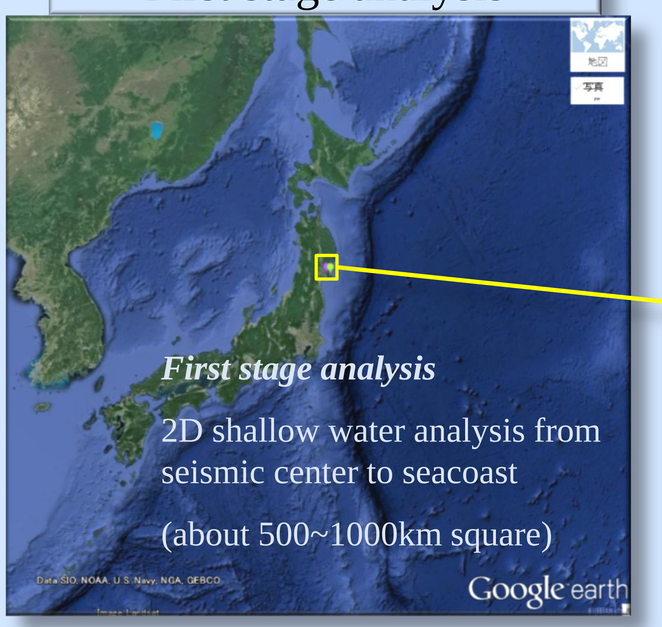
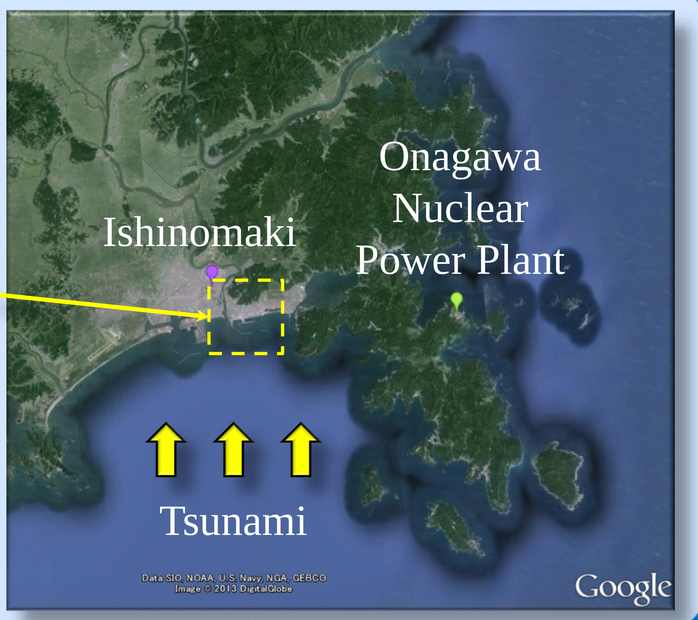
Development of distributed parallel explicit Moving Particle Simulation (MPS) method and zoom up tsunami analysis on urban areas

Kohei MUROTANI, Seiichi KOSHIZUKA (University of Tokyo), Masao OGINO (Nagoya University), Ryuji SHIOYA, Yasushi NAKABAYASHI (Toyo University)

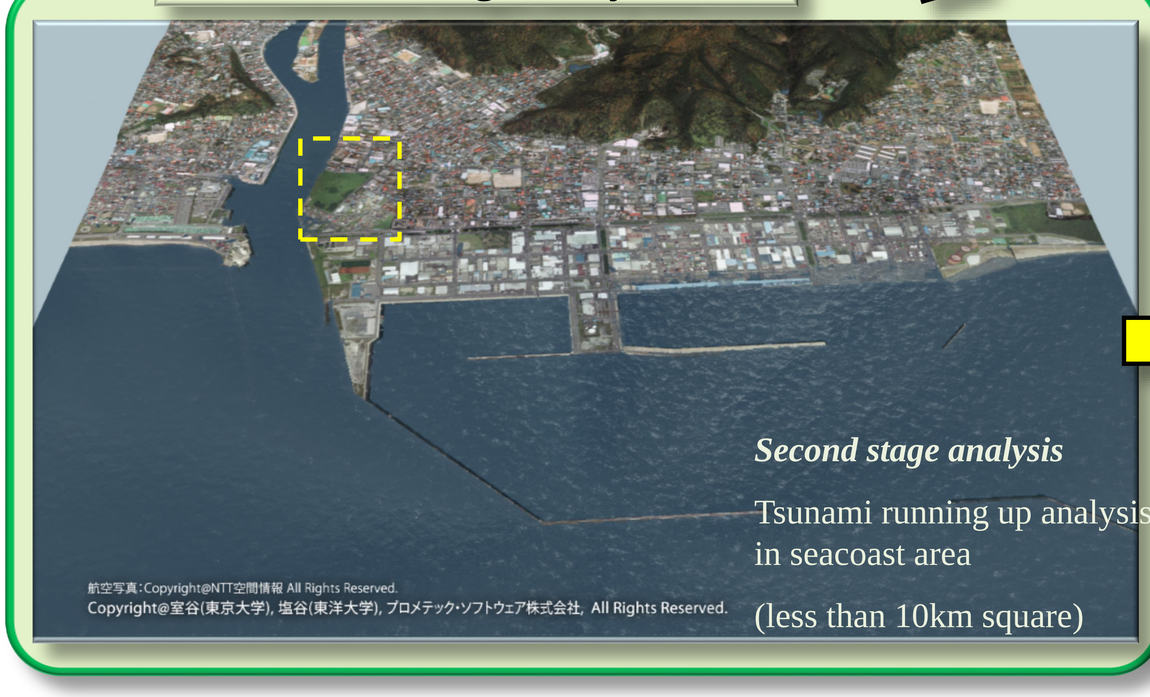
Zoom up tsunami analysis by three analyses stages

First stage analysis





Second stage analysis



Third stage analysis

This research is financially supported as one of JST CREST projects, named “Development of a Numerical Library based on Hierarchical Domain Decomposition for Post Petascale Simulation”. This research work is partly supported by results of HPCI and JHPCN Systems Research Projects (Project ID hp140199, 14-NA07).

High Performance Computing Systems used in this research

Machine name	Site (Univ.)	Processor / Accelerator	Clock Rate (GHz)	# core /node	# nodes
Fx10	Univ. of Tokyo	Fujitsu SPARC64 IXfx x1	1.848 GHz	16	4800
CX400	Nagoya Univ.	Xeon E5-2697 v2 (Ivy Bridge) x2 + Xeon Phi 3120	2.7 GHz	24	552
CX400	Kyushu Univ.	Xeon E5-2680 (Sandy Bridge) x2 + Tesla K20	2.7 GHz	16	1476

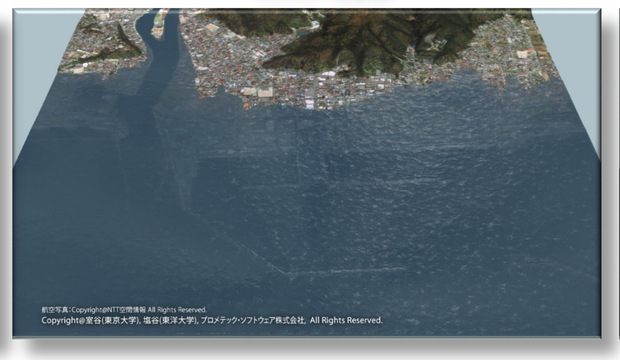
Second stage analysis : Tsunami run-up analyses for Ishinomaki bay and coastal area

Tsunami run-up analysis
Univ. of Tokyo, FX10-144 nodes (1,024 cores)

- Particle diameter: 1.0 m
- Analysis area: 4.0km×3.5km
- Time : 800 sec
- dt: 0.001 to 0.002 sec (Courant number = 0.1)
- Maximum number of particles: 260 million
- Wall-clock time: 1 week
- Time step: 5.5 sec
- Domain decomposition time: 20 to 72sec

Bay and coastal area model

400 sec



460 sec

600 sec

Third stage analysis : Tsunami run-up analyses for Ishinomaki urban area

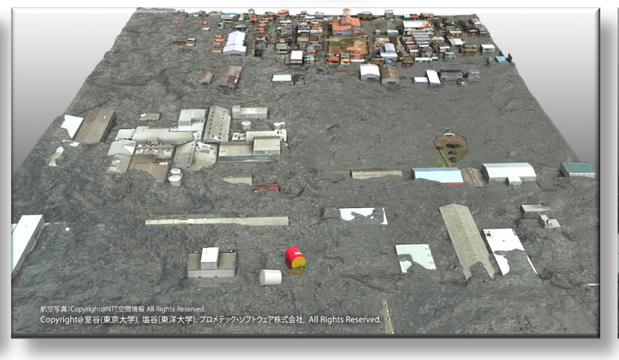
Tsunami run-up analysis with tow floating objects
Univ. of Tokyo, FX10-600 nodes (9,600 cores)

- Particle diameter: 0.5 m
- Analysis area: 400 m × 550 m
- Time : 200 sec
- dt: 0.001 to 0.002 sec (Courant number = 0.1)
- Maximum number of particles: 40 million
- Wall-clock time: 6 hours
- Time step: 0.2 sec
- Domain decomposition time: 2 to 12 sec

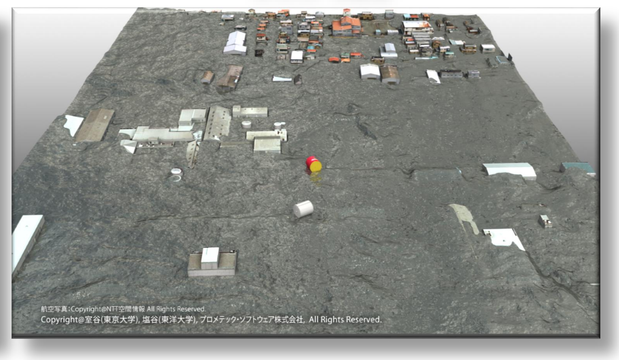
Urban area model

30 sec

75 sec



100 sec



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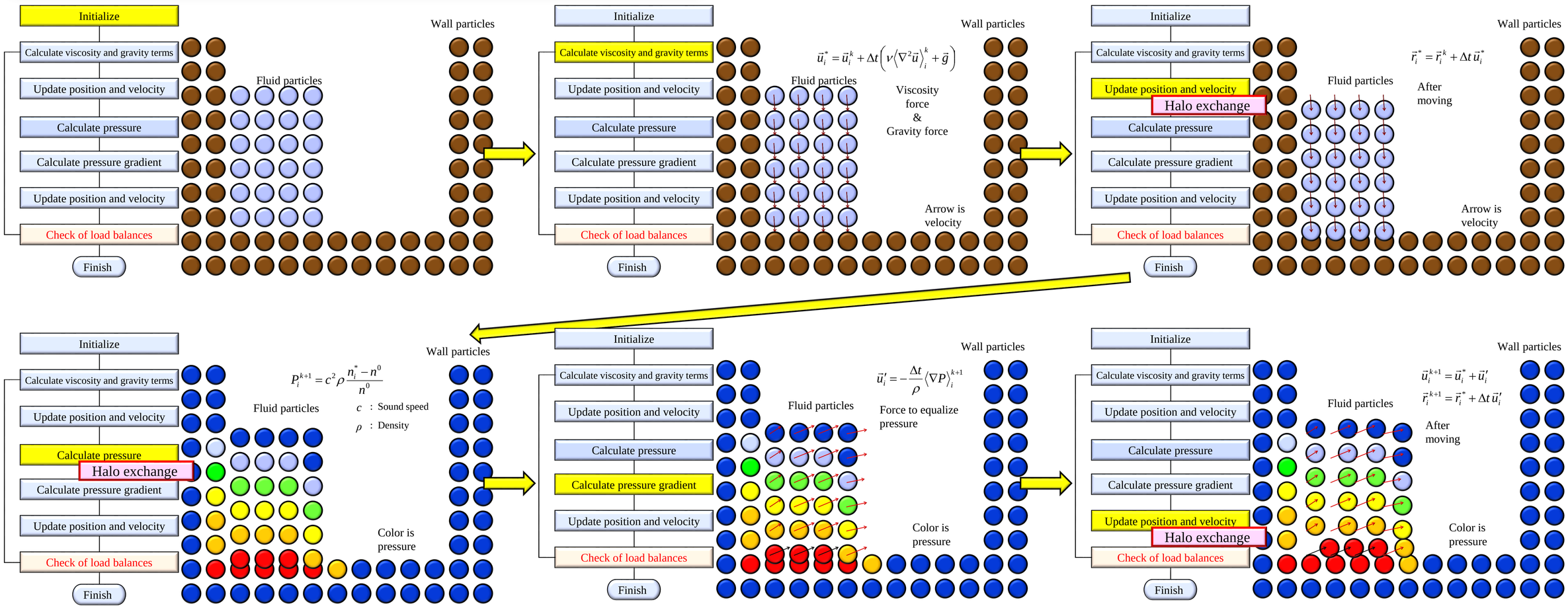
Explicit Moving Particle Simulation (MPS) method



Original MPS

Original MPS Gradient & Laplacian operators by Koshizuka (rough approximation)

$$\langle\nabla P\rangle_i = \frac{d}{n^0}\sum_{j\neq i}\left[\frac{P_j - \hat{P}_i}{\left|\vec{r}_j - \vec{r}_i\right|^2}\left(\vec{r}_j - \vec{r}_i\right)w\left(\left|\vec{r}_j - \vec{r}_i\right|\right)\right]$$

$$\langle\nabla^2 P\rangle_i = \frac{2d}{\lambda^0}\sum_{j\neq i}\left[\left(P_j - P_i\right)w\left(\left|\vec{r}_j - \vec{r}_i\right|\right)\right]$$

Least Square MPS

Least Square Gradient & Laplacian operators using First- & Second-order polynomial approximation by least square approximation for Taylor expansion

$$\langle\nabla P\rangle_i = \left(\frac{\partial P}{\partial x}, \frac{\partial P}{\partial y}, \frac{\partial P}{\partial z}\right)^T$$

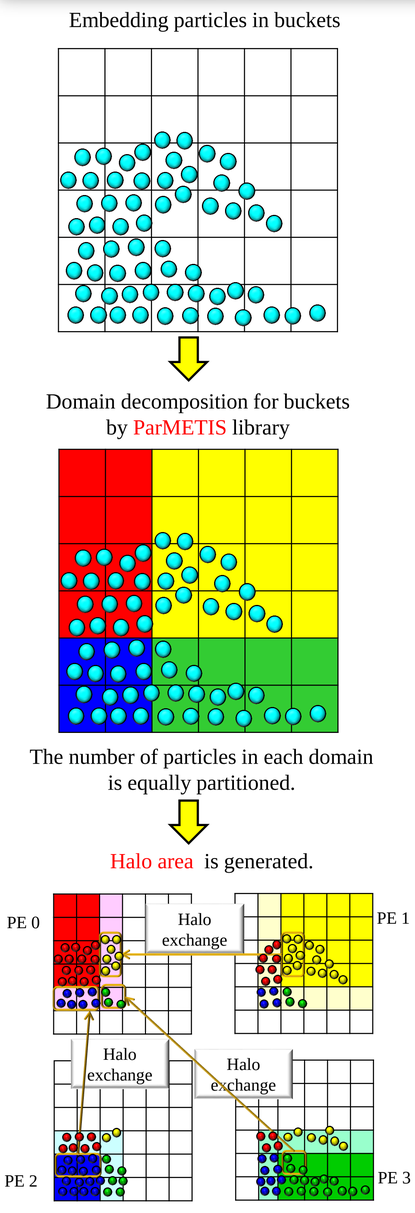
$$\langle\nabla^2 P\rangle_i = \frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} + \frac{\partial^2 P}{\partial z^2}$$

$\vec{r}_i = (x_i, y_i)$: position vector

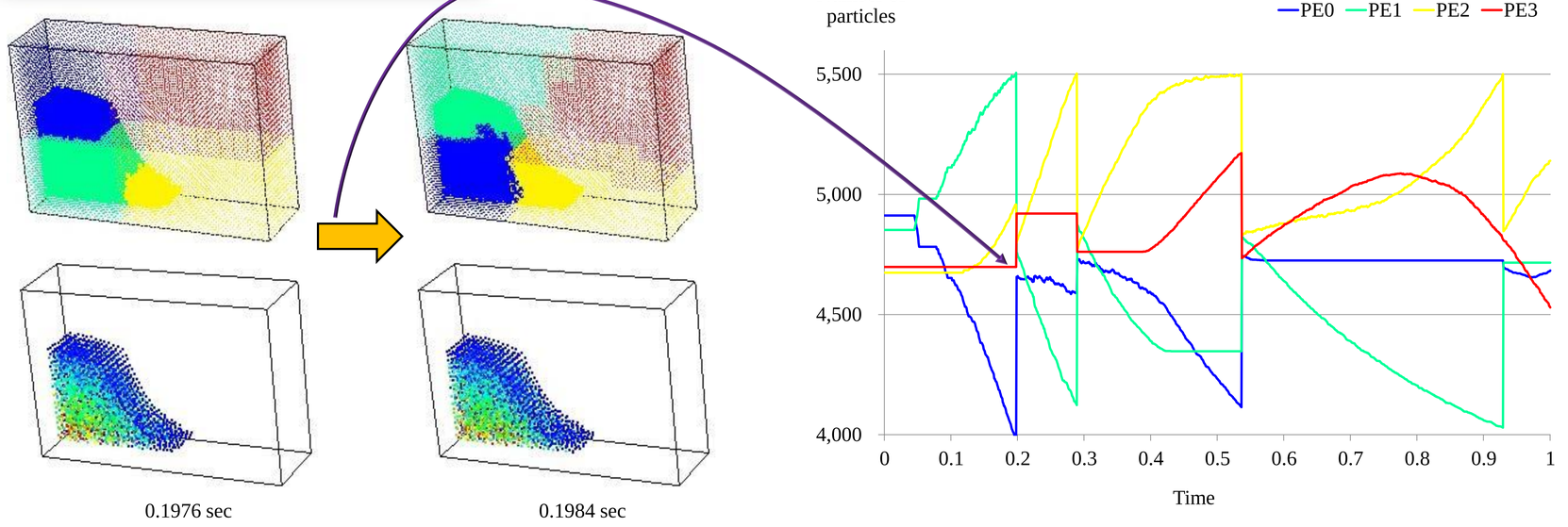
$x_{ij} = \frac{x_j - x_i}{r_s}$ $\quad y_{ij} = \frac{y_j - y_i}{r_s}$ $\quad z_{ij} = \frac{z_j - z_i}{r_s}$

$$\begin{pmatrix} \frac{\partial P}{\partial x} r_s \\ \frac{\partial P}{\partial y} r_s \\ \frac{\partial P}{\partial z} r_s \\ \frac{\partial^2 P}{\partial x^2} r_s^2/2 \\ \frac{\partial^2 P}{\partial y^2} r_s^2/2 \\ \frac{\partial^2 P}{\partial z^2} r_s^2/2 \\ \frac{\partial^2 P}{\partial x\partial y} r_s^2 \\ \frac{\partial^2 P}{\partial x\partial z} r_s^2 \\ \frac{\partial^2 P}{\partial y\partial z} r_s^2 \end{pmatrix} = \left[\sum_{j\neq i} w\left(\frac{\left|\vec{r}_j - \vec{r}_i\right|}{r_s}\right)\begin{pmatrix} x_{ij} \\ y_{ij} \\ z_{ij} \\ x_{ij}x_{ij} \\ y_{ij}y_{ij} \\ z_{ij}z_{ij} \\ x_{ij}y_{ij} \\ x_{ij}z_{ij} \\ y_{ij}z_{ij} \end{pmatrix} \otimes \begin{pmatrix} x_{ij} \\ y_{ij} \\ z_{ij} \\ x_{ij}x_{ij} \\ y_{ij}y_{ij} \\ z_{ij}z_{ij} \\ x_{ij}y_{ij} \\ x_{ij}z_{ij} \\ y_{ij}z_{ij} \end{pmatrix}\right]^{-1}\left[\sum_{j\neq i} w\left(\frac{\left|\vec{r}_j - \vec{r}_i\right|}{r_s}\right)\left(P_j - P_i\right)\begin{pmatrix} x_{ij} \\ y_{ij} \\ z_{ij} \\ x_{ij}x_{ij} \\ y_{ij}y_{ij} \\ z_{ij}z_{ij} \\ x_{ij}y_{ij} \\ x_{ij}z_{ij} \\ y_{ij}z_{ij} \end{pmatrix}\right]$$

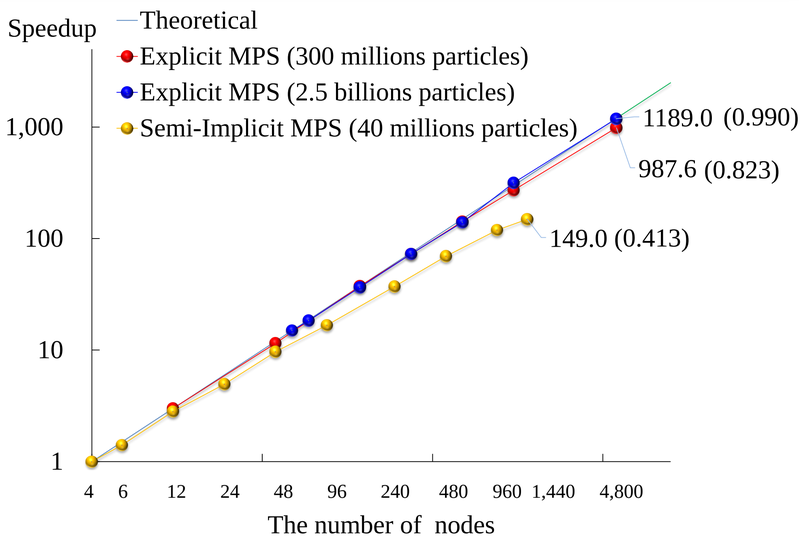
Domain decomposition and halo area



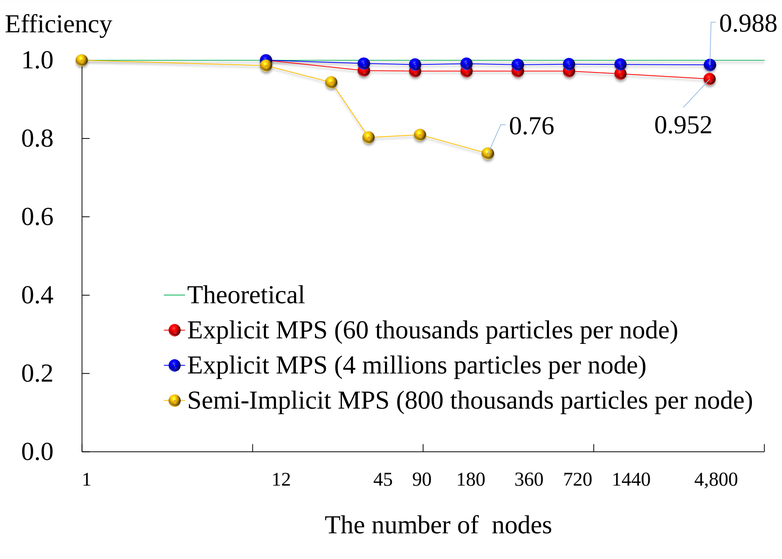
Dynamic load balance



Strong scaling by Univ. of Tokyo, FX10



Weak scaling by Univ. of Tokyo, FX10



Wall-clock time and performed efficiency to peak

Processor / Accelerator	Performance (GFLOPS)
Tesla K20	1174.7
Xeon E5-2697 v2 x2	518.4
Xeon Phi 3120	1003.2
SPARC64 IXfx	236.5