SPRAT: RUNTIME PROCESSOR SELECTION FOR ENERGY-AWARE COMPUTING

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OUTLINE

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- Introduction
  - PC = A hybrid computing system of CPU and GPU
- Stream Programming with Runtime Auto-Tuning (SPRAT)
  - A Programming Framework with Automatic Processor Selection
- Performance Evaluation
  - Processor Selection for Energy Saving
- Conclusion and Future Work

BACKGROUND

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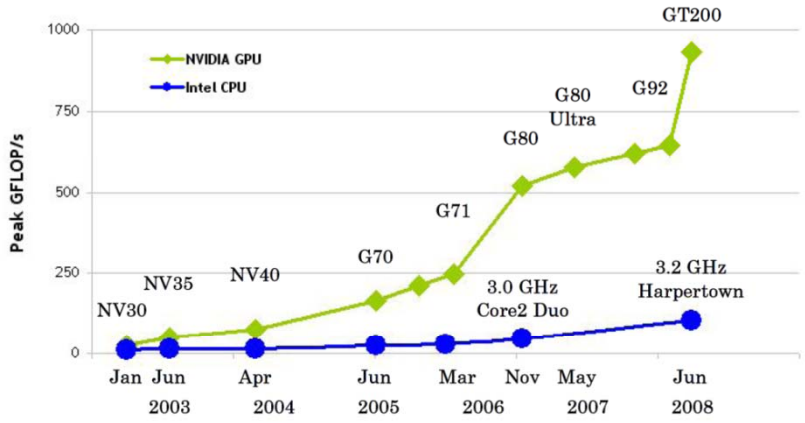
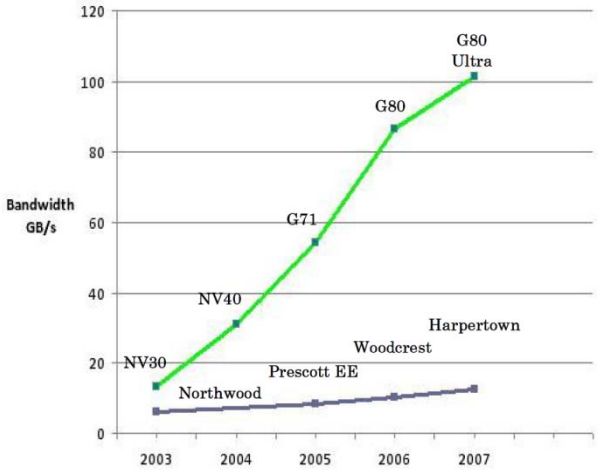
- PC is a hybrid computing system of CPU and GPU.
  - CPU and GPU are very different processors.
    - GPU's strengths and weaknesses
      - ☺ Raw performance (GFLOPS)
      - ☺ High memory bandwidth
      - ☹ Poor programming flexibility
      - ☹ Data transfer overhead from/to main memory



Peak Performance (Source: NVIDIA)



Memory Bandwidth (Source: NVIDIA)

MOTIVATION

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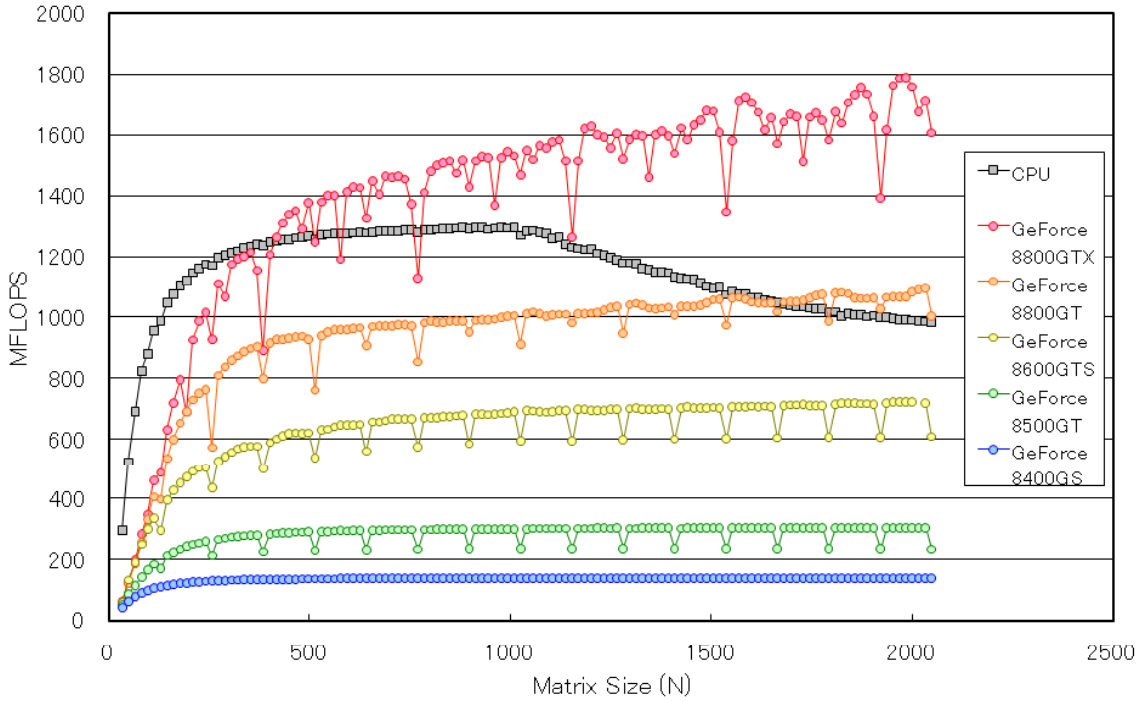
- The performance difference between CPU and GPU depends on the problem size.



- The problem size is often determined at runtime.
- The intersection point moves if the hardware configuration changes.

Which processor should be used for execution?

THIS WORK

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- Goal: programming framework for hybrid computing systems
  - Programmers do not care about which processor executes the code.
    - Each processor has its own strengths and weaknesses
    - Appropriate selection depends on hardware configuration and problem size.

  ⇨ ***Runtime Processor Selection***

- **SPRAT: Stream Programming with Runtime Auto-Tuning**
  - A SPRAT code is automatically translated into CPU and GPU codes.
  - Runtime processor selection based on performance prediction

GPU may work fast but also increases the power consumption.

⇨ ***GPU should be used only if it works fast enough to outweigh the additional power consumption.***

SPRAT LANGUAGE

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- A domain-specific language for stream processing.
  - C with additional keywords for stream processing
    - Similar to BrookGPU (Buck et al, 2004)
      - does not need any architecture-specific description
    - The execution time of a kernel is predictable.
      - Linear to the number of stream elements.

SPRAT decides which processor executes kernels.

SPRAT CODE

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- **Kernel**

  - Special function running on either CPU or GPU
    - `kernel map copy(…)`

- **Stream**

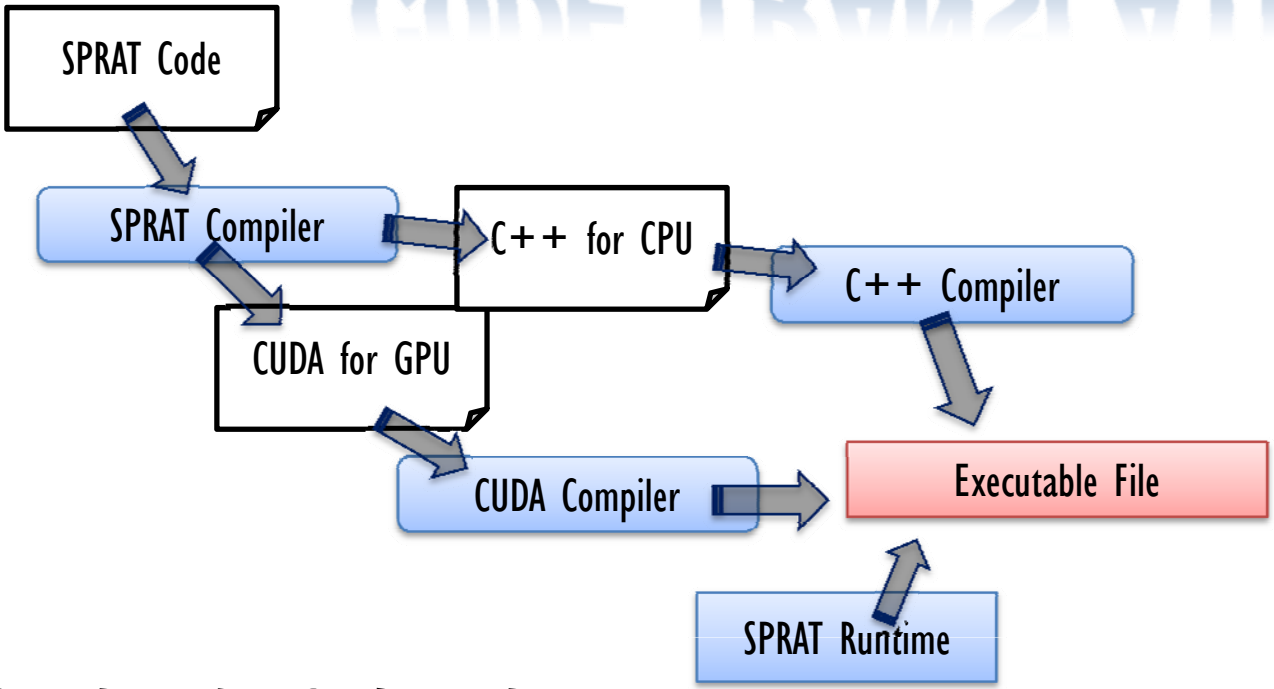
  - Data container accessed by kernels
    - `stream <float> sa, sb`

- **Data management**

  - Copy data from/to streams
    - `streamRead, streamWrite`

```
kernel map copy(in stream<float> sa,
                out stream<float> sb)
{
    sb = sa;
}

int main(int argc, char **argv)
{
    float aa[N][N];
    float ab[N][N];
    stream<float> sa(N,N);
    stream<float> sb(N,N);

    InitializeArray(aa);
    streamRead(sa, aa);

    copy(sa, sb);

    streamWrite(sb, ab);
    PrintArray(ab);

    return 0;
}
```

CODE TRANSLATION



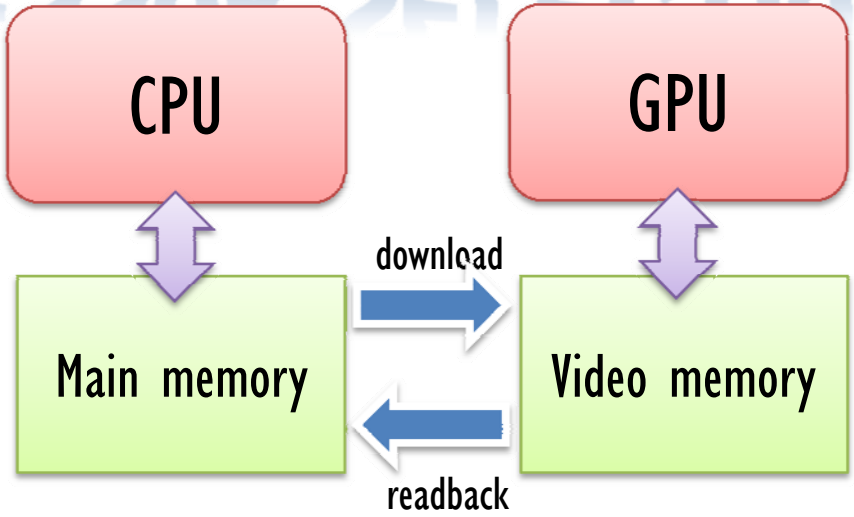
Sample code of a kernel

```
kernel map filter(gather stream<float> source, out stream<float> dest, float coeff)
{
    dest = source[-1][-1] + source[-1][ 0] + source[-1][ 1]
         + source[ 0][-1] + coeff * source + source[ 0][ 1]
         + source[ 1][-1] + source[ 1][ 0] + source[ 1][ 1];
    return;
}
```

A simple code is automatically translated into CPU and GPU codes.

Provides the opportunity to select which processor runs the code.

PROCESSOR SELECTION (1/2)



- Processor should be switched only if the total energy consumption reduces.
  - The data transfer increases the execution time and hence the energy consumption.
    - Frequent processor switching and data transfer will increase the energy consumption.
  - GPU must be much faster than CPU.
    - GPU generally needs more power than CPU!

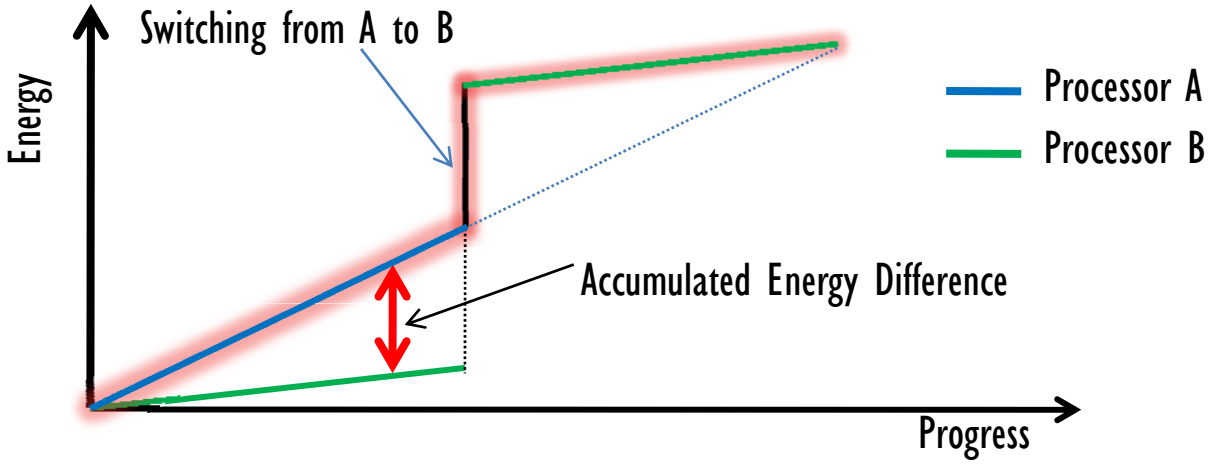
Is GPU fast enough to outweigh the power consumption and the data transfer overhead?

PROCESSOR SELECTION (2/2)

- Assumptions
  - Power consumption of each processor is constant for any kernel.
  - Kernel execution time is in proportion to the number of stream elements.
- Accumulated Energy Difference (AED)
  - How much the other processor can save the energy.

$$\tau_p \leftarrow \max\{\tau_p + (P_{q,ki}T_{q,ki} - P_{p,ki}T_{p,ki}), 0\}$$

SPRAT switches the processor if AED exceeds extra energy consumption for data transfer.



PERFORMANCE MODELING

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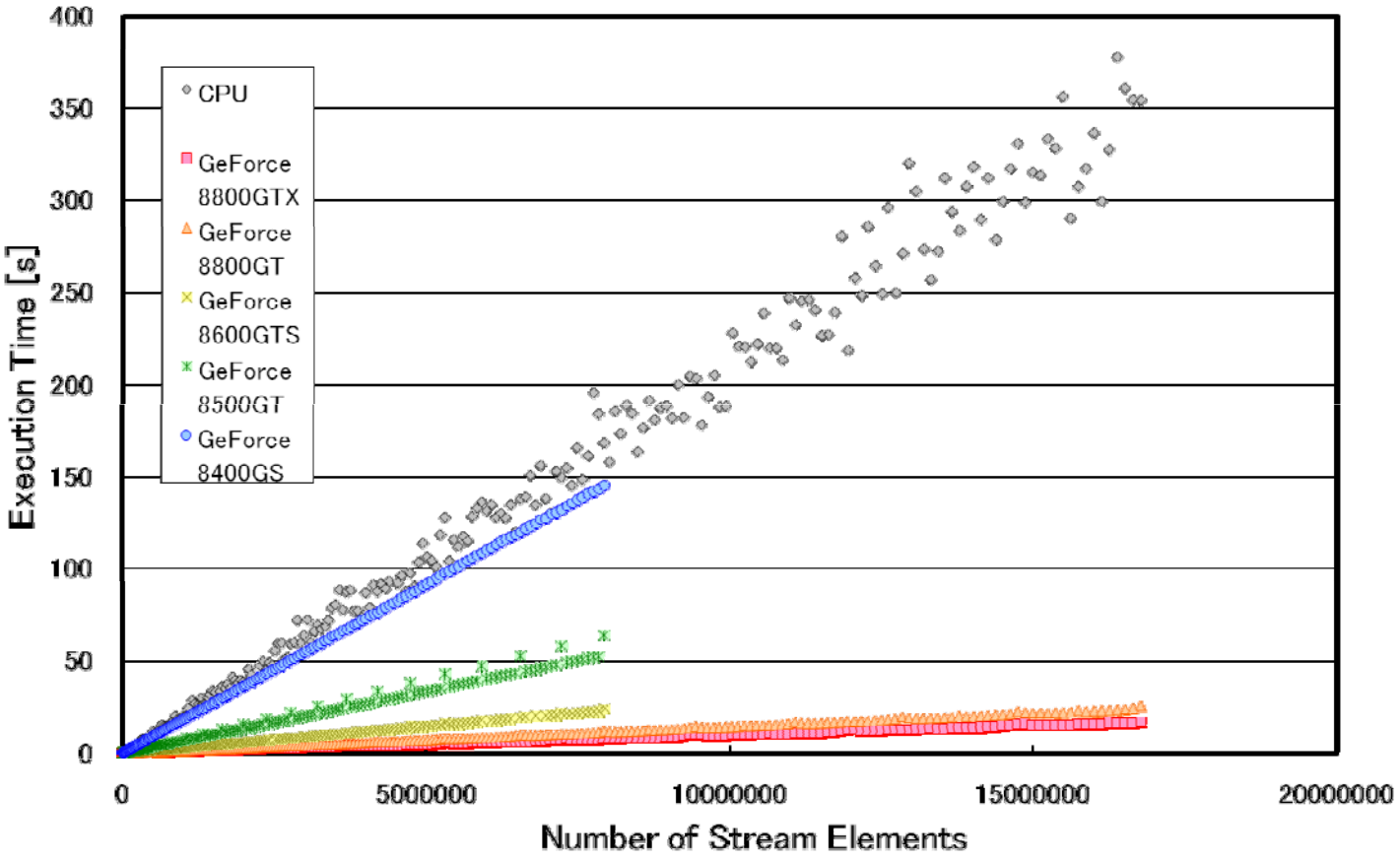
- Kernel execution time is proportional to the stream length.



SYSTEM CONFIGURATION

- Evaluated System
  - OS: CentOS (driver version 173.13)
    - C++ compiler: gcc 4.2.1
    - CUDA compiler: nvcc-release 1.1 V0.2.1221
  - CPU: Intel Core 2 Quad Q6600 (2.4GHz)
  - Mem: DDR2-800 4GB
  - GPU:

Model	# SMs	Mem [MB]	BW [GB/s]
GeForce 8800GTX	16	768	86.4
GeForce 8800GT	14	512	57.6
GeForce 8600GTS	4	256	32.0

POWER CONSUMPTION

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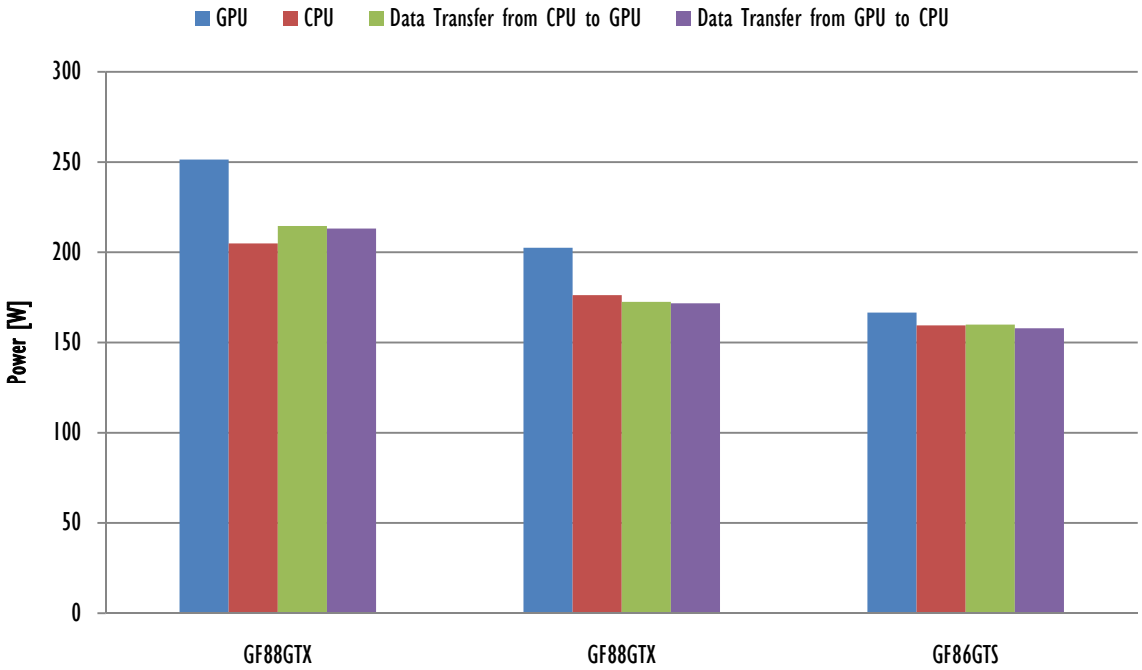
- Power Consumption of Each System Configuration
  - Each processor is loaded iteratively running the SAXPY kernel.
  - HIOKI HiTESTER 3334 is used for the measurement.



APPLICATION (1/2)

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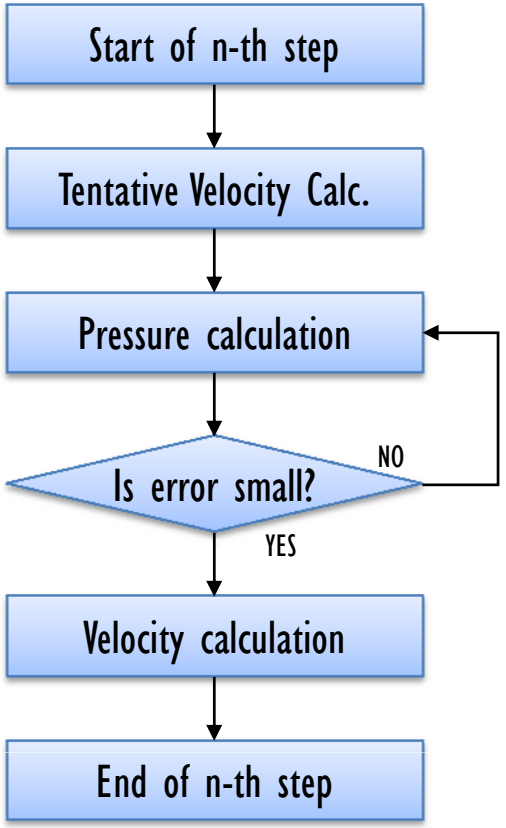
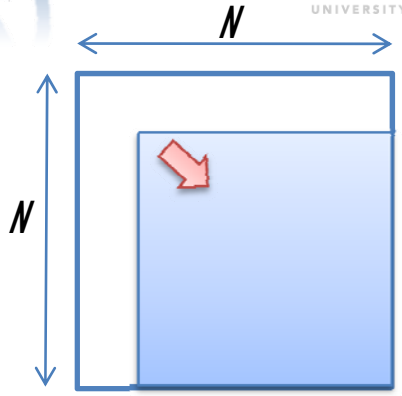
- 2-dimencional incompressible fluid simulation ($N \times N$)
  - Fractional Step Method
    - consists of 8 kernels.
      - Most kernels are simple stream computations
    - Stream size of each kernel does not change.
      - The performance is predictable from the history.



GPU will work well for this application.
SPRAT will switch the processor from CPU to GPU.

APPLICATION (2/2)



- LU decomposition
  - needs non-coalesced memory accesses
    - not suitable for GPU to run = CPU should run kernels.
  - The first kernel invocation is the most time-consuming
    - Stream size decreases at every kernel invocation.
    - GPU should be used only in the early stage of the execution.
      - But SPRAT does not switch the processor until AED exceeds data transfer overhead.

This application has disadvantageous features for GPU and SPRAT.

RESULTS FOR CFD

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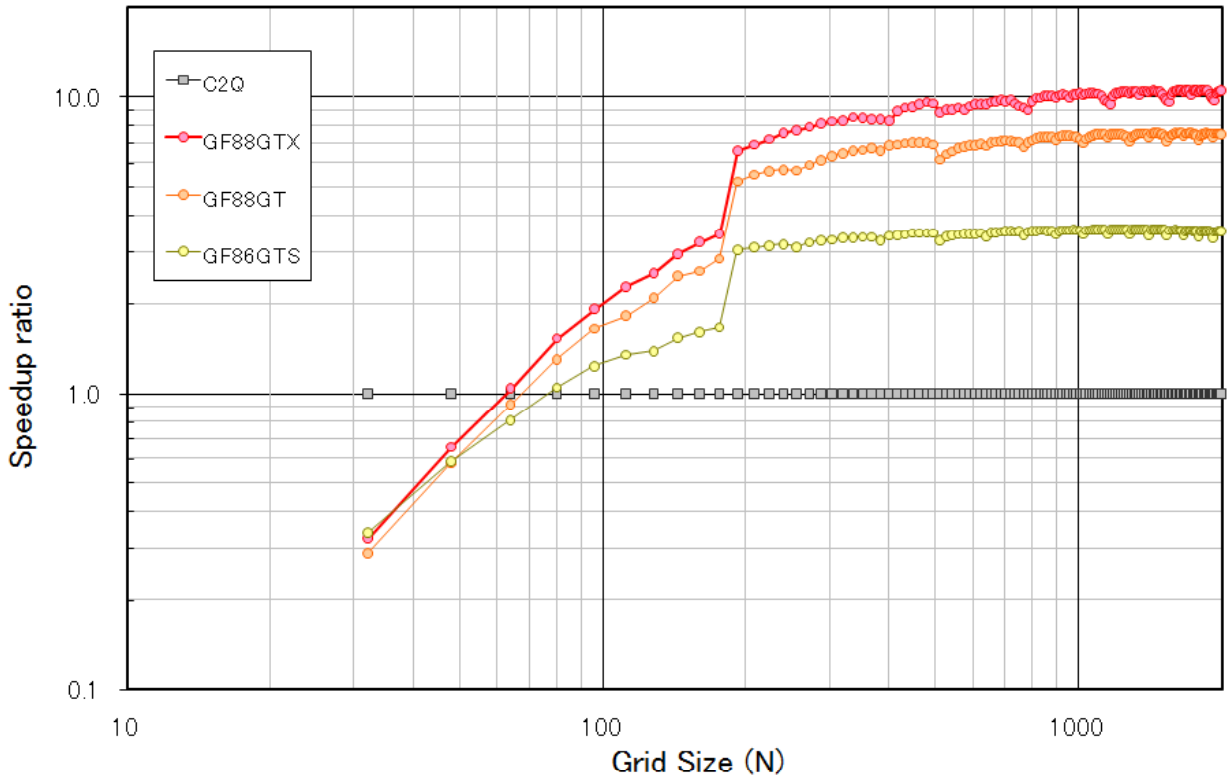
- GPUs improve the energy efficiency.



RESULTS FOR LU (1/2)

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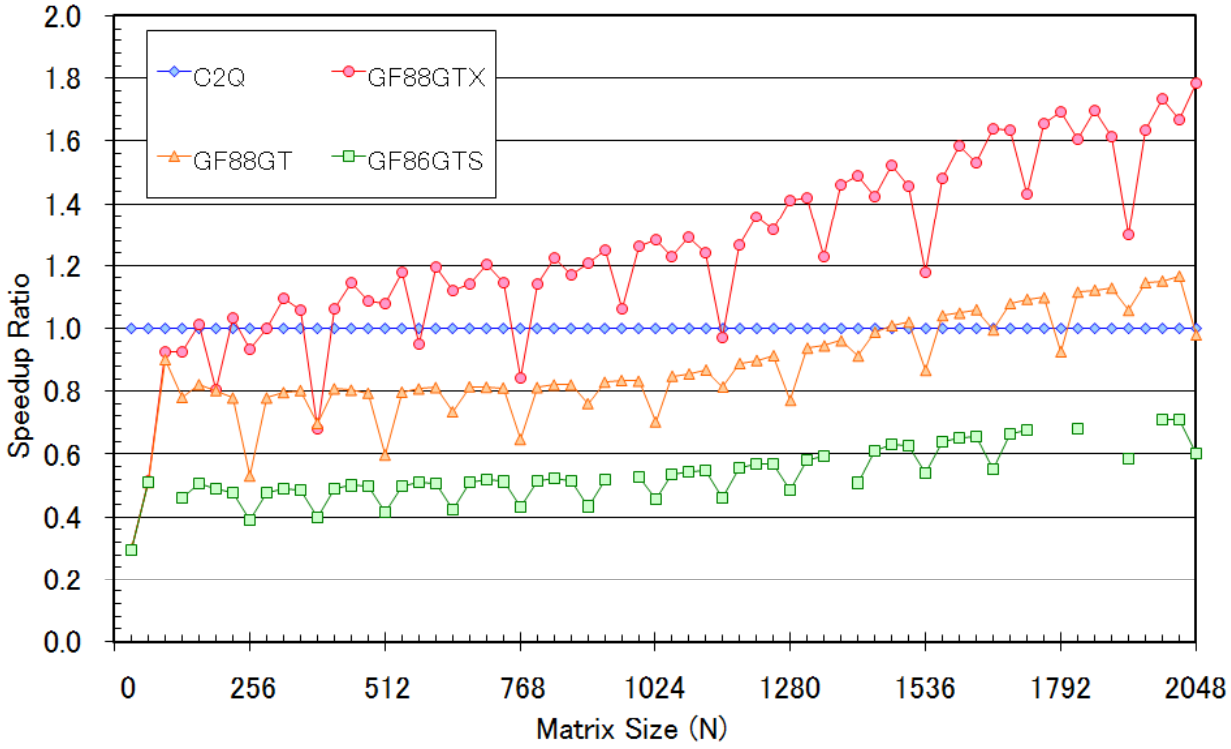
- Appropriate processor selection depends on the matrix size.



RESULTS FOR LU (2/2)

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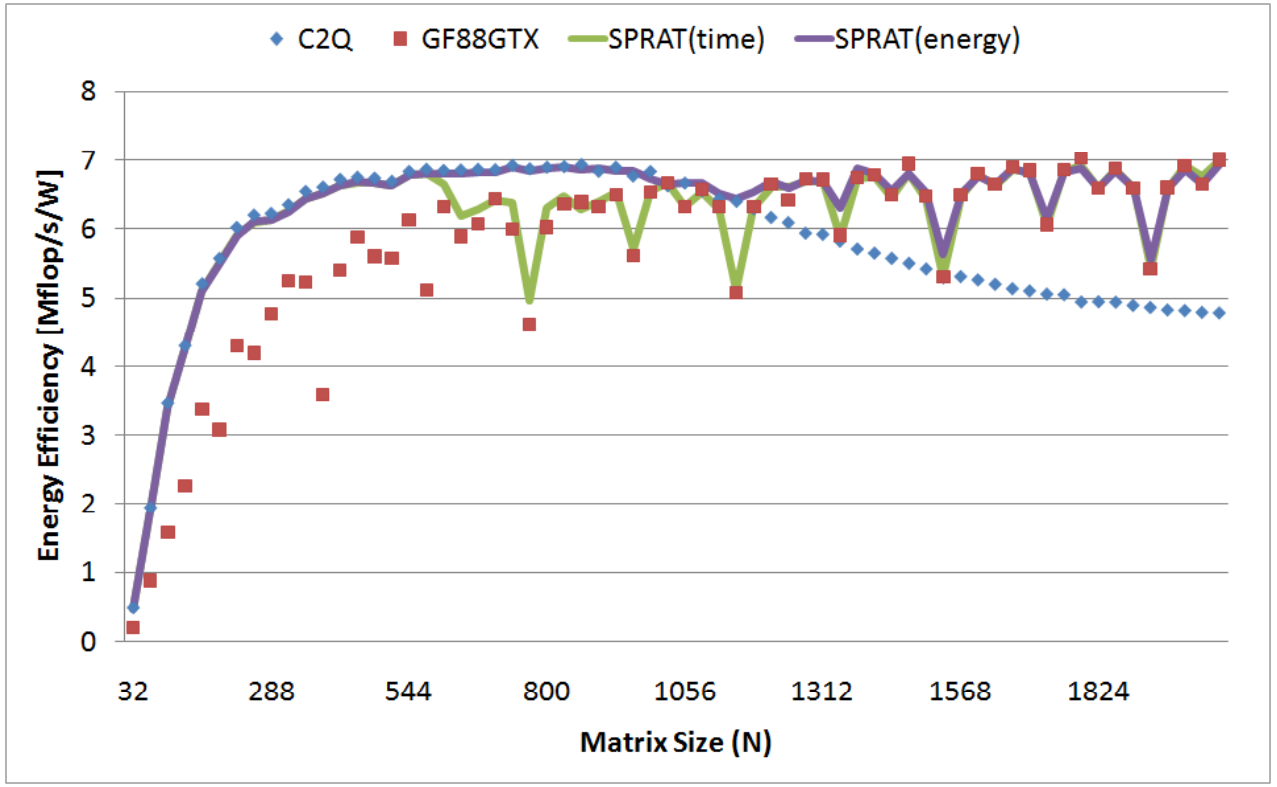
- SPRAT can select a more energy efficient processor for each matrix size.



CONCLUSION

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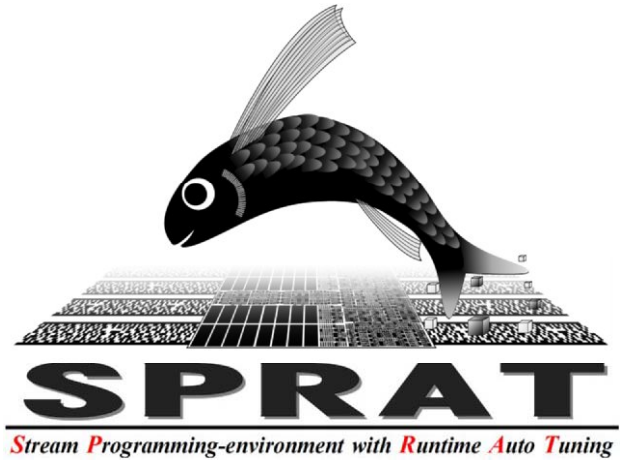
- **SPRAT: Stream Programming with Runtime Auto-Tuning**
  - SPRAT compiler automatically generates CPU and GPU codes.
  - SPRAT dynamically selects which processor runs the kernel.
    - The processor is switched from CPU to GPU only if improving the energy efficiency.



SPRAT is promising to automatically improve the energy efficiency of hybrid computing systems.

FUTURE WORK

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- Automatic optimization techniques
  - enable SPRAT compiler to generate more efficient code.
- Performance/energy prediction models
  - enable SPRAT to predict the performance/energy more accurately.
- Other accelerators
  - Cell broadband engine? FPGA? ClearSpeed? Vector Machines?

QUESTIONS?

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- Acknowledgments

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