Generation Numerical Weather Prediction[SC10]

Collaboration: Japan Meteorological Agency

Meso-scale Atmosphere Model:

Cloud Resolving Non-hydrostatic model [Shimokawabe et. al. SC10 BSP Finalist]

ex. WRF(Weather Research and Forecast)

Typhoon ~ 1000km

1~ 10km Tornado, Down burst, Heavy Rain

WSM5 (WRF Single Moment 5-tracer) Microphysics*

Represents condensation, precipitation and thermodynamic effects of latent heat release

1 % of lines of code, 25 % of elapsed time

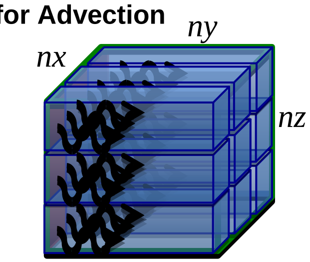
⇒ 20 x boost in microphysics (1.2 - 1.3 x overall improvement)

ASUCA : full GPU Implementation

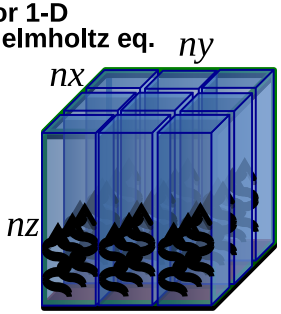
developed by Japan Meteorological Agency

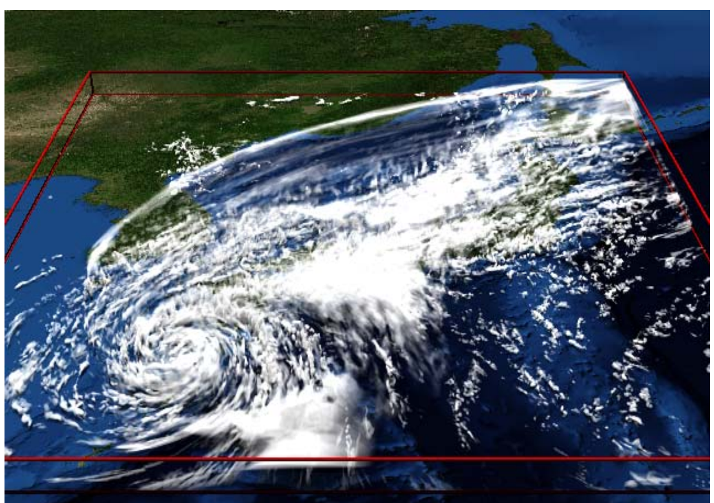
TSUBAME 2.0 : 145 Tflops World Record !!!

Block Division for Advection

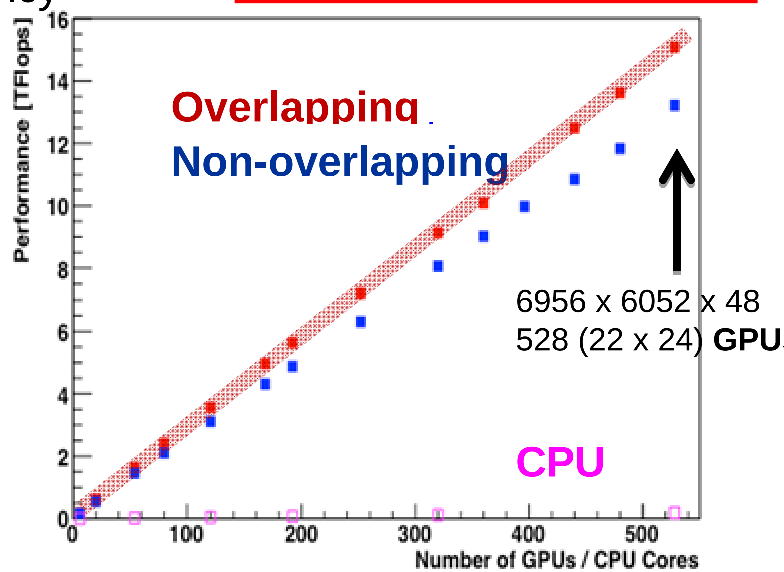


for 1-D Helmholtz eq.





Typhoon



ASUCA: Next Gen Weather Simulation Code

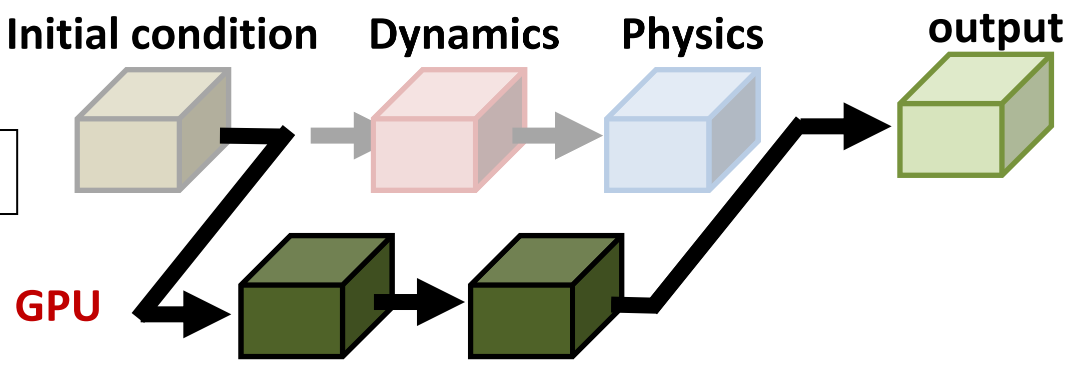
■ASUCA Production Code

- ✓ *A next-generation high resolution weather simulation code that is being developed by Japan Meteorological Agency (JMA)*
- ✓ *ASUCA succeeds the JMA-NHM as an operational non-hydrostatic regional model at JMA*

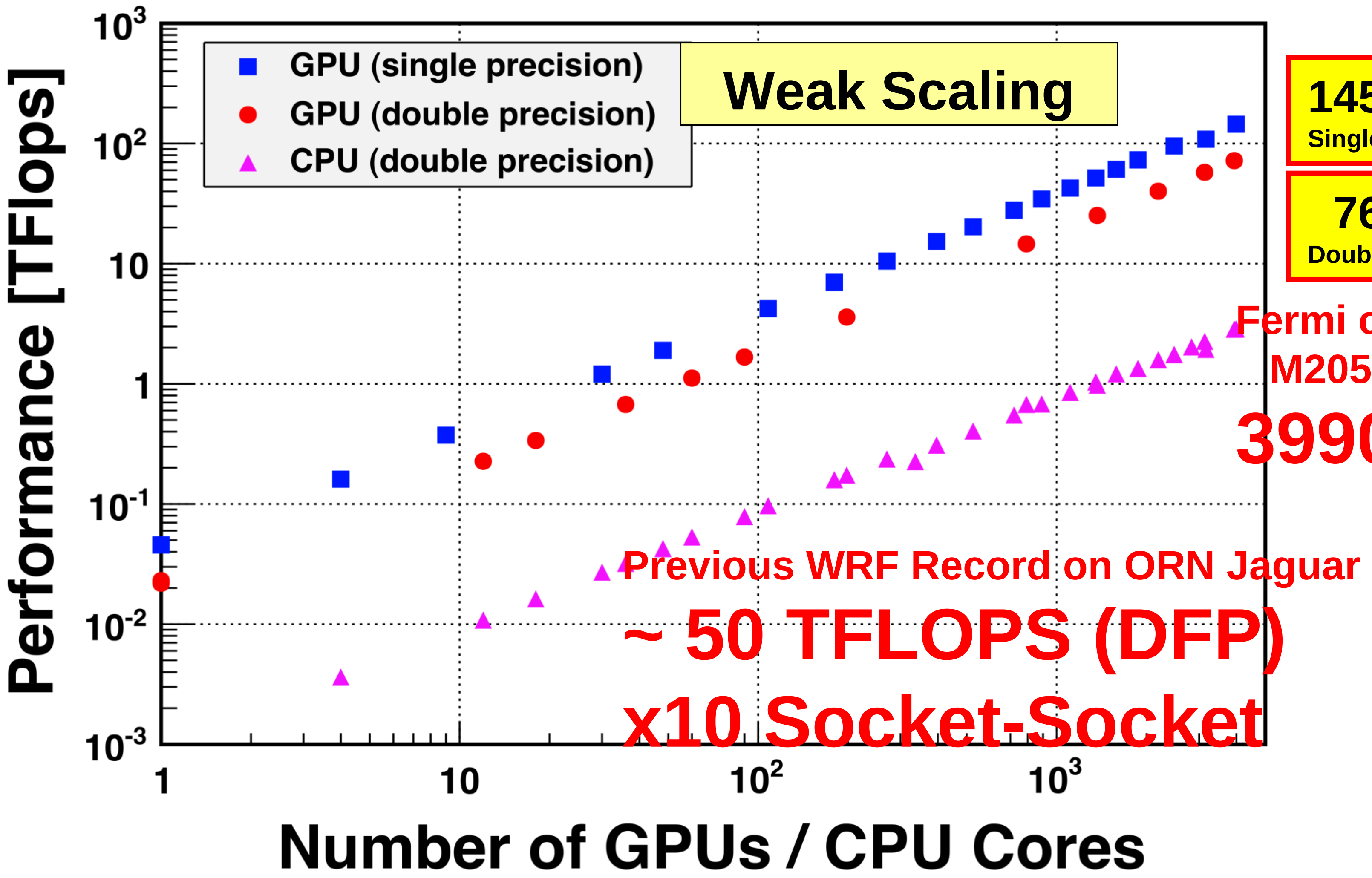
■Similar Structure as WRF

- ✓ *HEVI (Horizontally explicit Vertical implicit) scheme*
- ✓ *Dynamical Core uses a numerical scheme with 3rd-order accuracy in time and space*
  - *Flux-form non-hydrostatic compressible equation*
  - *Generalized coordinate*

Full GPU Approach



TSUBAME 2.0 ASUCA Weather SImulationPerformance



145.0 Tflops
Single precision

76.1 Tflops
Doublele precision

Fermi core Tesla M2050

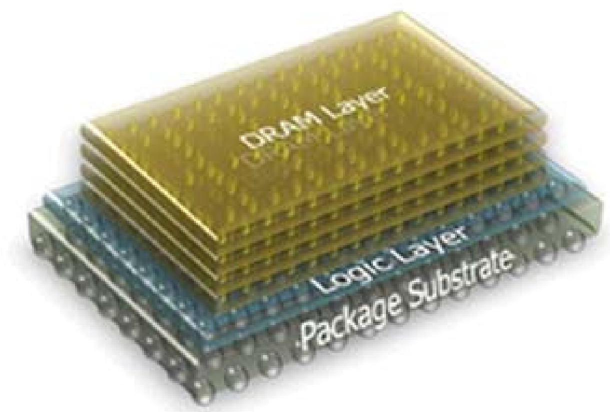
3990 GPUs

Memory Bandwidth Compared

Machine	Nodes	Stream BW/Node (GB/s)	GFLOPs /Node	Byte/Flop	Peak (PF)	Aggregate BW (TB/s)
Jaguar (2009)	18700	26	125	**0.2**	2.33	**486**
Tsubame 2.0 (2010)	4000 (GPUs)	130	515	**0.25**	2.06	**520**
K (2011)	80000	46	128	**0.35**	10	**3680**
BG/Q (2012)					20	**6-7000?**
Tsubame 3.0 (2015)	???	???	**???**	**???**	>25	**7000**

Many Core Drives Memory Innovation

- Disruptive DRAM memory packaging and interfaces beyond DDR3: TSV and Micron Hybrid Memory Cube



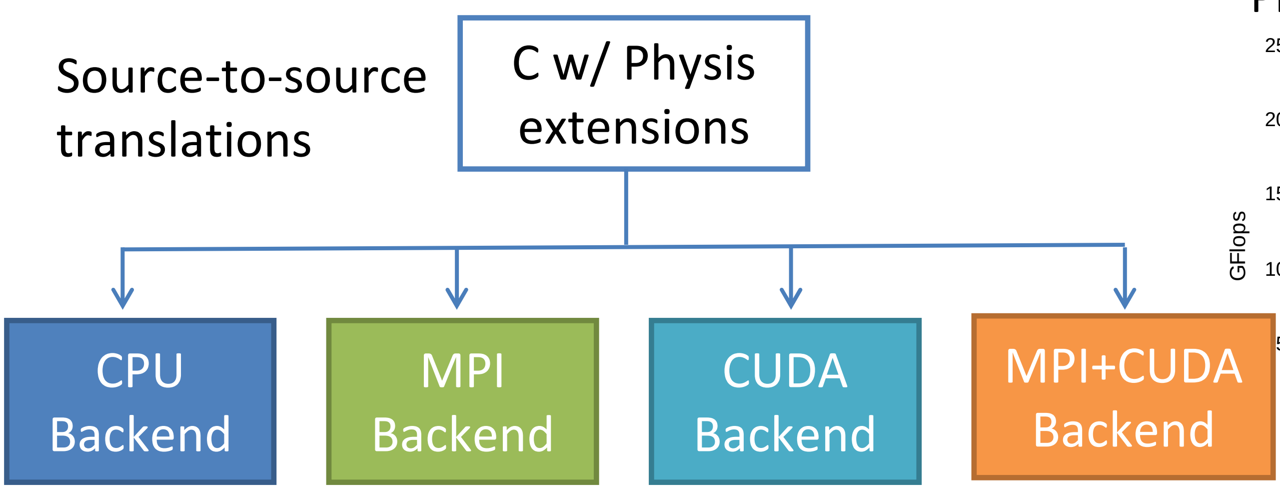
  - x20 bandwidth, low latency 1/10 power
  - Useful for Smarphones, too!

- Non-volatile memory
  - New flash, Phase Change Memory…

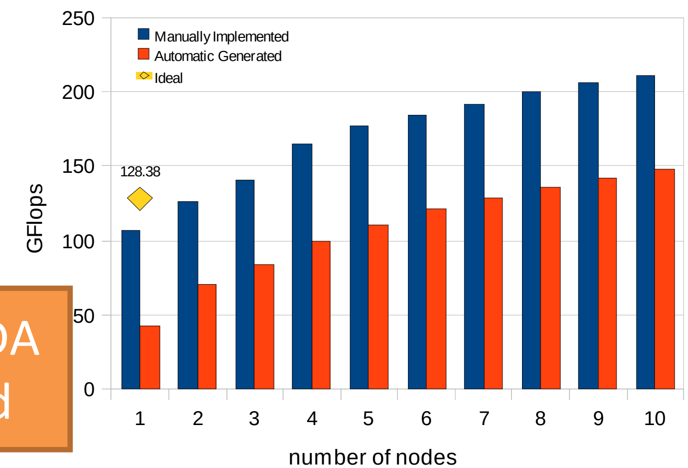
Physis: A Domain Specific Framework for Large-Scale GPU Clusters

- Portable programming environment for stencil computing on structured grids
  - Implicitly parallel
  - Distributed shared memory
- Provides concise, declarative abstractions for stencil computing

Source-to-source translations

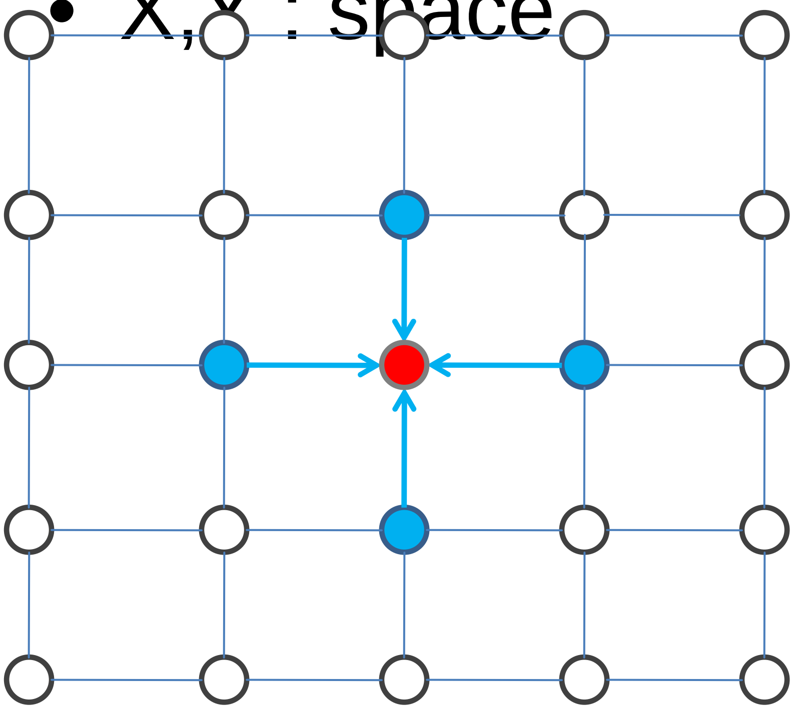


Preliminary Performance Results



A five-point stencil

- T : time
- X,Y : space



```
for (t = 0.0; t < T; t += dt) {
  for (y = 0; y < Y; y++) {
    for (x = 0; x < X; x++) {
      new_f(x,y) = e1*old(y,x)
       + e2*old(y,x-1) + e3*old(y,x+1)
       + e4*old(y-1,x) + e5*old(y+1,x);
    }
  }
}
```

An example of a 7-point stencil

```
__stencil__ void average(int x, int y, int z, grid3d_real g) {
    float ret = psGridGet(g,0,0,0)
       + psGridGet(g,-1,0,0) + psGridGet(g,1,0,0)
       + psGridGet(g,0,-1,0) + psGridGet(g,0,1,0)
       + psGridGet(g,0,0,-1) + psGridGet(g,0,0,1);
    psGridEmit(g, ret / 7.0);
}
```

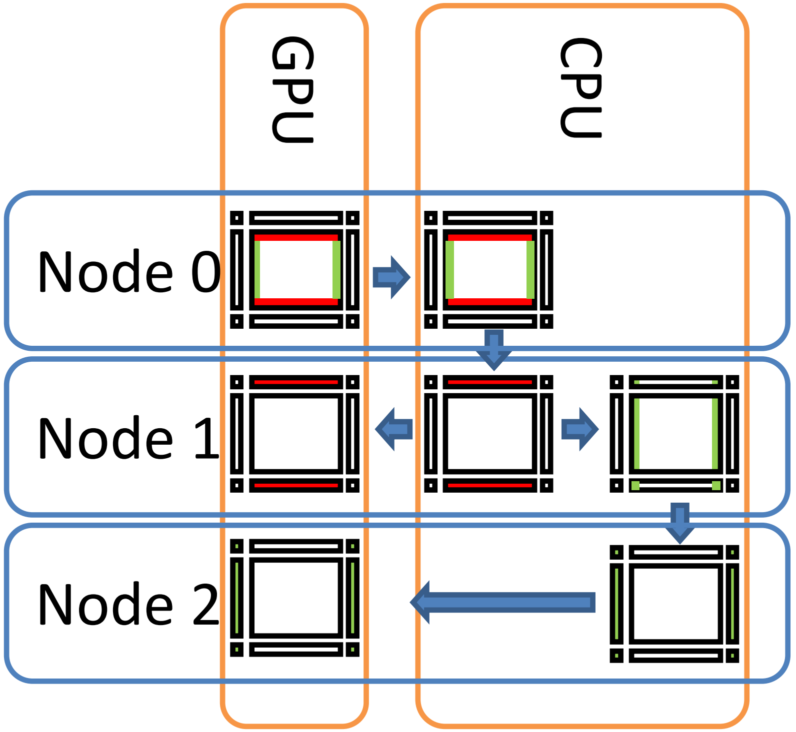
Parallel execution

```
void computation(float *inbuff, float *outbuff) {
  PS_Grid g = psGridNew(float, N,N,N);
    psGridCopyIn(g, inbuff);
    for (int t = 0; t < T; t += dt) psStencilMap(average, g);
    psGridCopyOut(g, outbuff);
}
```

Apply stencil kernel to a grid

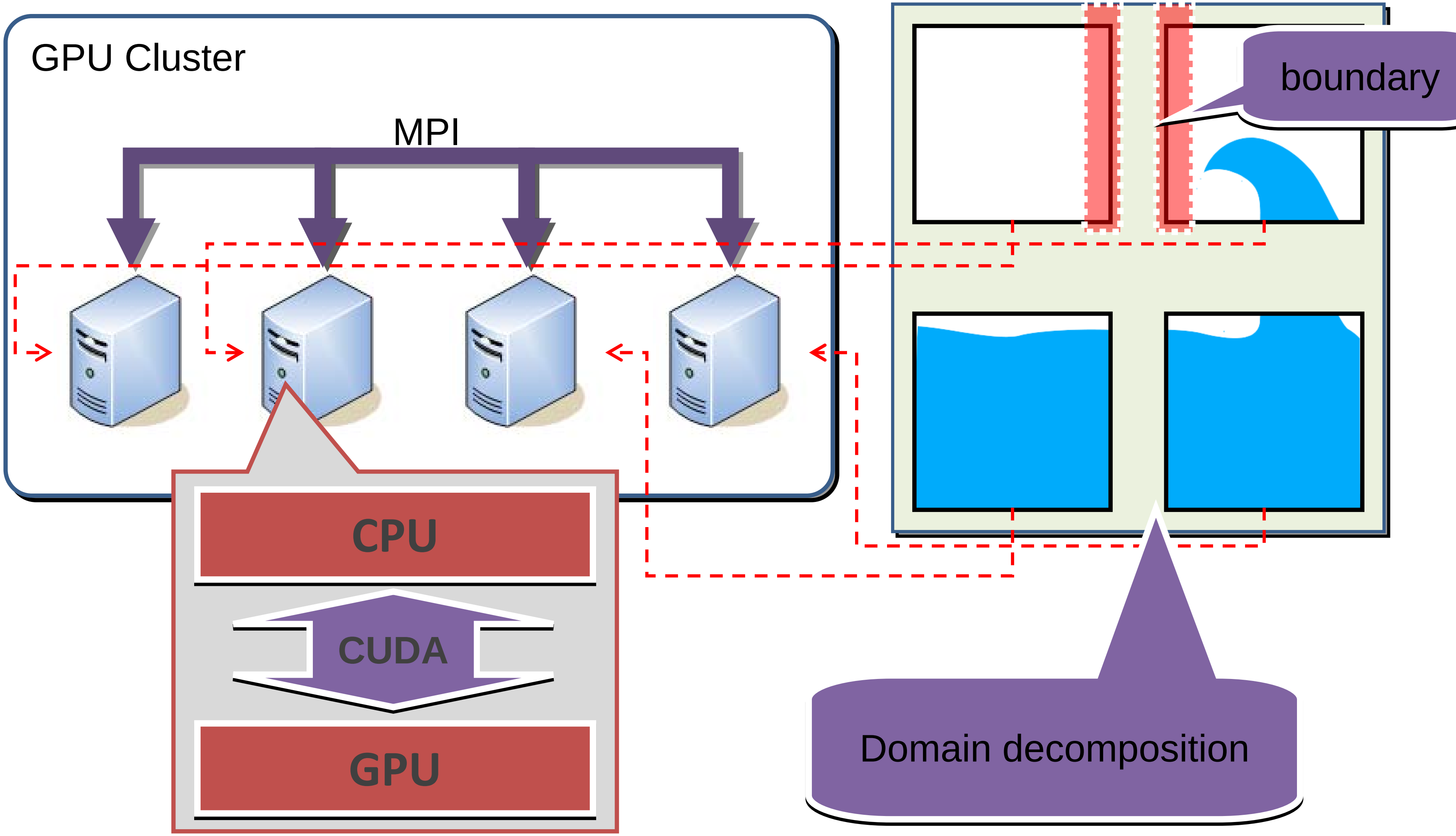
Complexity of implementation

- CPU,GPU,MPI
- Code for omputation is concise, code for parallelization isn't.
  - Problem decomposition
  - Boundary exchange
  - GPUs cannot communicate directly
  - GPU->CPU **->** CPU->GPU
- Code for optimization brings more complicacy
- Most difficult parts are non-essential for stencil computation

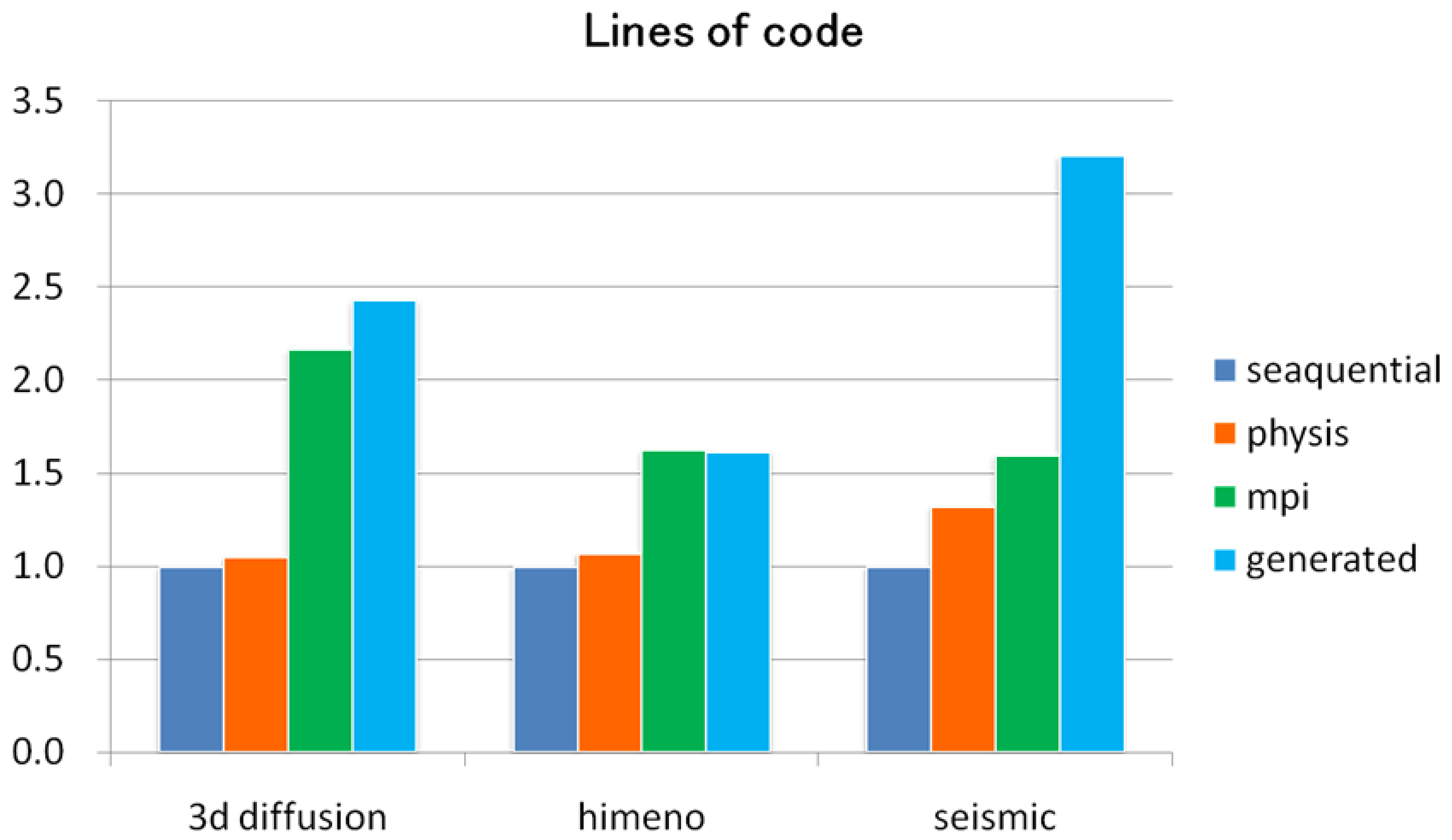


Procedure of boundary exchange

Implementation on GPU clusters

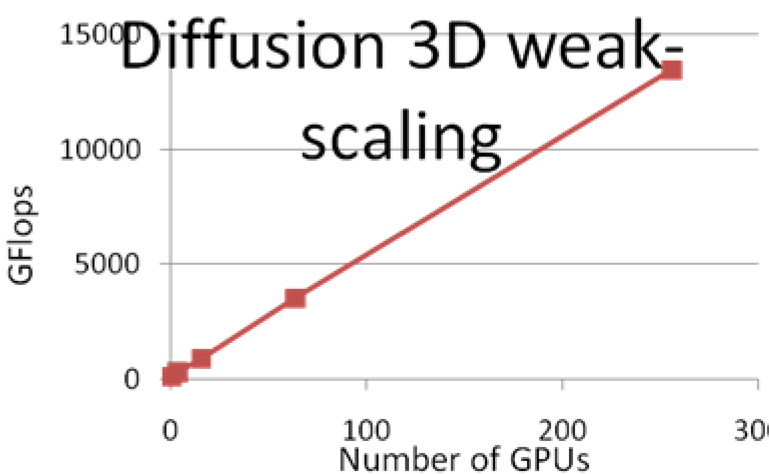


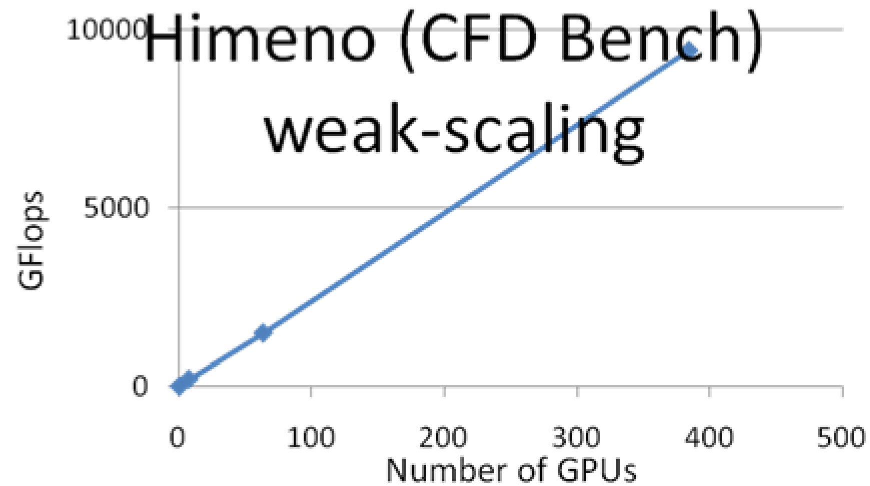
Productivity

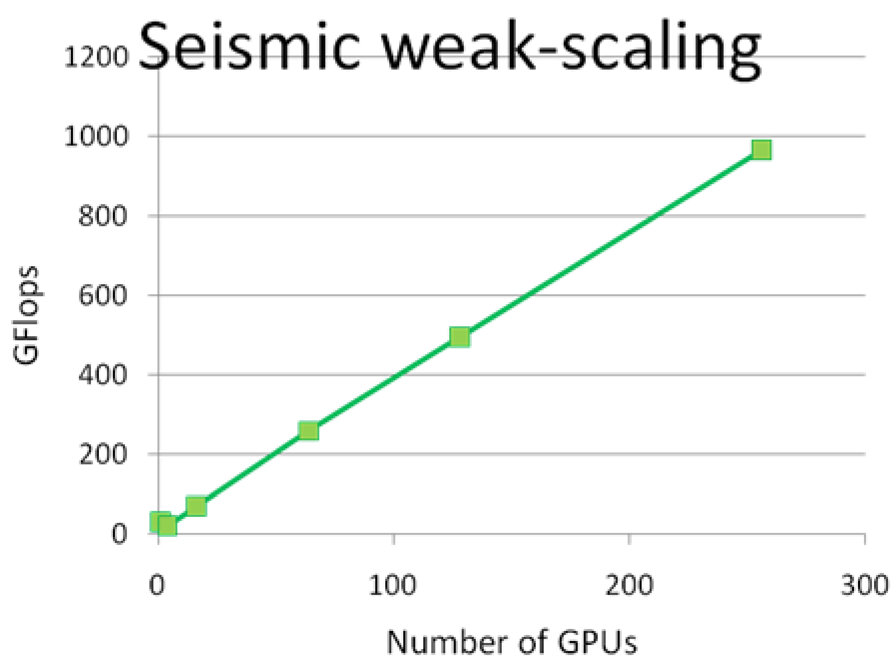


(Original FORTRAN code courtesy of Prof. Takashi Furumura)

Weak Scalability







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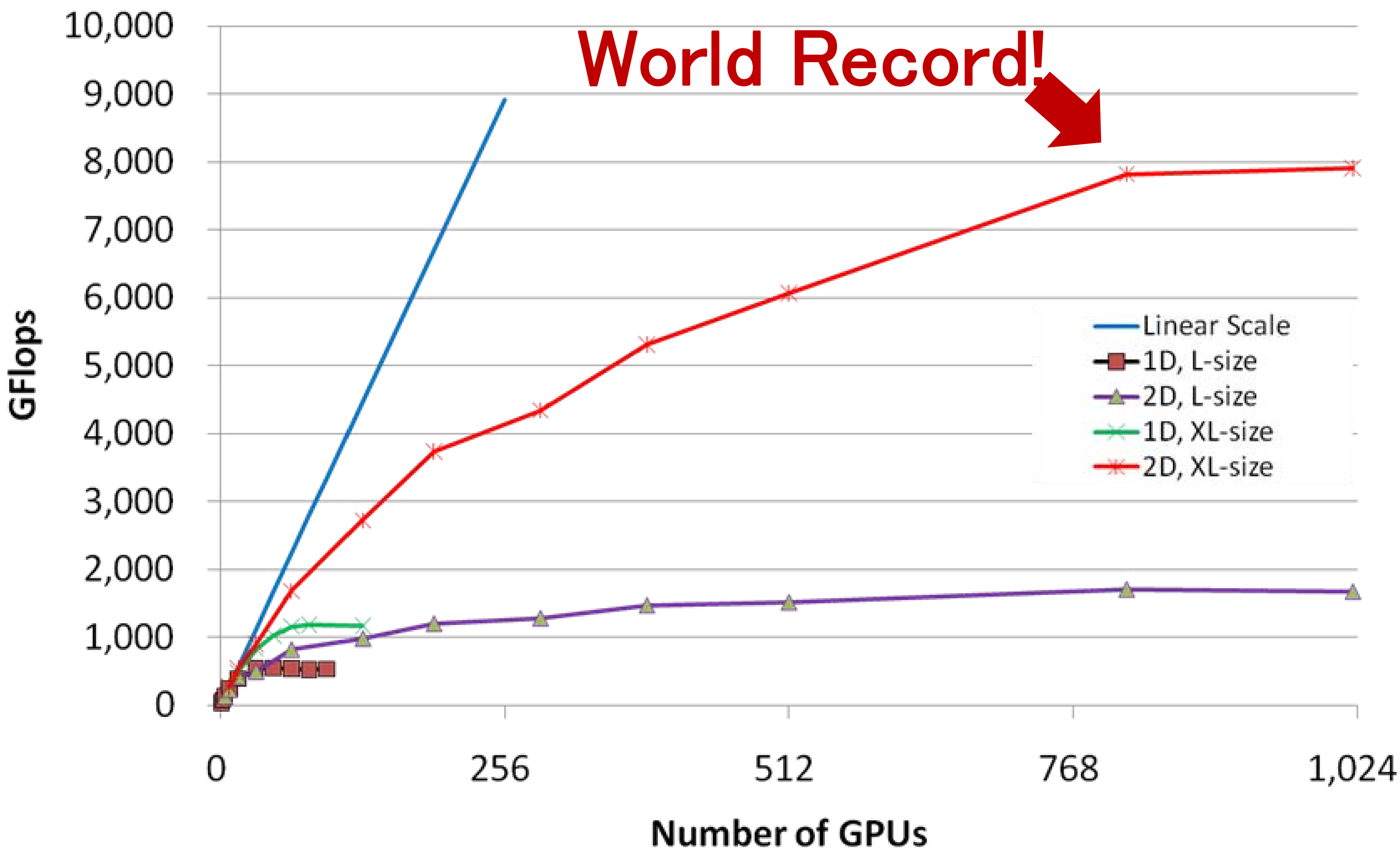
Strong scalability – Himeno bench



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