Japanese Supercomputer Project

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However, I do not know much about Japanese projects in general (apar from the names, Earth Simulator, PACS-CS, Post Earth Simulator)

So I will talk about our project.

Current status of GRAPE Project

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Talk overview

- GRAPE Project

- GRAPE-DR: Next-Generation GRAPE

GRAPE project

- basic idea

- hardware

- usage example

- GRAPEs in the world

GRAPE project: Rationale

GOAL:

Design and build specialized hardware for simulation of stellar systems.

Rational:

You can do larger simulations (better resolution) for same amount of money.

GRAPE-6	(2002, 64 TF)	4M$
ASCI White	(2001, 12 TF)	200M$
ASCI Q	(2002, 30 TF)	200M$
Earth Simulator	(2002, 40 TF)	300M$
BG/L	(2005?, 360 TF?)	??M$

Basic idea of GRAPE

Special-purpose hardware for force calculation
General-purpose host for all other calculation

$$\frac{d^2 \mathrm{x}_i}{dt^2} = \sum_{j \neq i} -Gm_j \frac{\mathrm{x}_i - \mathrm{x}_j}{|\mathrm{x}_i - \mathrm{x}_j|^3}$$

Host
Computer

$\boldsymbol{x, m}$

$\boldsymbol{a,} \ \psi$
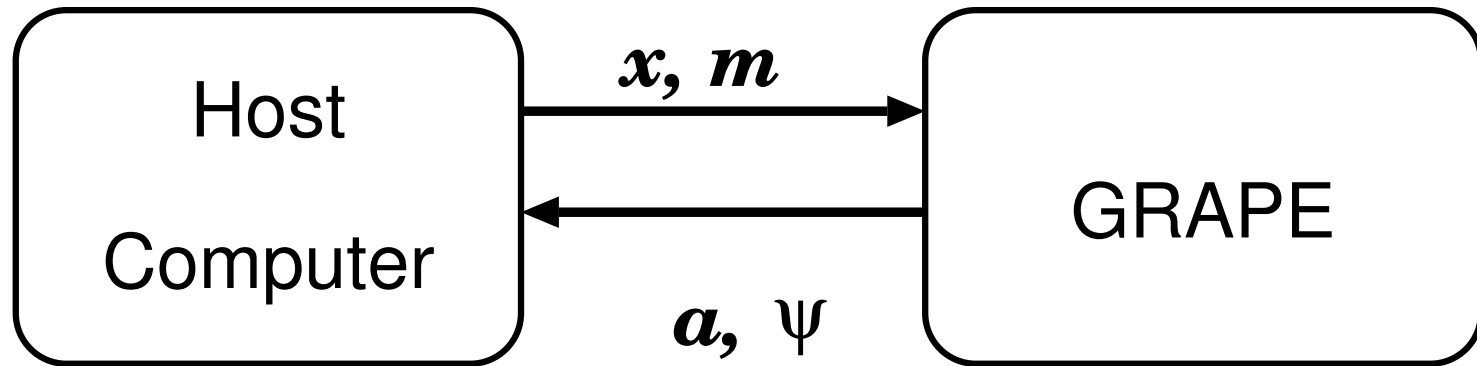
GRAPE

Time integration,
IO, etc

Force calculation

Flexibility

High performance

GRAPE Pipeline procesor

$$\ddot{v}_j = G \sum_i \frac{M_i}{r_{ij}^3} v_{ij} \quad (v_{ij} = v_i - v_j)$$

Chikada 1988, the original proposal

GRAPE machines

1989	GRAPE-1	240 MF	Low accuracy(LA)
1990	GRAPE-2	40 MF	High accuracy(HA)
1991	GRAPE-3	15 GF	LA, custom chip
1995	GRAPE-4	1.08 TF	HA, custom chip
1998	GRAPE-5	40*n GF	LA, 2 pipelines in a chip
2001	GRAPE-6	64 TF	HA, 6 pipelines in a chip

Molecular Dynamics

1992	GRAPE-2A	120MF	
1996	MD-GRAPE	2.4GF	custom chip
2001	MDG2(MDM)	75 TF	RIKEN
2006?	MDG3	0.6PF	RIKEN

Next Generation

2008?	GRAPE-DR	2PF
2009?	MDG4?	16PF?
2001x?	GDR2??	16PF???

Evolution of peak performance
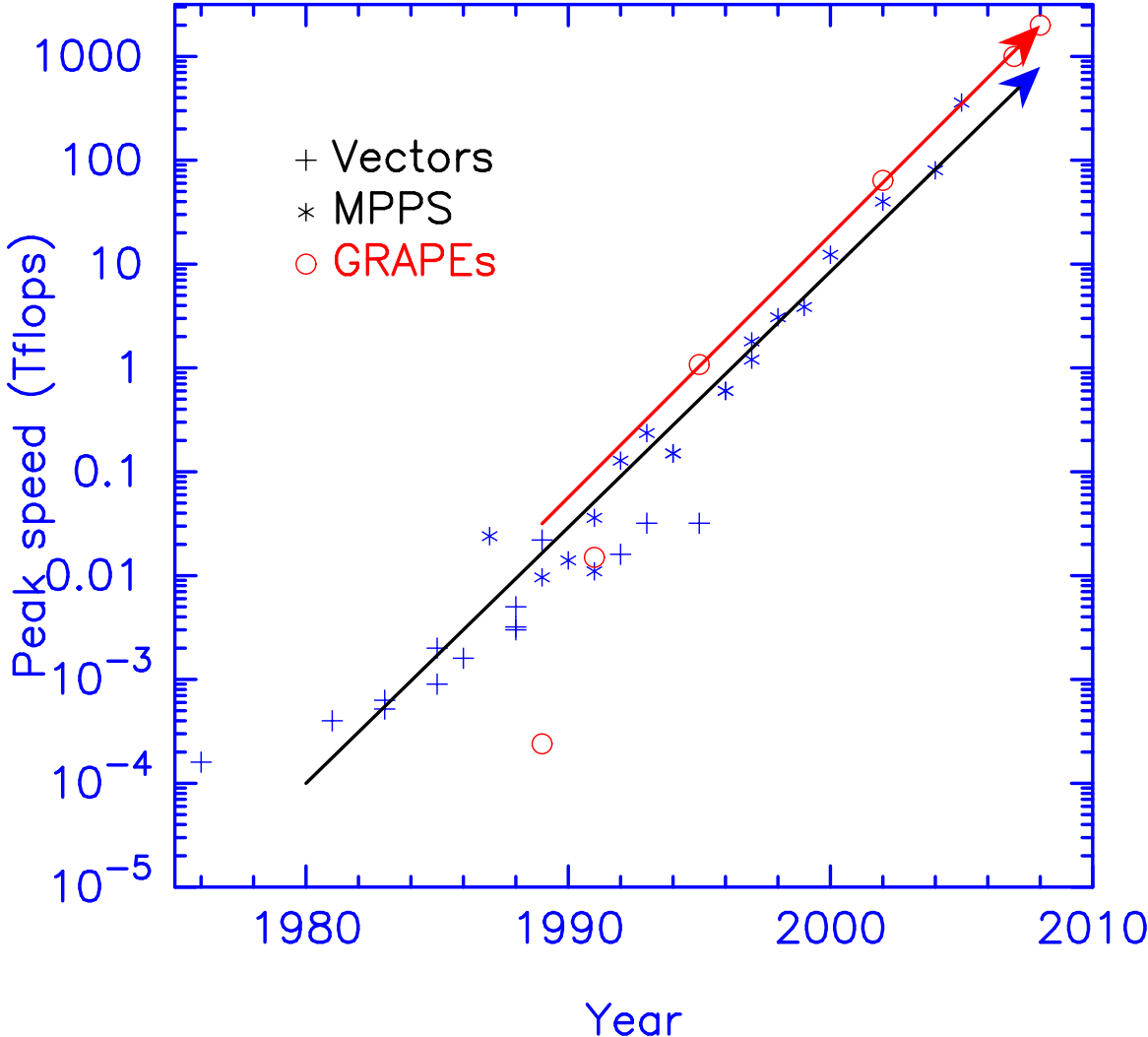
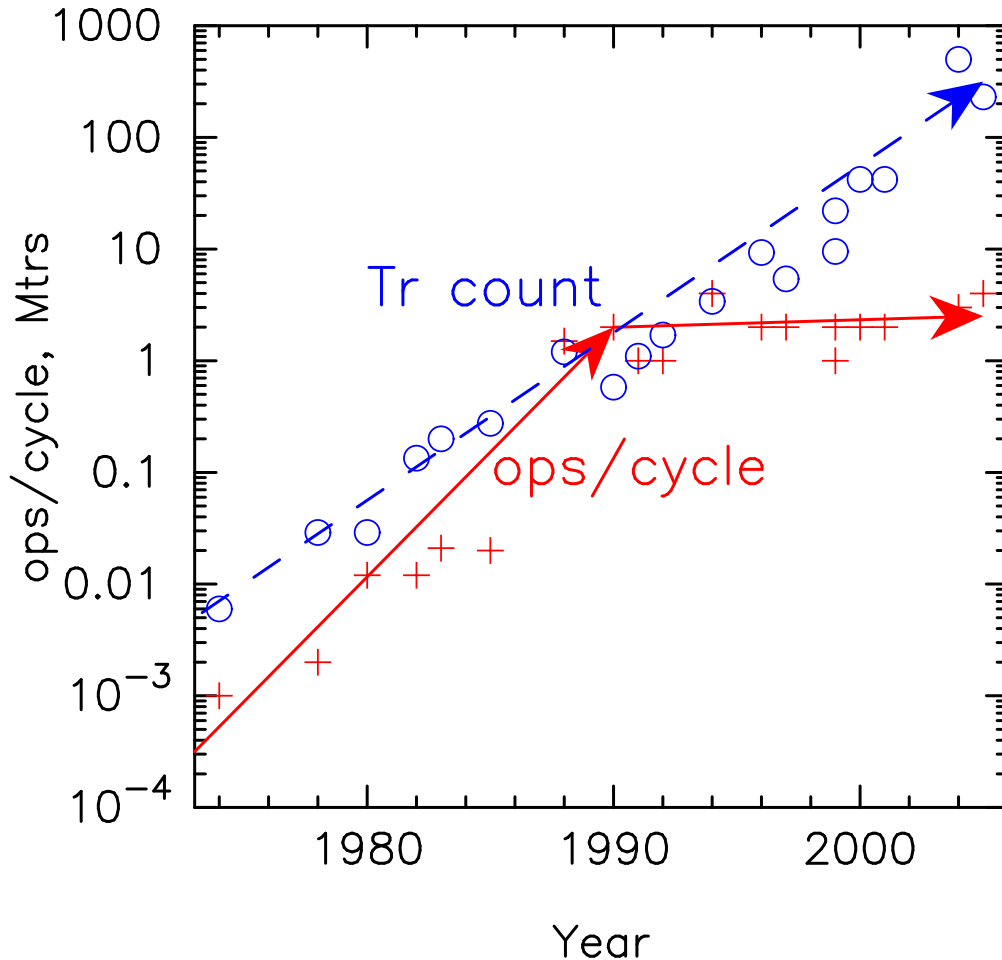# Intel P4 and GRAPE-6
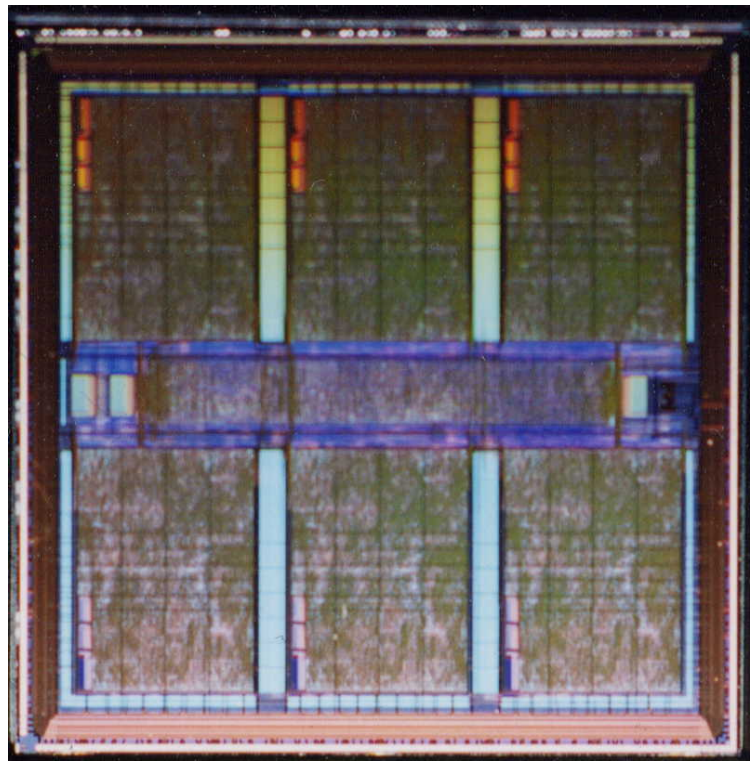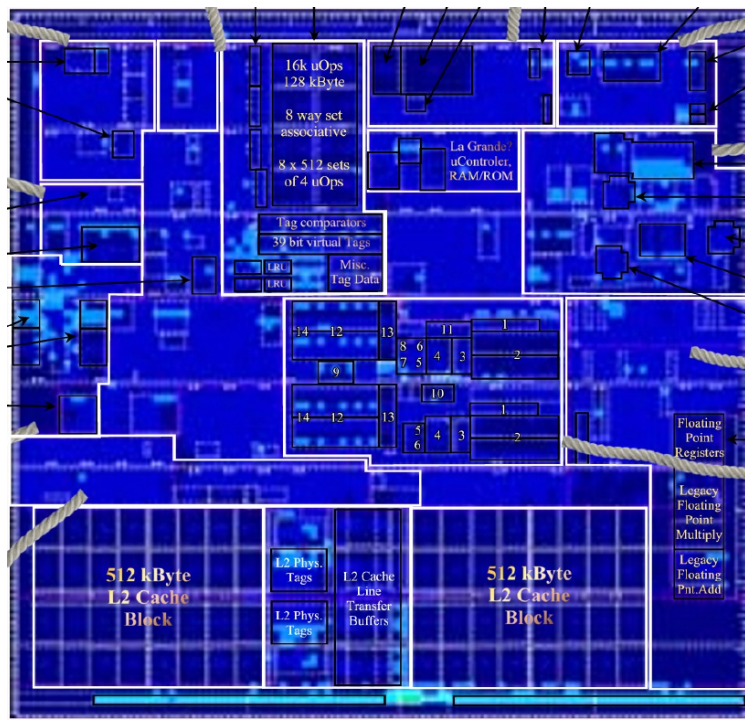
Intel Prescott (2004)
2 FP ops/clock
90nm, 7.6 GF, > 100W?

GRAPE-6 chip (2000)
$\sim$ 400 FP ops/clock
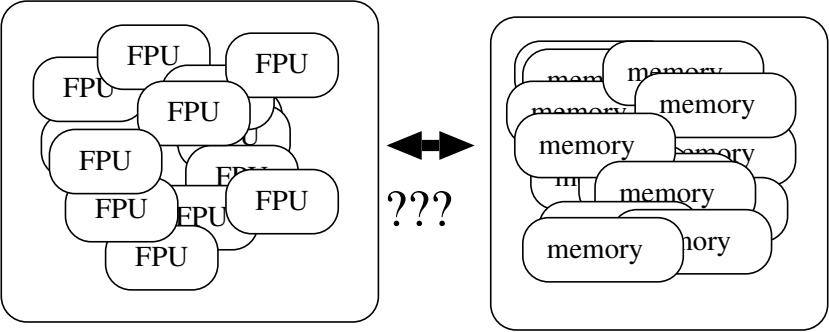0.25μm, 31 GF, 10W

Evolution of microprocessors

Number of transistors doubles every 18 months (*"Moore's Law"*)

Number of floating point units got stuck at $O(1)$. Never reached more than 4.

You can do much better than COTS microprocessor if you can use more than 10% of transistors for FP operations!
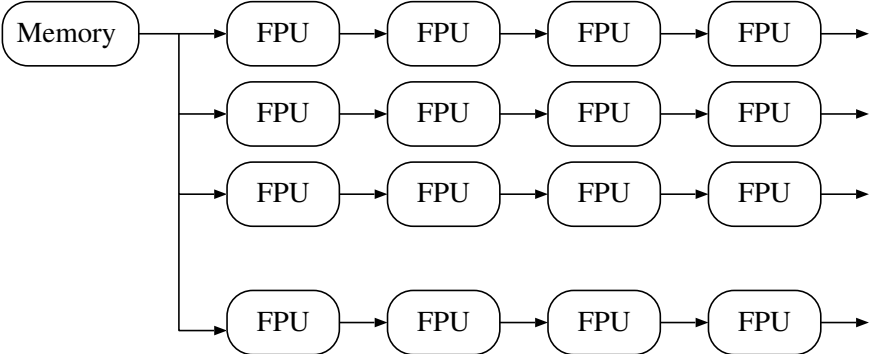
The GRAPE approach

General-purpose

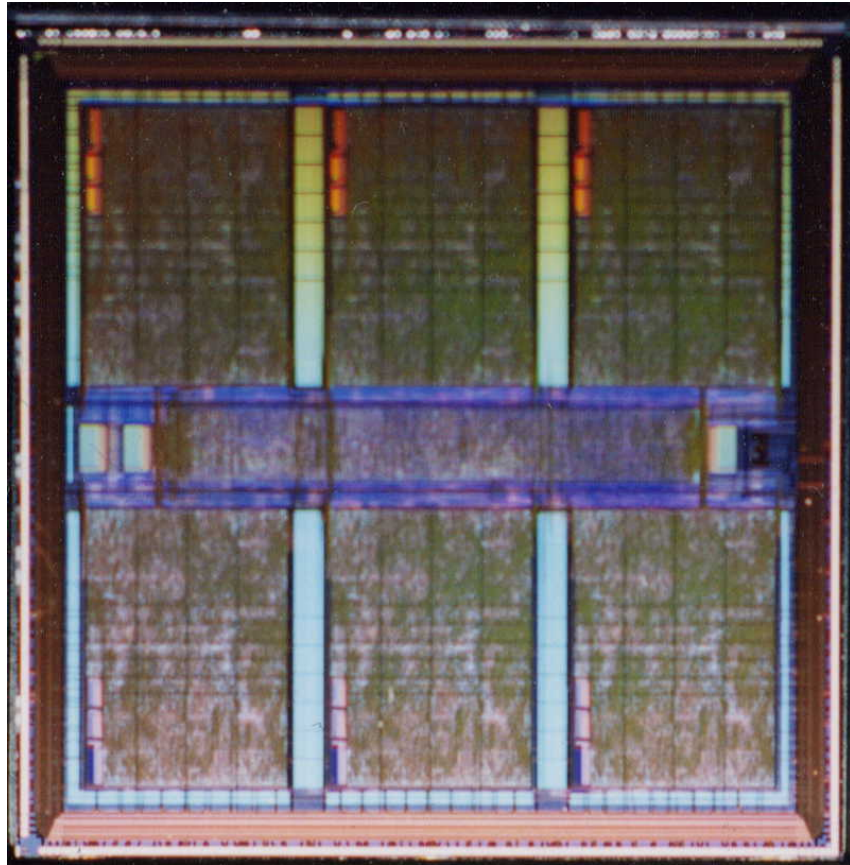How to connect processors and memories???

GRAPE

Hardwired pipeline
One memory serves many pipelines

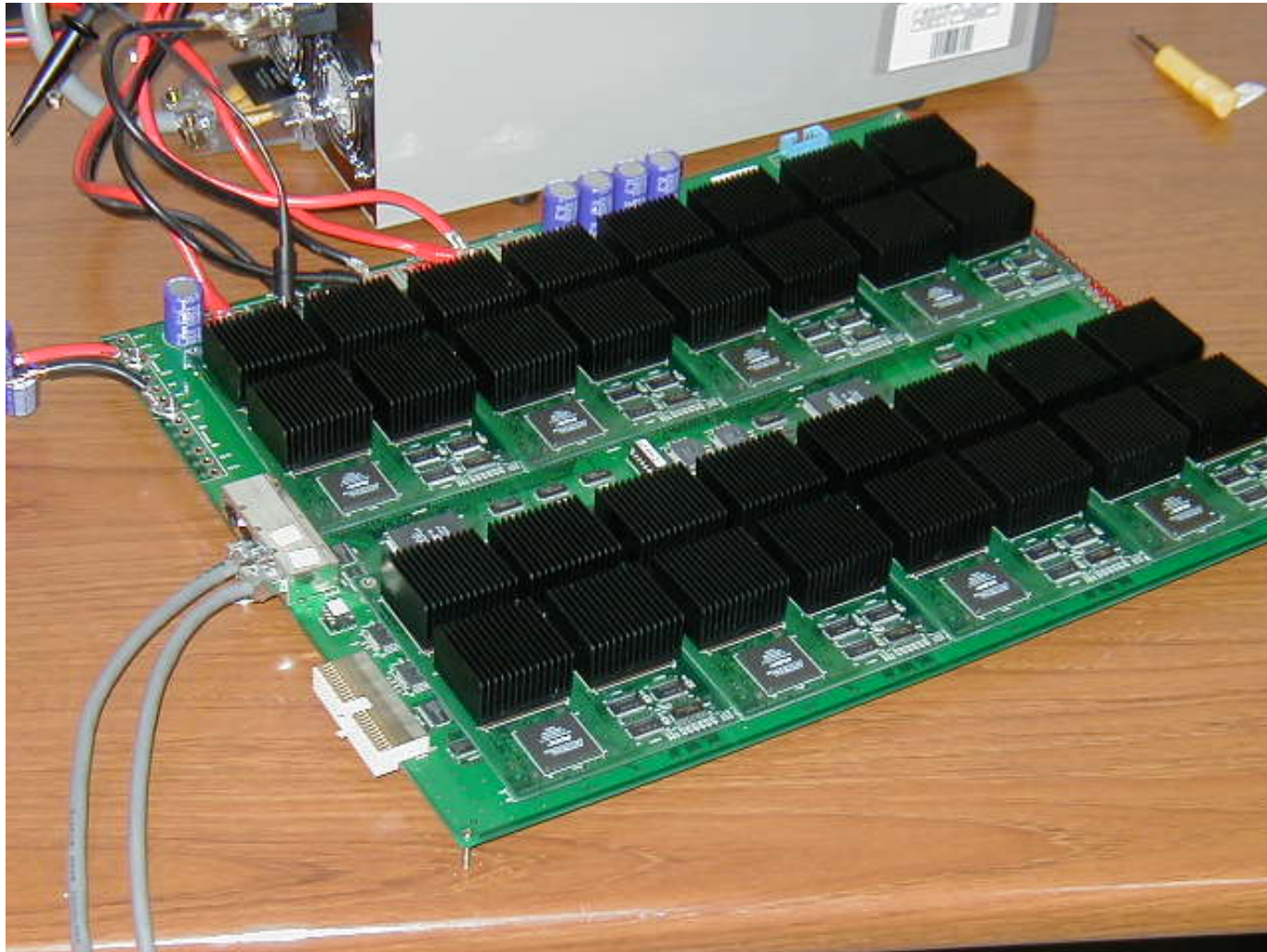# GRAPE-6

- processor chip
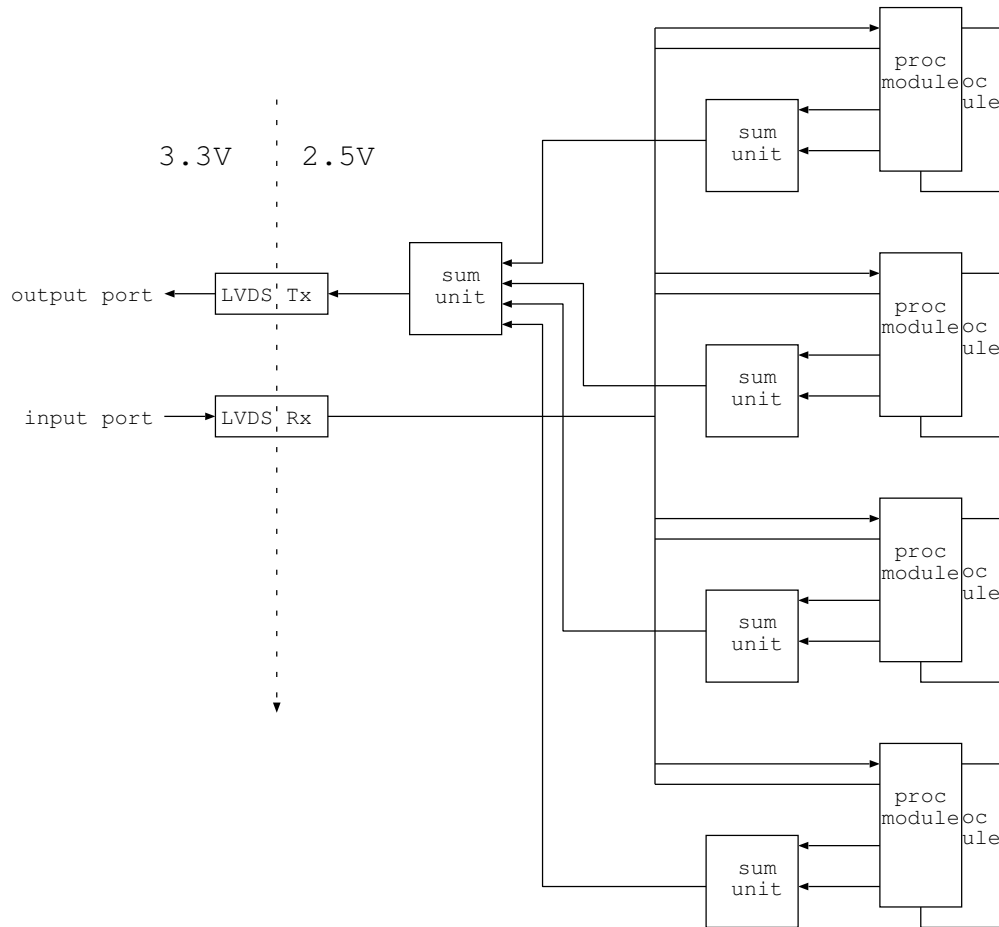
- processor board

- total system

Pipeline LSI

- 0.25 μm design rule (Toshiba   TC-240, 1.8M gates)

- 90 MHz clock

- 6 pipelines

- one predictor pipeline

- 31 Gflops /chip

GRAPE-6 processor board

GRAPE-6 Processor board

3.3V   2.5V

output port ← | LVDS Tx |

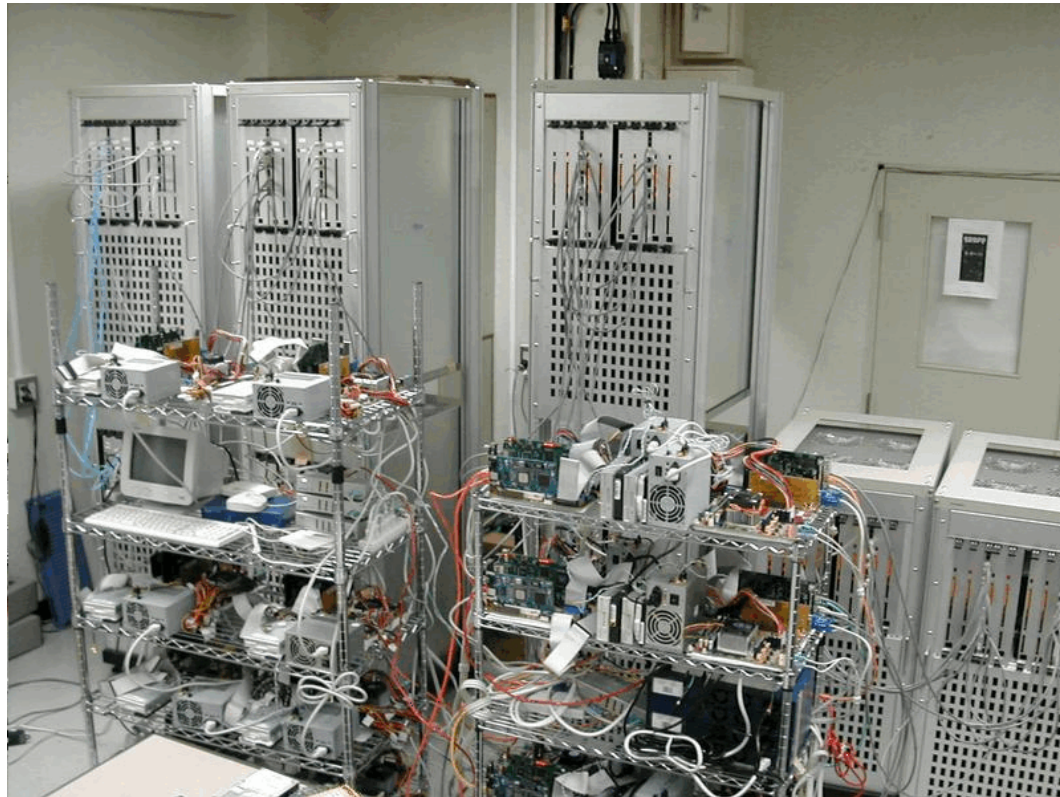input port → | LVDS Rx |

sum unit

proc module / module

- **32 chips/board**

- **Semi-serial (LVDS) interface(350MHz clock, 4 wires)**

- **Tree network for data broadcast and reduction**

The 64-Tflops GRAPE-6 system

Present 64-Tflops system.

4 blocks with 16 host computers.

The full 64 Tflops GRAPE-6 system
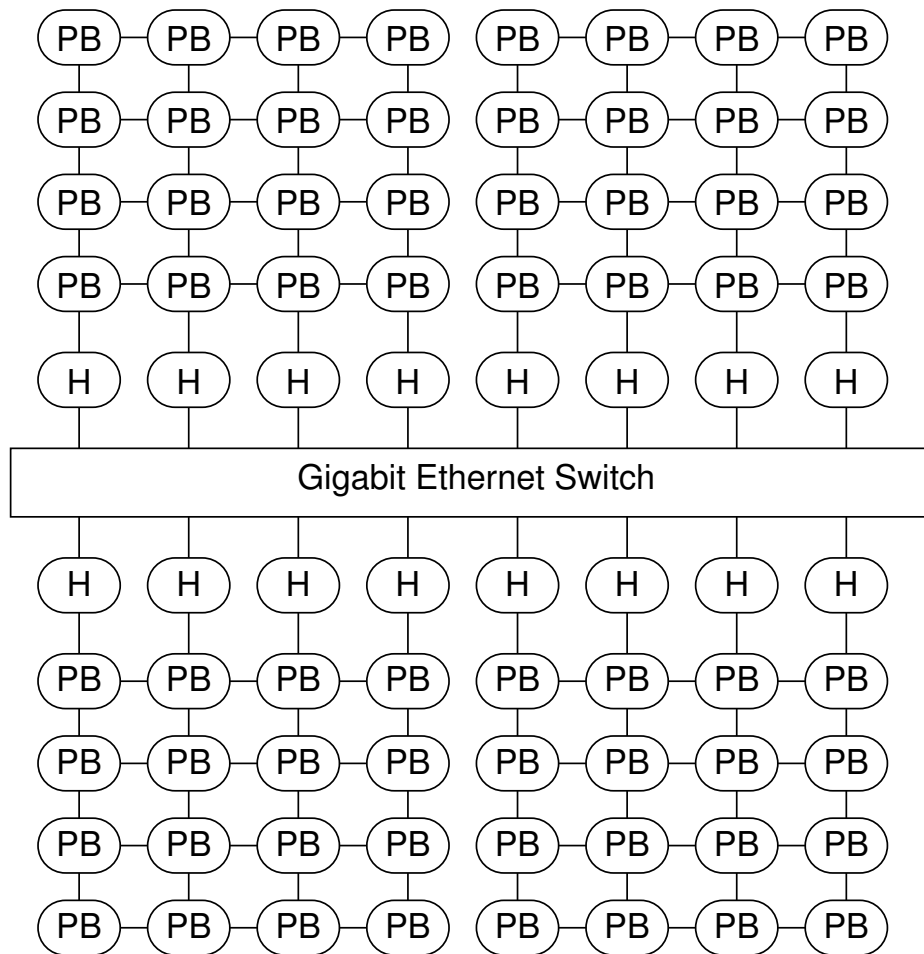
- 4-host, 16-board "block" with dedicated network

- 4 "blocks" connected through GbE network

Combination of host network solution and dedicated network solution.

Some performance numbers

Gordon Bell Prizes

- 2000 1.34 TF on 64-chip system

- 2001 11.2 TF on 1024-chip system

- (2002 29.5TF on 2048-chip system)

- 2003 33.4TF 2048-chip system

BabyGRAPE (aka microGRAPE)

Fukushige et al 2005
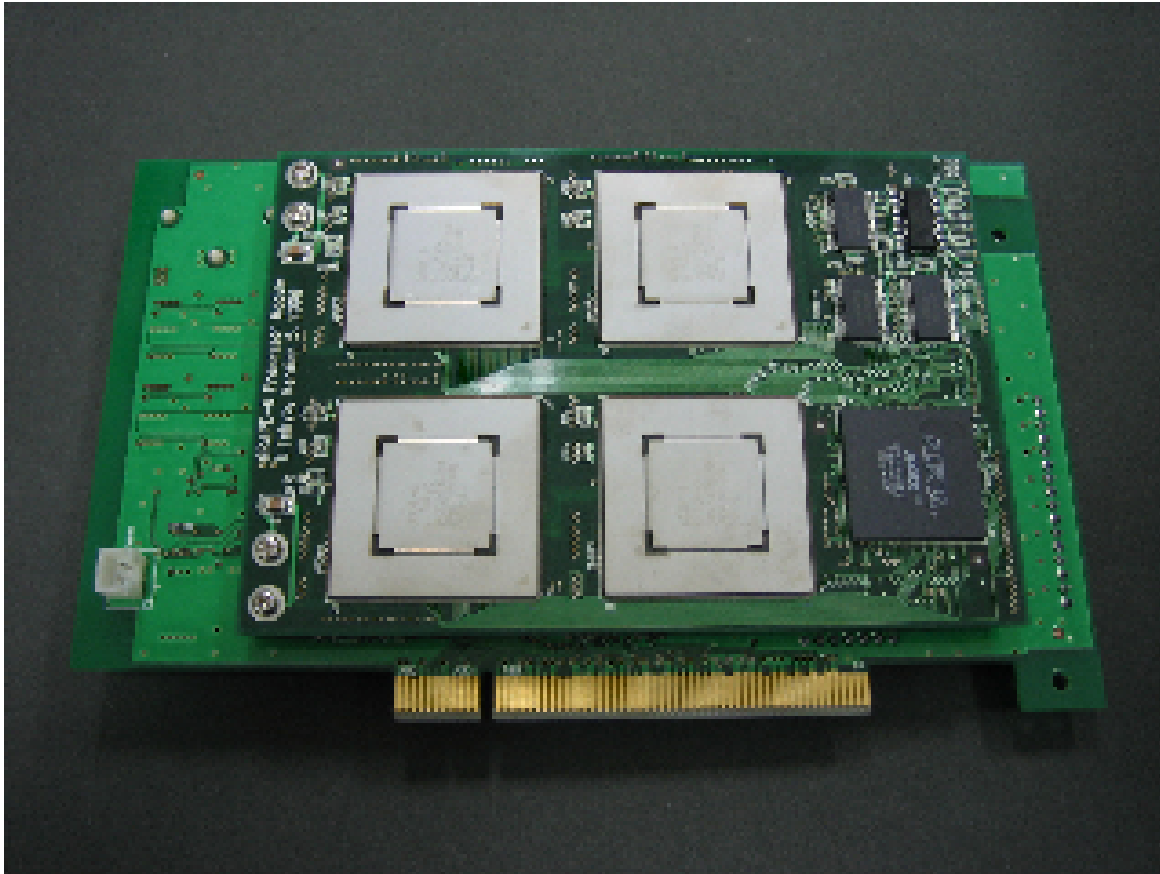
Single PCI card with peak speed of 123 Gflops

Commercial version: `http://www.metrix.co.jp/micro_grape_eng.html`

GRAPE6 worldwide

incomplete list of GRAPE-6s

AMNH 4 G6s
Amsterdam
ARI Heidelberg **32** BGs
Bonn
Cambridge
Drexel 2 G6s?
Indiana
Marseilles
McMaster
Michigan

MPIA
Munich
NAOJ 12 G6s
Rochester **32** BGs
TIT
Tsukuba **256** BGs (06?)

Science with GRAPE

- Cosmology (CDM halo)

- Globular clusters

- Galactic nuclei (black hole binaries)

- Planet formation

- Star formation

- Young star cluster (Portegies Zwart)

- Galactic dynamics

- galaxy formation

- ...

- ...

CDM halo simulation

GRAPE-5 Cluster
8 nodes, 40 Gflops each
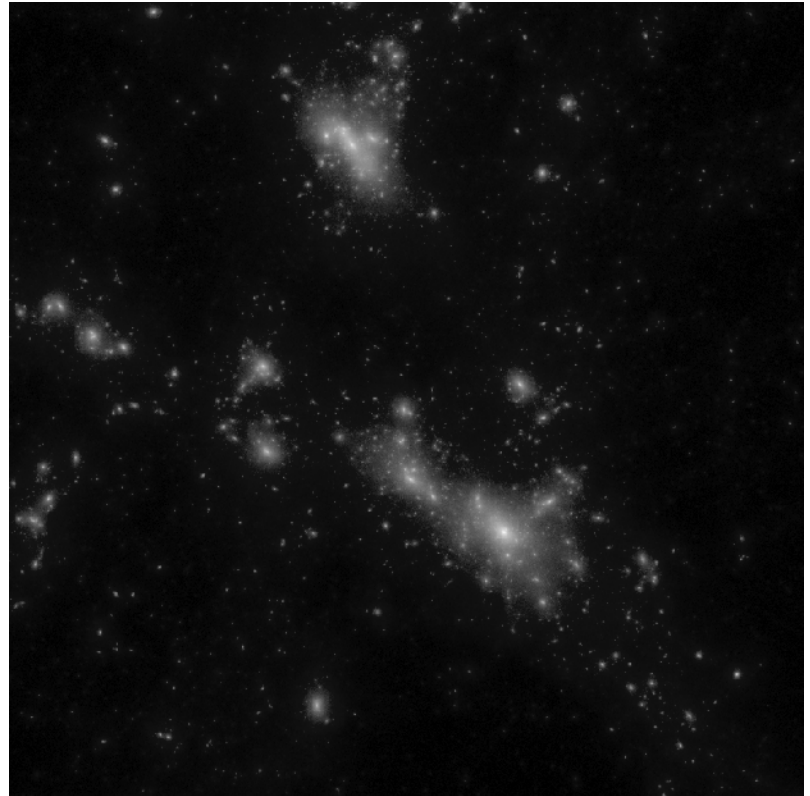
Simulated Cluster
60M particles in a single DM halo
Largest calculation of this kind.

Globular clusters with central black hole

Baumgardt, J.M. and Hut (ApJL 620, 238, 2005)
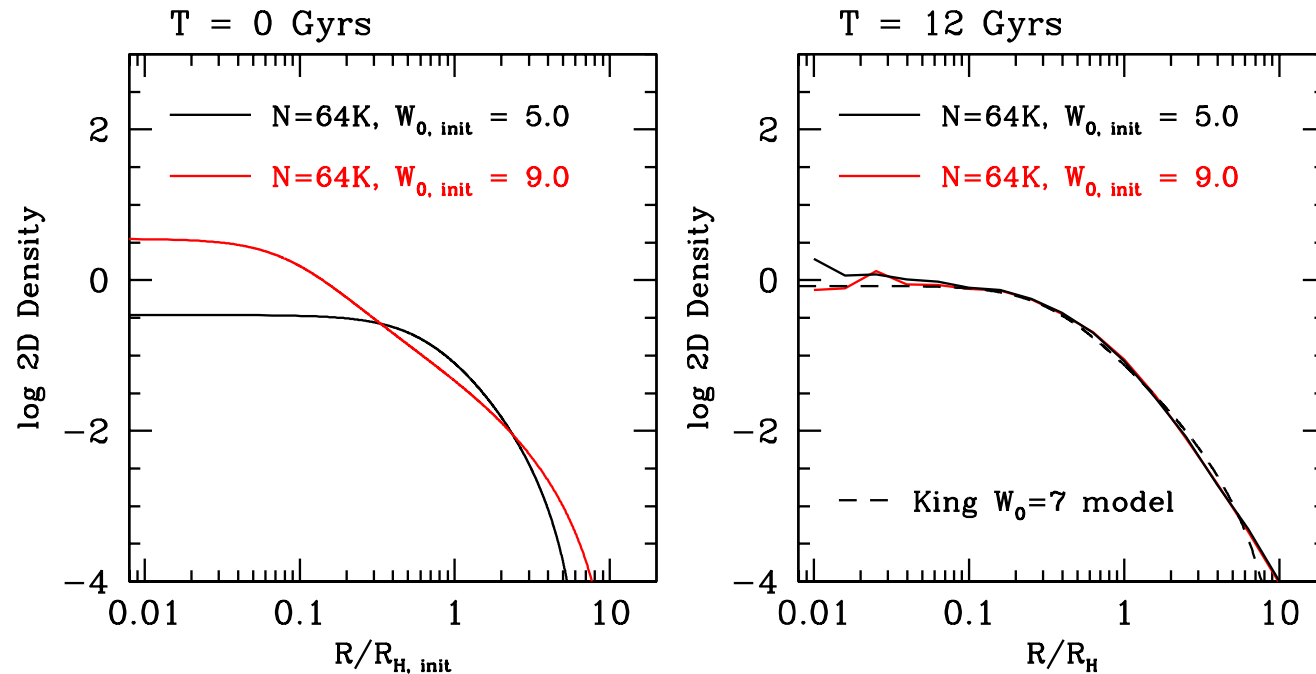
Surface brightness profile becomes King7-like, almost independent of initial profile and BH mass (in the range of 0.1% to 1%)

Next-Generation GRAPE — GRAPE-DR

- Budget approved. (2.5M$ × 5 years)

- Planned peak speed: 2 Pflops

- New architecture — wider application range than previous GRAPEs

- Planned completion year: FY 2008 (early 2009)

GRAPE-DR processor structure

Host Computer

External Memory

Result

Memory Write Packet

Control Processor
(in FPGA chip)

Instruction

SING Chip

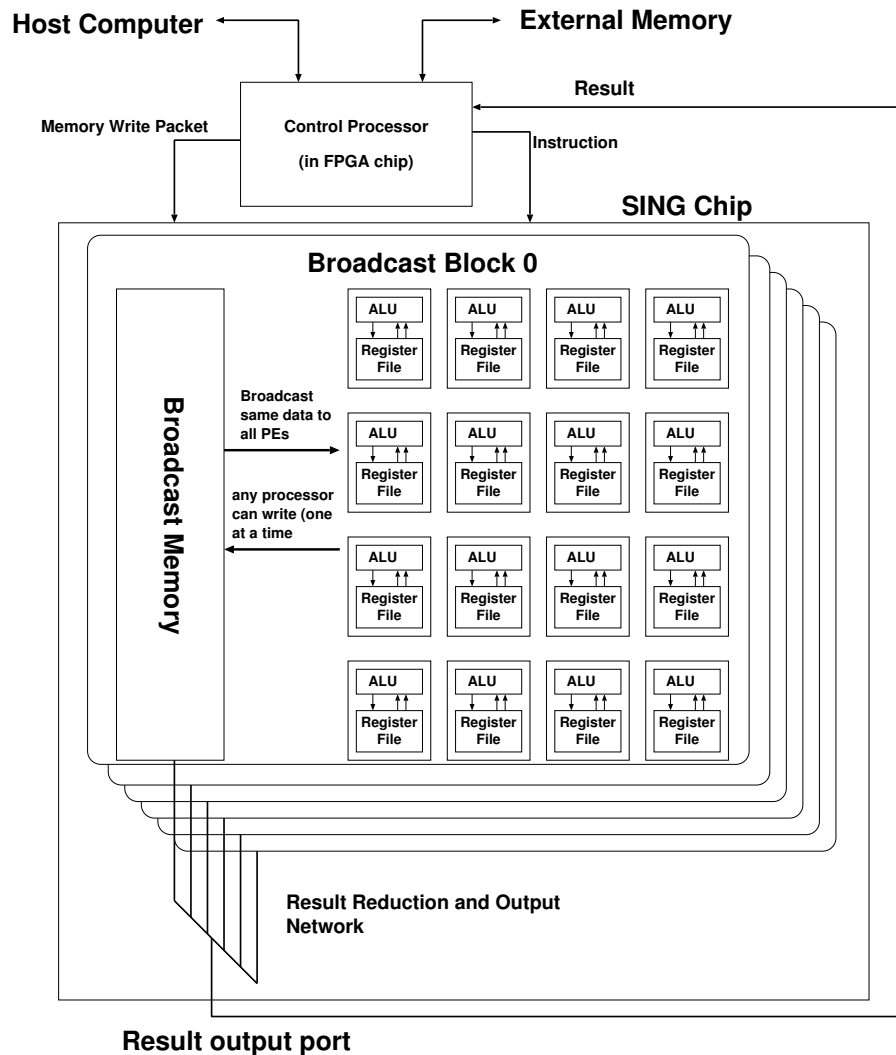**Broadcast Block 0**

Broadcast Memory

Broadcast same data to all PEs

any processor can write (one at a time

| ALU | ALU | ALU | ALU |
| Register File | Register File | Register File | Register File |

| ALU | ALU | ALU | ALU |
| Register File | Register File | Register File | Register File |

| ALU | ALU | ALU | ALU |
| Register File | Register File | Register File | Register File |

| ALU | ALU | ALU | ALU |
| Register File | Register File | Register File | Register File |

Result Reduction and Output Network

Result output port

Collection of small processor, each with ALU, register file (local memory)

One chip will integrate 512 processors
Single processor will run at 500MHz clock (2 operations/cycle).

Peak speed of one chip: 0.5 Tflops (20 times faster than GRAPE-6).

High-level architecture

- Single card: 4 chips, PCI-X/PCI-E/Hypertransport(? interface, 2 Tflops.

- Two cards per single node, host: x86 PCs.

- Host network: 512 node, fast 10GbE switches?

Difference from GRAPE-6:

- No custom network

- No large card

Development schedule

(tentative)

2006 Fall	First sample chip
2007 Spring	Prototype board
2008 Spring	Large parallel system
2009 Spring	Final system

Summary

- GRAPE project has successfully developed very high performance computers for astrophysical particle-based simulations.

- This high performance is achieved by designing a custom processor chip with very large number of arithmetic units, connected in the form of application-specific hardwired pipeline.

- The next machine, GRAPE-DR, will have wider application range than traditional GRAPEs, with programmable processors.