Cosmogrid Project

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Center for Computational Astrophysics

Talk Summary

- We performed large-scale cosmological simulation, on a "grid" of two supercomputers connected via 10G line(s): Cray XT4 at CfCA/NAOJ and Huygens(IBM p6/575) at SARA/UvA.
- Efficiency of calculation for production runs (2048^3 particles) is pretty high (better than 80%)
- (The communication throughput during the production runs is less than impressive though...)
- For daily use, the main difficulty is how to schedule two or more machines for single calculation...

Talk Overview

- Brief overview of NAOJ
- Brief overview of CfCA
- Cosmogrid Project
  - Background
  - What we tried to do
  - What we have achieved so far
  - Future directions

Brief overview of NAOJ

- National center for Japanese Astronomy
- Ground-Based observation facilities
  - Subaru Telescope
  - Nobeyama Radio Observatory
  - Okayama Observatory, and several other small telescopes
- Space Astronomy: Collaboration with ISAS/JAXA (Akari, Hinode)
- Theoretical and Computational Astronomy

国立天文台の研究施設

国立天文台の研究・観測施設は日本各地にとどまらず、すばる望遠鏡や建設中のALMA（アルマ）のように海外にも進出しています。天文学の観測では、可視光、赤外線、電波、重力波などの観測手段と、太陽とそれ以外の宇宙などの観測対象に応じて、最適の観測条件と環境とが必要とされるからです。

野辺山エリア

野辺山宇宙電波観測所
Nobeyama Radio Observatory

日本の電波天文学を世界のトップレベルに押し上げた観測施設です。写真の45m電波望遠鏡（右）は、ミリ波で世界最大の望遠鏡で、新たな星間分子の発見や原始惑星系の回転ガス円盤の発見など、数々の画期的な成果を挙げています。

野辺山太陽電波観測所
Nobeyama Solar Radio Observatory

太陽面爆発を高精度で観測する干渉計システム「電波ヘリオグラフ」（写真下）で、太陽活動のモニターを行っています。

乗鞍岳エリア

太陽観測所・乗鞍コロナ観測所
Solar Observatory:Norikura Solar Observatory

北アルプス・乗鞍山系摩利支天岳（海抜2876m）の頂上に位置する太陽観測所です。太陽物理現象の精密な観測を行うために3台のコロナグラフが設置されています。

岡山エリア

岡山天体物理観測所
Okayama Astrophysical Observatory

国内最大級の口径188cmの反射望遠鏡を中心に、銀河・恒星・太陽系天体などの光学赤外線観測研究の国内の拠点となっています。また、赤外線分光装置や赤外線超広視野カメラなど、宇宙を見る新しい目を次々と開発しています。

水沢エリア

水沢観測所
Mizusawa Astrogeodynamic Observatory

旧緯度観測所として長い歴史をもつ施設です。位置天文学・測地学の研究が盛んで、日本の標準時を決める天文保時室などがあります。

江刺地球潮汐観測施設
レーザー光線を利用して地面の伸縮の変化を測るレーザー歪計です。潮汐による地球の微妙な変形をモニターします。

VERA観測所・水沢観測局
VERA Observatory：Mizusawa station

銀河系の3次元地図を作成するVERA観測局のひとつです。

三鷹エリア（本部）

三鷹キャンパス
三鷹キャンパスは、国立天文台の本部が置かれ、さまざまなプロジェクト、センター、研究部、事務部が集まっています。

チリ・エリア

ALMA（アタカマ大型ミリ波サブミリ波干渉計）
ALMA (Atacama Large Millimeter/submillimeter Array) Project

ALMA（アルマ）は、日米欧が共同でチリの標高5000mの高原に建設中の巨大な電波望遠鏡群（イラスト）で、国立天文台が現在総力を挙げて取り組む大型プロジェクトです。

VERA・4局（水沢局を含む）
銀河系の3次元地図を作成します。

VERA観測所・入来観測局
VERA Observatory
：Iriki station

VERA観測所・石垣島観測局
VERA Observatory
：Ishigakizima station

VERA観測所・小笠原観測局
VERA Observatory
：Ogasawara station

銀河系の3次元地図を作成するVERA観測局のひとつです。

ハワイ・エリア

ハワイ観測所
Subaru Telescope

すばる望遠鏡
ハワイ島のマウナケア山頂（標高4200m）に設置された口径8.2mの世界最大級の可視・赤外線望遠鏡です。平成12年度から本格的な観測を始め、現在、世界最先端の研究成果を挙げつづけています。

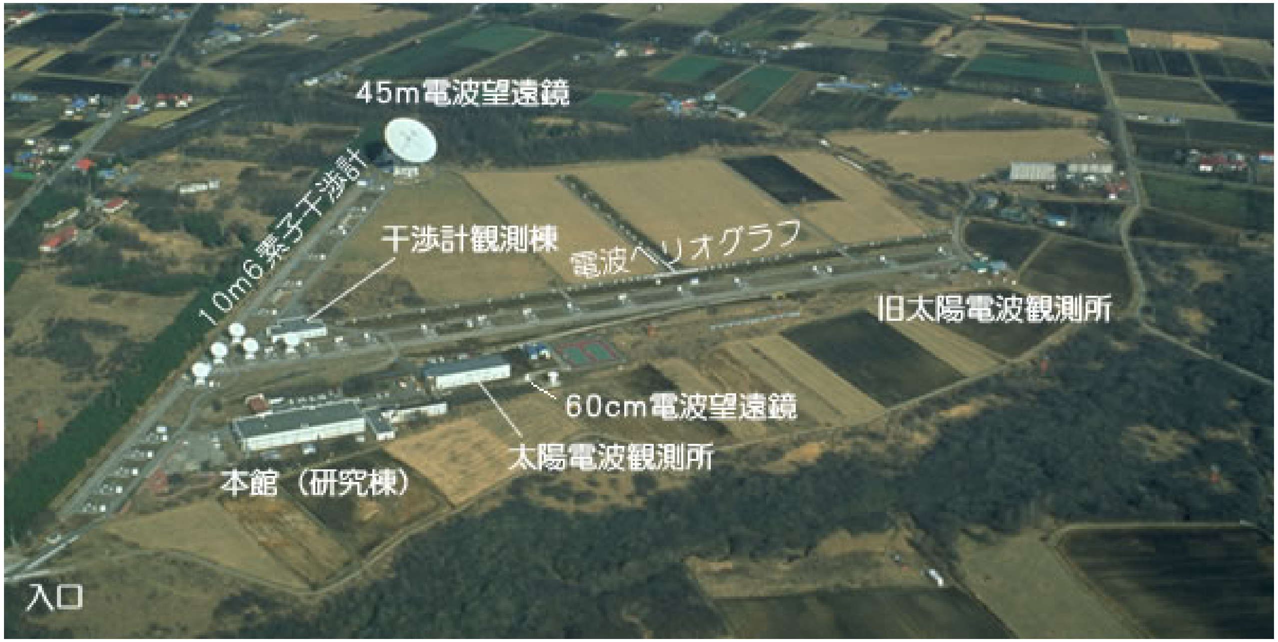
ヒロ・オフィス（写真右上）
ハワイ島ヒロ市にあるハワイ観測所の本部です。「すばる望遠鏡」による観測研究の拠点となっています。

Subaru Telescope

Hawaii, Mauna Kea
8.2m mirror

Only eight-meter-class telescope with a prime-focus camera (Suprime-Cam), 30 arcminutes field of view (100 times that of Hubble Space telescope)
Plan to extend to 2-degree field of view (Subaru HSC)

Nobeyama Radio Observatory



Started operation in 1982. First world-class ground-based observation facility in Japan
Follow-up: ALMA (US-EU-Asia joint project, observation will start in 2010?)

Other projects (incomplete list...)

- Hinode (Solar observation Satellite)
- TAMA300 (Experimental gravity Wave detector)
- VERA VLBI (Very Long Baseline Interferometer)
  - Real-time signal processing using optical network
- VSOP-2 (Space VLBI)

Center for Computational Astronomy

Two goals:

- **Theory group within NAOJ**
- **Computer Center for Japanese (and International) Theoretical/Computational Astronomy**

History

1965 “Domestic Computing Facilities ”
“for Artificial Satellites”

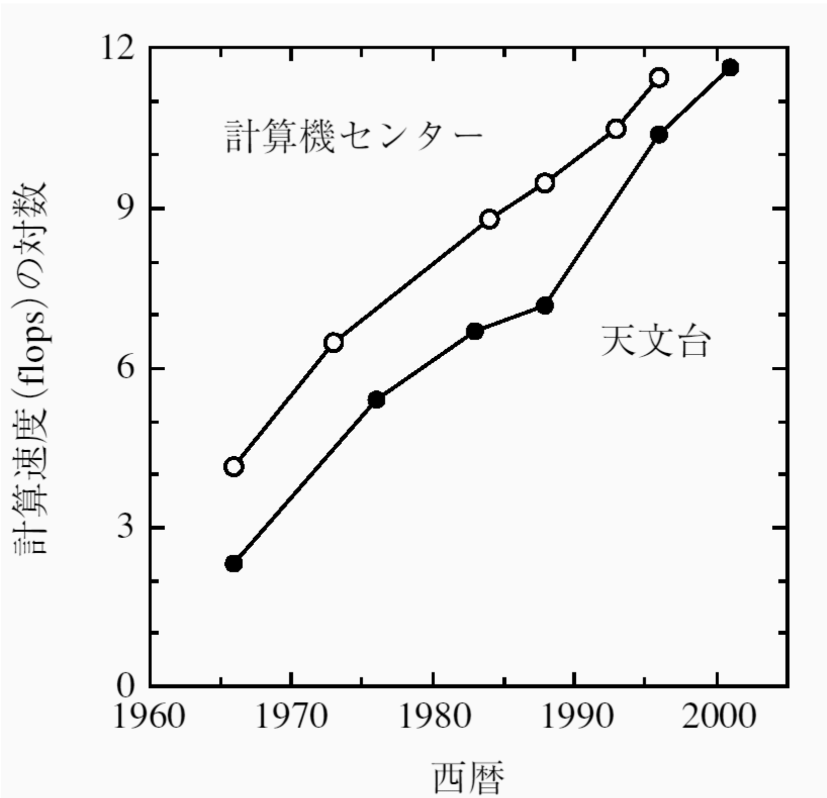
1988 ADAC (Astronomical Data Analysis center)

1988 Division Theoretical Astronomy

2006 reorganized to ADC (Astronomical Data Center) and CfCA

A unique center dedicated to “Theory and Simulation for Astronomy/Astrophysics”

Evolution of CPU power



(till 2001)

Year - log of computing speed (12=1Tflops)
Open: U. Tokyo
Filled: ADAC/CfCA

1/10 — 1/100 of UT

Current System

- **Vector-Parallel: NEC SX-9 16CPU+8CPU**
- **Scalar: Cray XT4 9 cabinets (812 nodes, 28.6TF)**

CfCA Cray XT4

Front panel CG

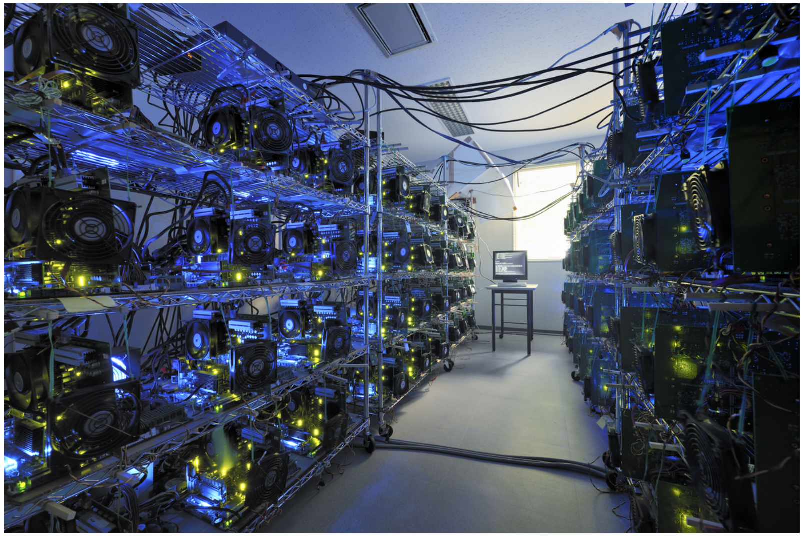
Simulation: Takayuki Saitoh (CfCA/NAOJ)
Visualization :Takaaki Takeda (4D2U/NAOJ)

Cray box in ORNL, before and after 2008

before

after

We also have:



GRAPE-DR
Accelerator with the peak DP speed of $\sim$ 1 Tflops/card
A 144-node system up and running

Hardware completed. Tuning underway.

CosmoGrid Project

- **Background**
- **What we tried to do**
- **What we have achieved so far**
- **Future directions**

Background

- **In "Principle"**
  - **We want to do large-scale simulations which are impossible on a single supercomputer, by connecting multiple supercomputers with high-speed grid.**
- **In "reality"**
  - **One of the goals of "GRID" is the above. But we rarely see successful examples of one single large-scale calculation actually performed.**
  - **If we can demonstrate a working example,**
    - **We may be able to get large chunks of machine time (thus effectively make it possible to do calculations not possible in single supercomputer center)**
    - **This is interesting and potentially useful research project.**

Large-scale parallel simulations on Grid?

- Lots of papers claiming "we did it"
- Almost all works are on job-level parallelism, using Grid-based job schedulers. Not a single large calculation.

Why?

Large-scale parallel simulations on Grid?

- Lots of papers claiming "we did it"
- Almost all works are on job-level parallelism, using Grid-based job schedulers. Not a single large calculation.

Why?

Because Grid is a "parallel computer" which is
the most difficult to use

- Extremely small communication bandwidth (1/1000 of a typical IB cluster)
- Impossibly large communication latency (1000 times that of typical IB network)

Large-scale parallel simulations on Grid? (cont'd)

So why to try **the most difficult to use** environment?

- To get more cycles
- We will improve simulation algorithms

Latency-tolerant algorithms which are not bandwidth-demanding

↓

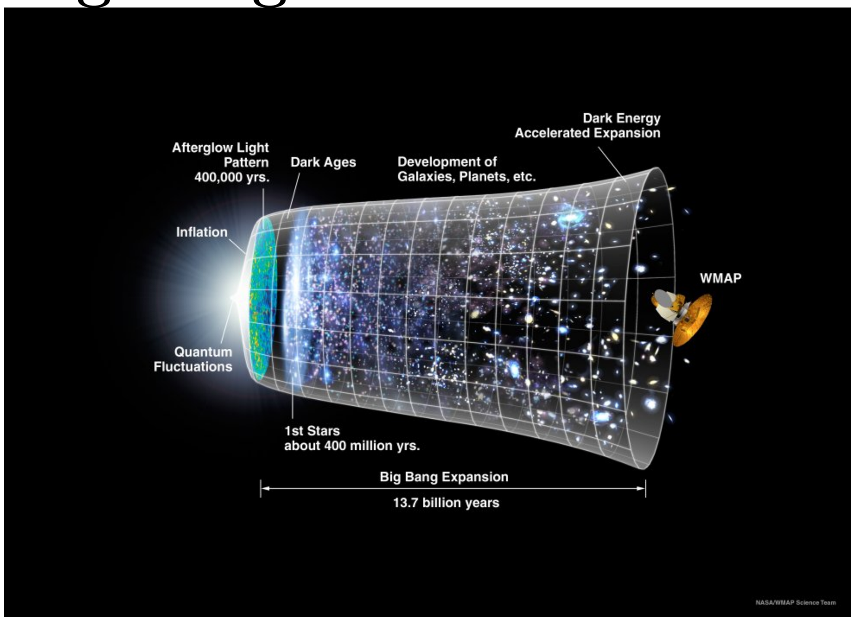
High efficiency and high scalability on future large-scale parallel machines

What we did

- **Performed Cosmological *N*-body simulation**
- **On a grid of Cray XT4 of CfCA/NAOJ and Huygens (IBM p6/575) at SARA/UvA connected by 10G network**
- **Test calculation with 256^3 particles: successfully completed**
- **2048^3: Succeeded to run several timesteps on Grid.**
- **Currently developing softwares to use more than to machines in EuroGrid.**

What is a cosmological N-body simulation?

Big bang



After Big bang, “hot” universe starts to expand
As the universe expand, the temperature drops

Density fluctuations starts to grow through gravitational instability ← We simulate this process

Animations: (a)(b)

What can we learn from simulations?

- How galaxies (or what accounts for about 85% of its mass: dark matter halos) formed
- Theoretical predictions for mass and size distribution of galaxies, spacial distribution (statistical properties)

By comparing these theoretical predictions with observations, we can get some knowledge on what makes up the dark matter:

- Mass of one particle, total mass
- If there are any interactions other than gravity
- etc etc...

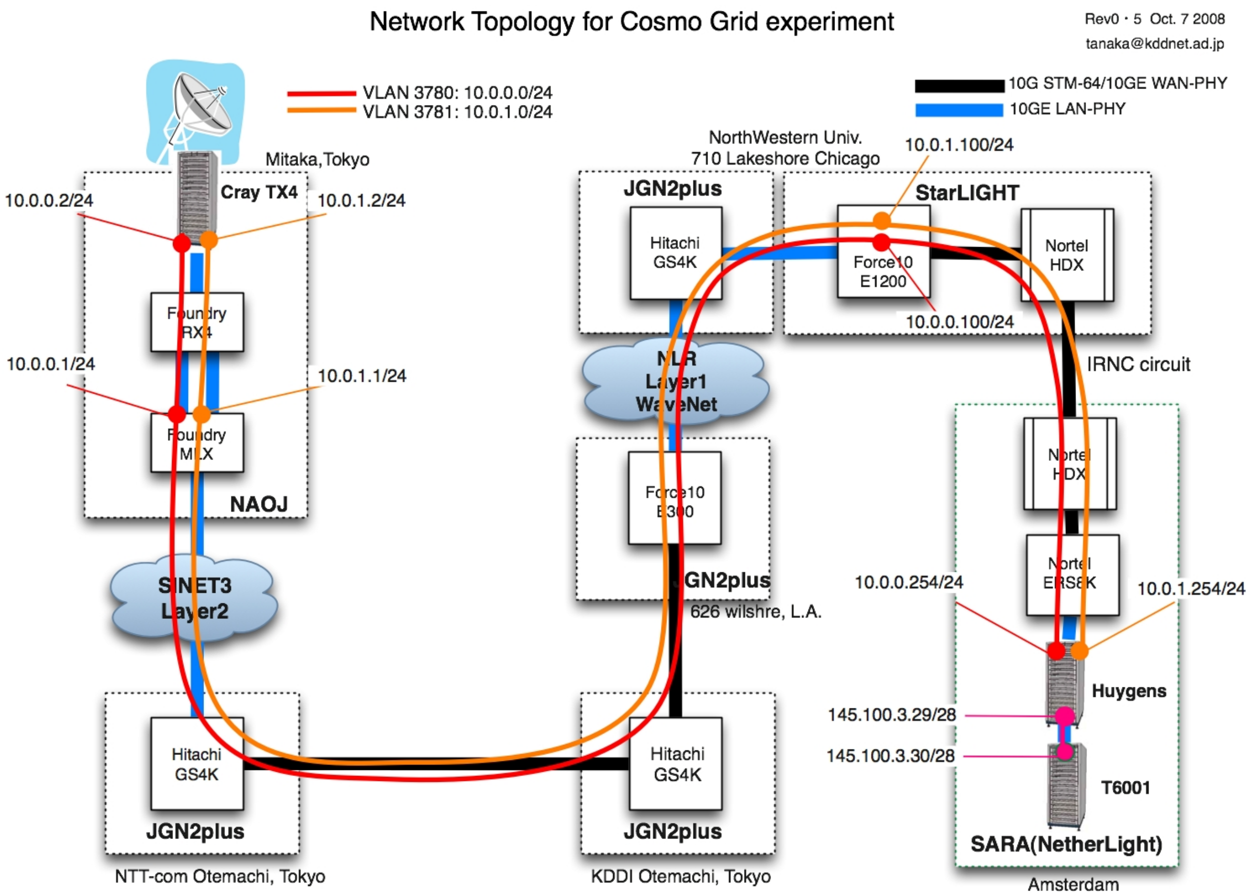
Why Grid?

- State-of-the-arts calculations are truly of large scale ($N \sim 10^{10}$)
- Number of steps is rather small (less than 10^5)
- Size of calculation limited by CPU speed, several minutes per timestep.
- Parallelization very well studies and understood.

In other words,

- Very long latency (more than 100 msec) is okay, since one timestep takes more than 100 seconds and communication occurs less than 10 times per step.
- Amount of communication is also small: $O(N^{2/3})$.
- We do want to do large calculation. If using Grid helps to get more cycles, then...

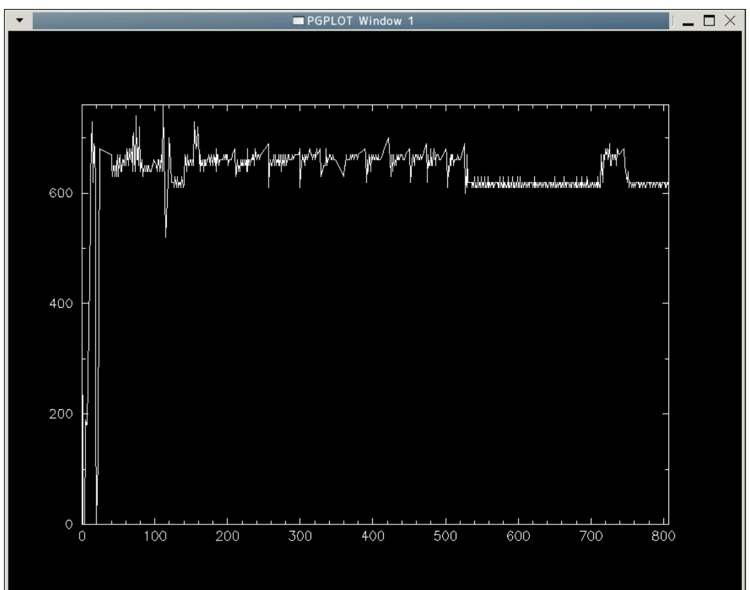
Grid Structure



The network environment itself is similar to the experimental setup used by Hiraki and coworkers. To that setup, we connected two supercomputers at the both end.

Network performance

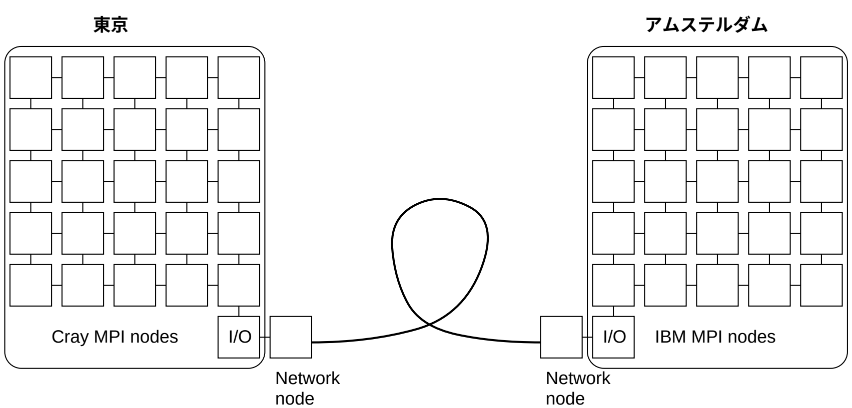
- latency (ping rtt) 280ms
- Bandwidth: Cray XT4's 10G card is the bottleneck. S2IO Xframe with PCI-X interface, connected to AMD 8131.
- Cray-Cray loopback test (loop at Chicago or Amsterdam): up to 6Gbps



Example of loopback test
Horizontal: time (seconds)
Vertical:measured bandwidth (iperf, MB/s)

Calculation code

- MPI within a site
- One of MPI nodes is dedicated to communication. All communications with the other site is through this "communication node"
- This "communication node" actually talks with another I/O node with TCP/IP
- I/O nodes in two sites communicate with TCP/IP



Development of the calculation code

- In-site parallelization: used our existing code (Developed by T. Ishiyama)
- Collection of data to the "communication node": Fairly easy
- Communication between I/O nodes: Various performance tuning required. Prof. Hiraki knows every tricks.
- Need to dynamically change the domain decomposition to reach good load balance (extension of what is done in in-site parallel code)

Nothing difficult, just a lot of bookkeeping...

How real experiments took place

- We ask collaborators to set up the network for two weeks or so.
- Lots of troubles happen and ping starts to work after ... days.
- More troubles happen in supercomputers...

International collaborative experiments are very difficult.

Simulation completed so far

$N = 256^3$ run
Communication performance ($N = 2048^3$, 1024 cores at both ends)

	Data size(MB)	Time (sec)	Fraction (%)
Calculation	—	350	86
Grid for FFT	70	5.8	1.4
Particles exchange	770	51	13

- The calculation is already pretty efficient (communications less than 15% of total time)
- A factor of 10 reduction of communication time should be possible.
- For larger N, relative cost of communication decreases (as $N^{-1/3}$)

Grid of two machines in different continents is actually useful for large-scale cosmological N-body simulations.

Caveats

Practical difficulties

- **Both machines are operated with job-queuing systems. How do we schedule two machines to start the calculation at the same time?**
- **Can we exclusively use fast network for extended period? (maybe note so severe: 1Gbps is fine)**

Scheduling issue is critical if we are to do production runs, not just a few experiments. Other users would complain if we give Grid jobs special priority.

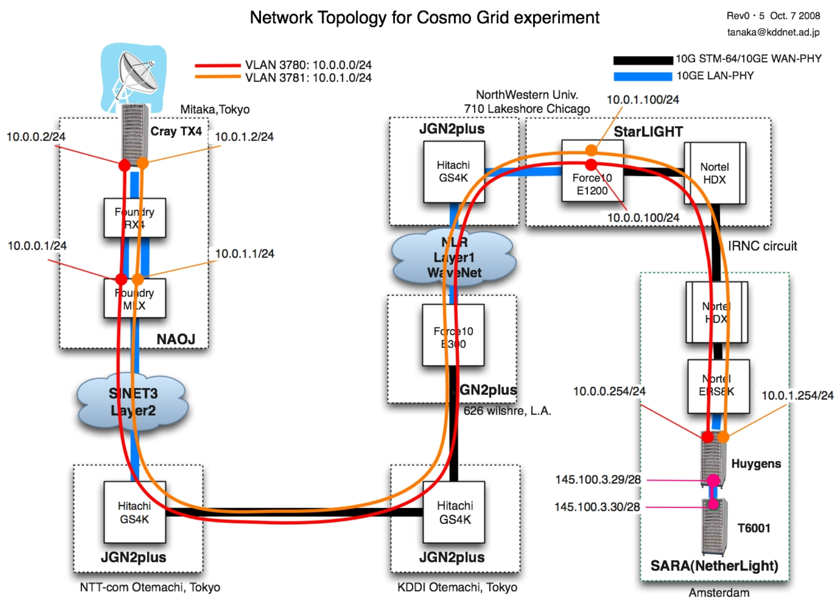
Possible solution for scheduling

(Not implemented yet, just ideas)

- Schedule two machines independently.
- When both machines are available do grid calculation
- When only one machine is available continue with non-grid run
- When the number of machines changes, migrate the workload dynamically.

Theory is simple, but...

Summary



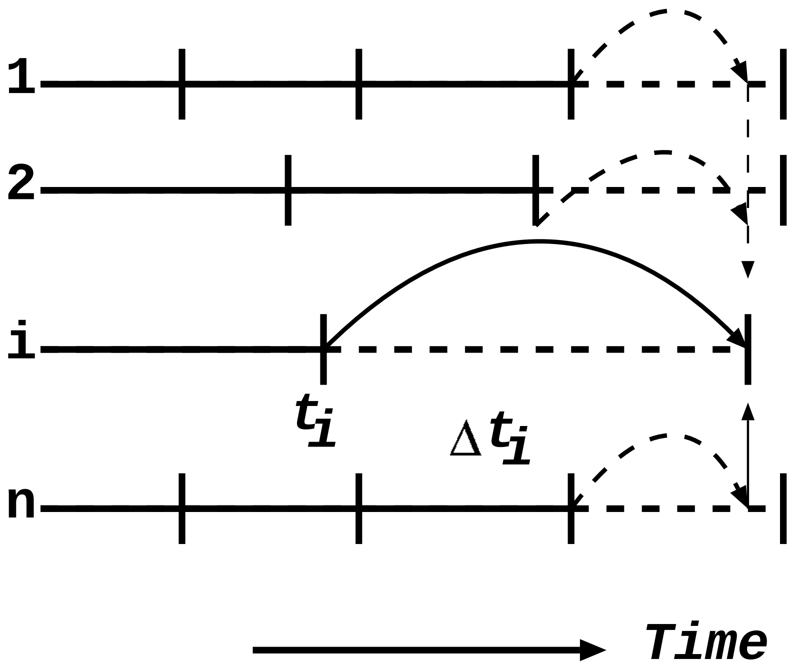
- We developed an N-body code for cosmological simulation using NAOJ XT4 and UvA p6/575 connected by 10G network.
- Performance of TCP/IP communication is more than enough
- In real calculation, TCP/IP performance is not impressive, but still sufficient.
- In other words, we have shown this kind of calculation can be run efficiently on multi-continent Grid.
- Practical issues: Do we (managers of computer centers) want this kind of Grid jobs? How to schedule? Should applications be modified to keep other users happy?

Numerical methods

- **Wide range in both space and time**
  - **Spatial: Gpc to 10 km (radius of neutron stars)**
  - **Time: Gyr to milliseconds**

Numerical integration should ideally cover these ranges.

Time domain: Individual timestep



(Aarseth 1963)

- **Each star has its own time and timestep**
- **Event-driven integration: — star with minimum $t_i + \Delta t_i$ is selected**

Requirements for integration scheme

- High-accuracy predictor necessary
- Variable stepsize necessary
- Cannot use scheme which require the calculation of acceleration at intermediate points (eg: Runge-Kutta)
  - Linear Multistep method OK
  - Runge-Kutta not OK
  - Symplectic schemes not OK

Space domain

How do we calculate the right-hand side of the equation of motion?

For a while we forget about the individual timestep scheme...

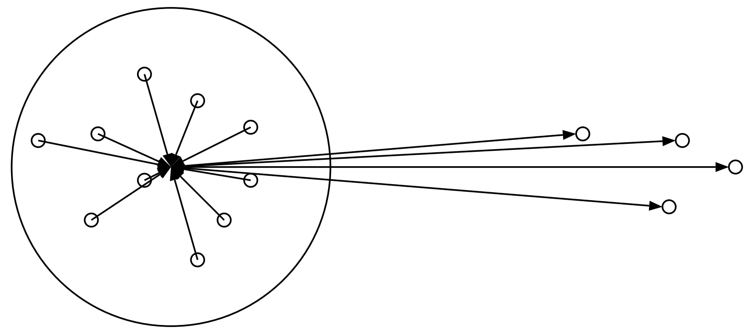
Widely used method: Barnes-Hut treecode
Widely know method: Fast-multipole method (FMM)

Basic idea for tree method and FMM

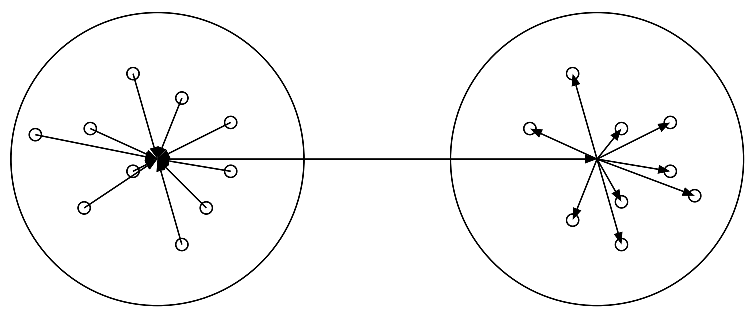
Force from distant particle: Weak

↓

Can't we evaluate many forces at once?



Tree



FMM

- Tree: aggregate stars which exert the forces
- FMM: aggregate both side

How do we aggregate — Barnes-Hut tree

Use tree structure

- **First make a cell with all stars in it**
- **Recursively subdivide the cells to 8 subcells**
- **Stop if there is small enough stars**