Optimizing Collective Communication on Multicores

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[1]University of California, Berkeley

(2009)

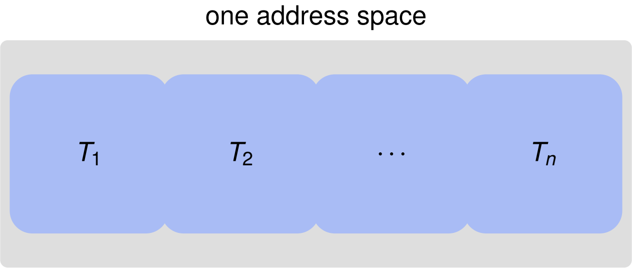
Algorithms for Scalable Synchronization on Shared-Memory Multiprocessors

John M. Mellor-Crummey, Michael L.Scott
(1991)

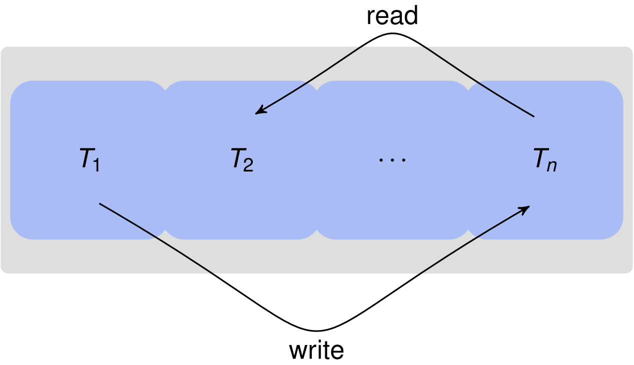
PGAS Languages

- Focus on Partitioned Global Address Space languages

Partitioned Addresspace



One Sided Communication

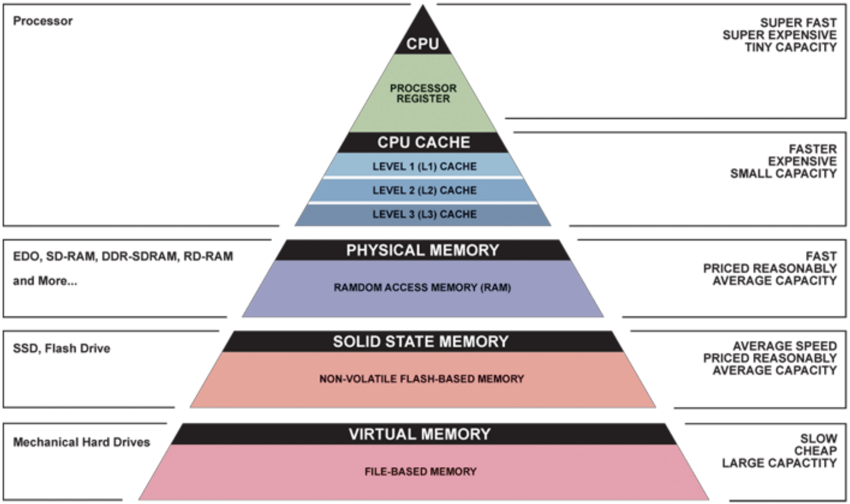


PGAS Languages

- UPC, Unified Parallel C
- CAF, Co-array Fortran
- Titanium, a Java dialect

Context

- The gap between processors and memory systems is still enormous



http://images.bit-tech.net/content_images/2007/11/the_secrets_of_pc_memory_part_1/hei.png

- Today: processors don't get faster, but we see more and more processors on a single chip

Processor	GHz	Cores (Threads)	Sockets
Intel Clovertown	2.66	8 (8)	2
AMD Barcelona	2.3	32 (32)	8
Sun Niagara 2	1.4	32 (256)	4

Table: Experimental Platforms

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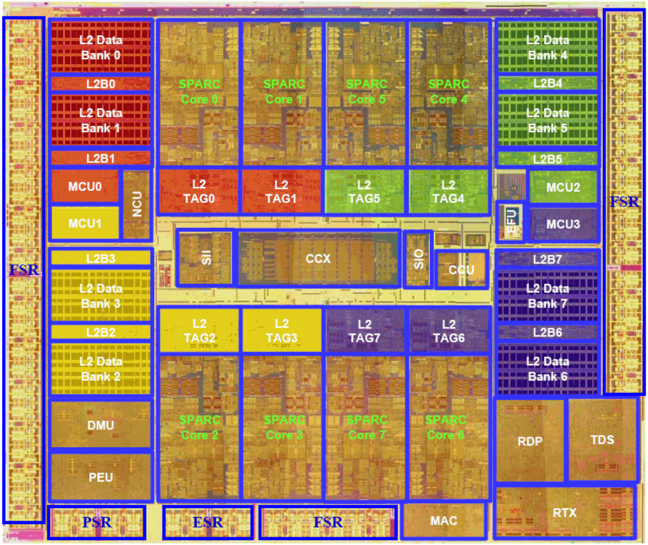
Sun Niagara 2



http://www.rz.rwth-aachen.de/aw/cms/rz/Themen/hochleistungsrechnen/ rechnersysteme/beschreibung_der_hpc_systeme/ultrasparc_t2/ rba/ultrasparc_t2_architectural_details/?lang=de

- The number of processors on a chip grows at an exponential pace

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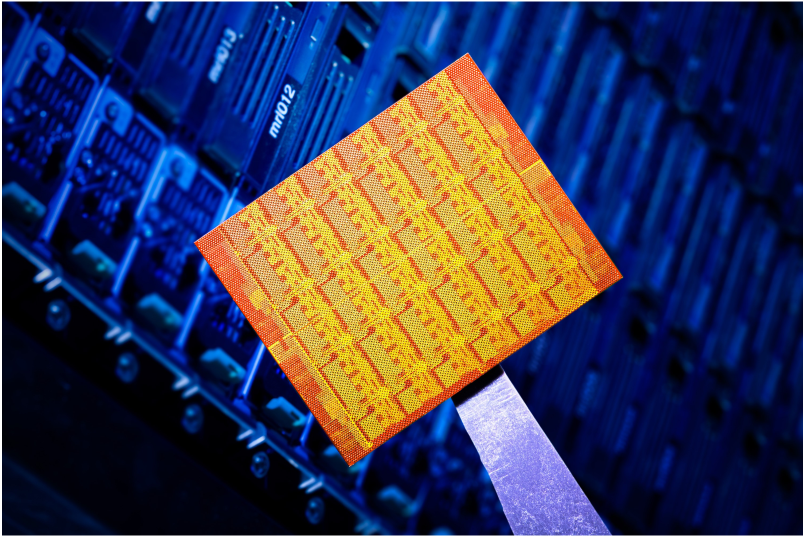
Intel Single-Chip Cloud Computer (48 Cores)



http://techresearch.intel.com/ProjectDetails.aspx?Id=1

- Communication in its most general form is the movement of data within cores, between cores or within memory systems

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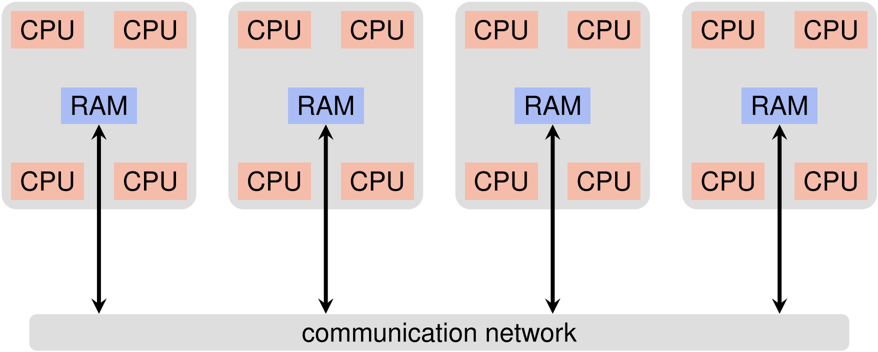
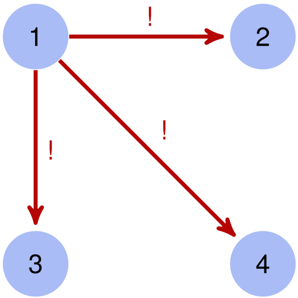

CPU
CPU
RAM
CPU
CPU
CPU
CPU
RAM
CPU
CPU
CPU
CPU
RAM
CPU
CPU
CPU
CPU
RAM
CPU
CPU
communication network

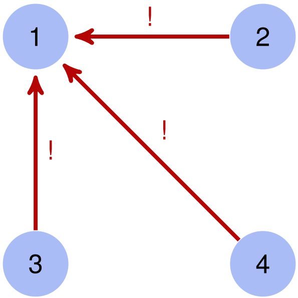
Collective Communication

- Communication-intensive problems often involve global communication

Broadcast



Gather



- These operations are thought of as collective communication operations

Example: Sum of Vector Elements

1	2	3	4	5	6	7	8	9	10

Example: Sum of Vector Elements

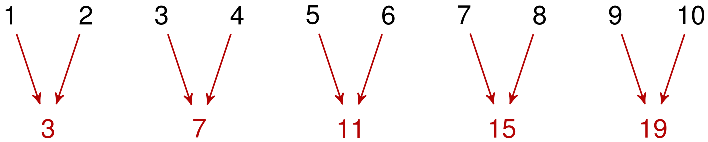
- Create workers

1 2 3 4 5 6 7 8 9 10

W_1 W_2 W_3 W_4 W_5

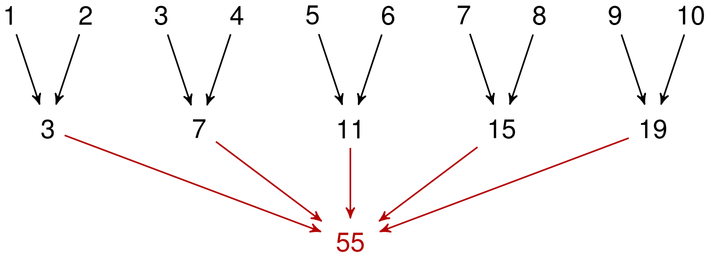
Example: Sum of Vector Elements

- Every worker sums up it’s part of the vector



Example: Sum of Vector Elements

- The main thread gathers the partial results and sums them up



Example: Sum of Vector Elements

Pseudocode (main thread):

```
double [] vector = read_vector();
Thread [] workers = spwan_workers();

start_workers(workers);
double result = calculate_result(workers);
```

Example: Sum of Vector Elements

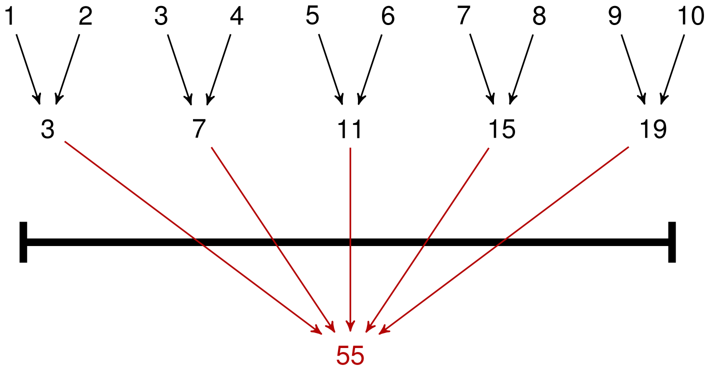
Pseudocode (main thread):

```
double [] vector = read_vector();
Thread [] workers = spwan_workers();

start_workers(workers);
wait_until_everything_finished(workers);
double result = calculate_result(workers);
```

Barrier

- Synchronization method for a group of threads
- A thread can only continue it's execution after every thread has called the barrier


1
2
3
4
5
6
7
8
9
10
3
7
11
15
19
55

Collective Communication Operation

"... group of threads works together to perform a global communication operation ..."

Reduce

- Divide a problem into smaller subproblems
- Every thread contributes it’s part to the solution
- Example: Calculate the smallest entry of a vector

Flat vs. Tree

- For communication among threads, different topologies can be used

Flat Topology

- Example: we have a reduce operation
- in the end the main thread W_{main} has to wait for every worker thread $W_1, \ldots, W_7$

W_{main} W_1 W_2 W_3 W_4 W_5 W_6 W_7

$$\begin{tikzcd}
W_{main} \arrow[d] & W_1 \arrow[dl] & W_2 & W_3 & W_4 & W_5 & W_6 & W_7 \\
W_{main} & & & & & & &
\end{tikzcd}$$

$$
\begin{tikzcd}
W_{main} \arrow[d] & W_1 \arrow[dl] & W_2 \arrow[ddll] & W_3 & W_4 & W_5 & W_6 & W_7 \\
W_{main} \arrow[d] & & & & & & & \\
W_{main} & & & & & & &
\end{tikzcd}
$$

$$
\begin{tikzcd}
W_{main} \arrow[d] & W_1 \arrow[dl] & W_2 \arrow[ddll] & W_3 \arrow[dddlll] & W_4 & W_5 & W_6 & W_7 \\
W_{main} \arrow[d] & & & & & & & \\
W_{main} \arrow[d] & & & & & & & \\
W_{main} & & & & & & &
\end{tikzcd}
$$

$$
\begin{tikzcd}
W_{main} \arrow[d] & W_1 \arrow[dl] & W_2 \arrow[ddll] & W_3 \arrow[dddlll] & \color{red}{W_4} \arrow[ddddllll, red] & W_5 & W_6 & W_7 \\
W_{main} \arrow[d] & & & & & & & \\
W_{main} \arrow[d] & & & & & & & \\
\color{red}{W_{main}} \arrow[d, red] & & & & & & & \\
W_{main} & & & & & & &
\end{tikzcd}
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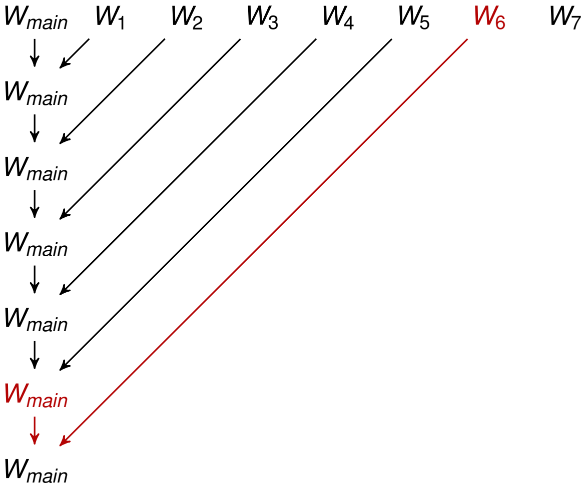
\begin{tikzcd}
W_{main} \arrow[d] & W_1 \arrow[dl] & W_2 \arrow[ddll] & W_3 \arrow[dddlll] & W_4 \arrow[ddddllll] & W_5 \arrow[dddddlllll] & W_6 & W_7 \\
W_{main} \arrow[d] \\
W_{main} \arrow[d] \\
W_{main} \arrow[d] \\
W_{main} \arrow[d] \\
W_{main}
\end{tikzcd}
$$


W_{main} W_1 W_2 W_3 W_4 W_5 W_6 W_7
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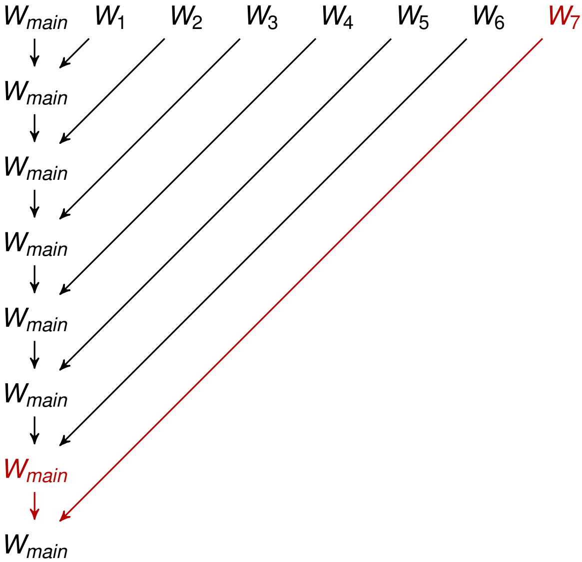
W_{main}


W_{main} W_1 W_2 W_3 W_4 W_5 W_6 W_7
W_{main}
W_{main}
W_{main}
W_{main}
W_{main}
W_{main}
W_{main}

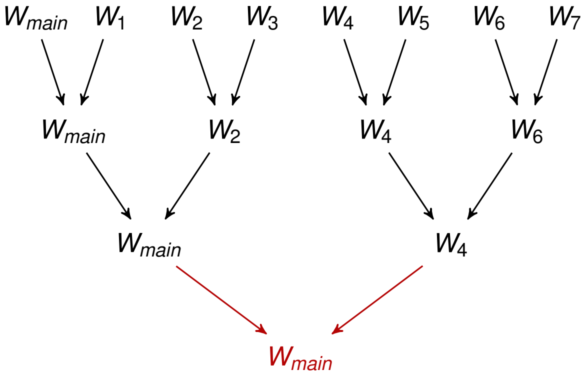
Tree Topology

- Example: we have a reduce operation
- in the end the main thread W_{main} has to wait for every worker thread $W_1, \ldots, W_7$

$$W_{main} \quad W_1 \quad W_2 \quad W_3 \quad W_4 \quad W_5 \quad W_6 \quad W_7$$

$$\begin{tikzcd}[column sep=small]
W_{main} \arrow[dr] & & W_1 \arrow[dl] & W_2 \arrow[dr] & & W_3 \arrow[dl] & W_4 \arrow[dr] & & W_5 \arrow[dl] & W_6 \arrow[dr] & & W_7 \arrow[dl] \\
& W_{main} & & & W_2 & & & W_4 & & & W_6 &
\end{tikzcd}$$

$$
\begin{tikzcd}
W_{main} \arrow[d] & W_1 \arrow[dl] & W_2 \arrow[d] & W_3 \arrow[dl] & W_4 \arrow[d] & W_5 \arrow[dl] & W_6 \arrow[d] & W_7 \arrow[dl] \\
W_{main} \arrow[d] & & W_2 \arrow[dll] & & W_4 \arrow[d] & & W_6 \arrow[dll] & \\
W_{main} & & & & W_4 & & &
\end{tikzcd}
$$


W_{main} W_1 W_2 W_3 W_4 W_5 W_6 W_7
W_{main} W_2 W_4 W_6
W_{main} W_4
W_{main}

Analysis

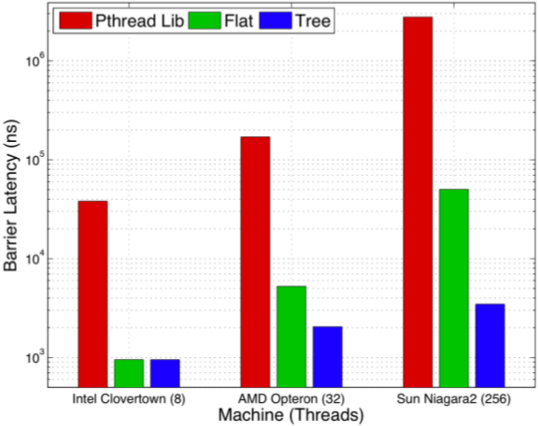


Figure: Barrier Performance

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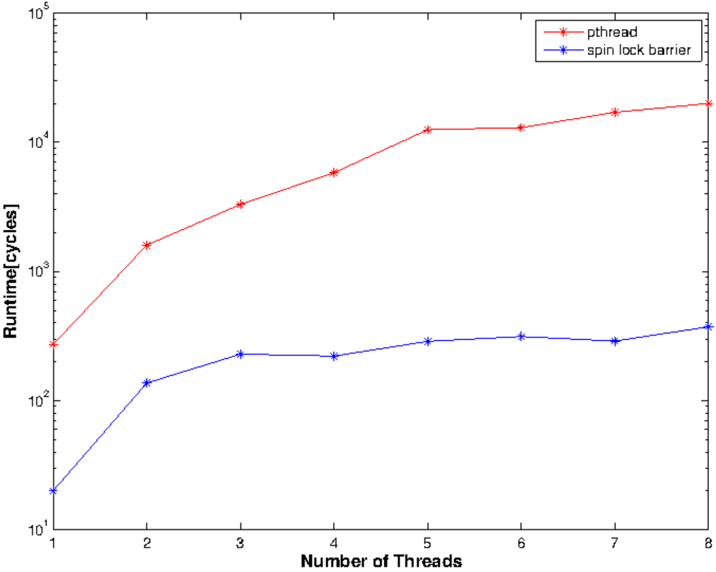
Barrier Implementation

```c
#define N 4

pthread_t threads[N];
volatile int ready[N];
volatile int go[N];

void barrier(int id) {

    if (id == 0) {
        //wait for each thread
        for (int i = 1; i < N; i++)
            while (ready[i] == 0);

        //reset the ready flags
        for (int i = 0; i < N; i++)
            ready[i] = 0;

        //signal each thread
        for (int i = 0; i < N; i++)
            go[i] = 1;
    }
    else {
        ready[id] = 1;
        //wait until thread is signalled
        while (go[id] == 0);
        go[id] = 0;
    }
}
```

Experiment: Barrier Implementation



- Strict synchronization: Data movement can only start after all threads have entered the collective and must be completed before the first thread exits the collective

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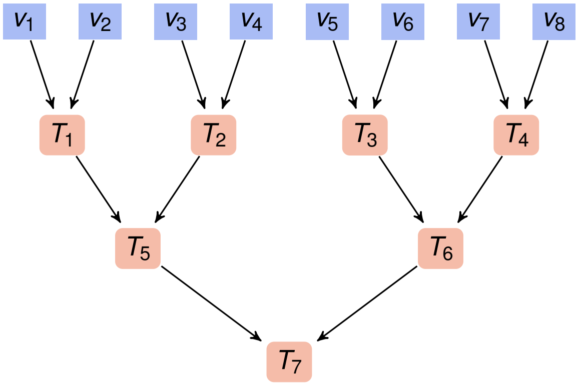
Strict Synchronization



Loosening Synchronization Requirements

- Loose synchronization: Data movement can begin as soon as any thread has entered the collective and continue until the last thread leaves the collective

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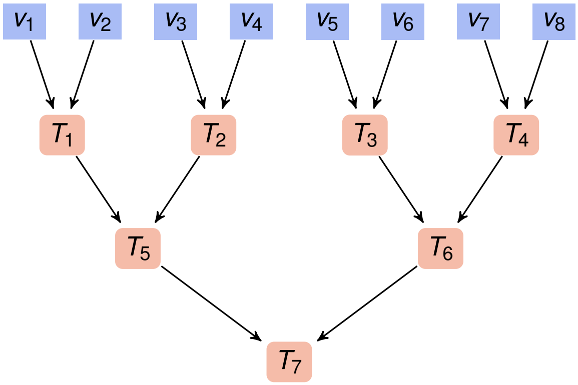
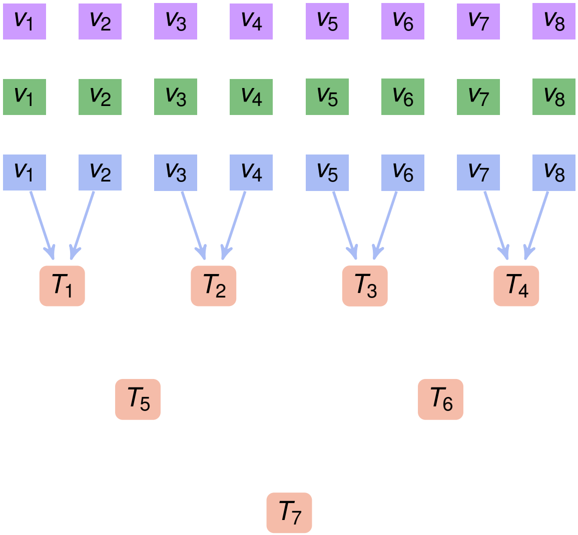
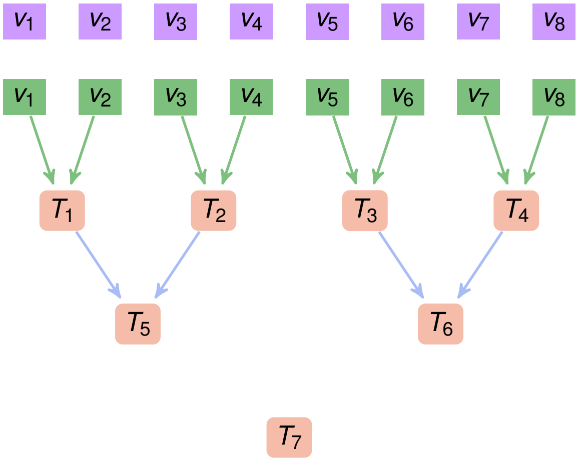
Loose Synchronization




v_1 v_2 v_3 v_4 v_5 v_6 v_7 v_8
v_1 v_2 v_3 v_4 v_5 v_6 v_7 v_8
v_1 v_2 v_3 v_4 v_5 v_6 v_7 v_8
T_1 T_2 T_3 T_4
T_5 T_6
T_7


v_1
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v_8
v_1
v_2
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T_1
T_2
T_3
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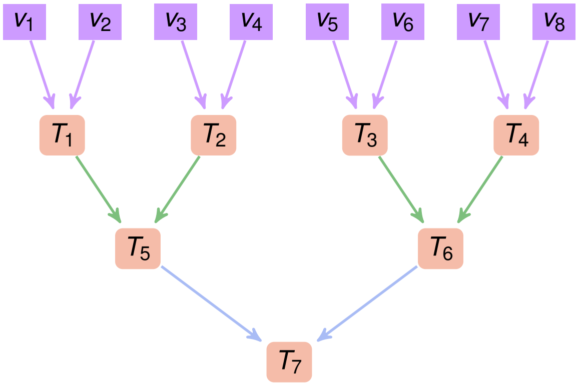
T_6
T_7



v_1
v_2
v_3
v_4
v_5
v_6
v_7
v_8
T_1
T_2
T_3
T_4
T_5
T_6
T_7

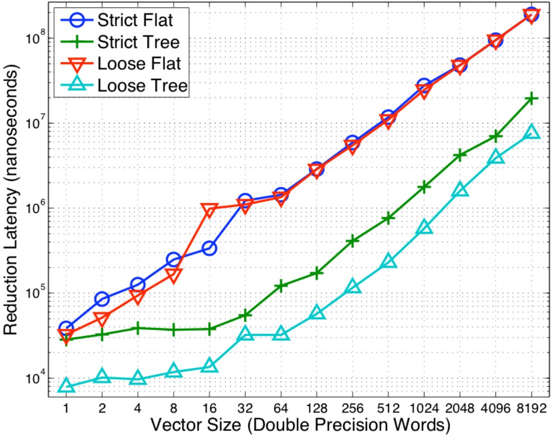


Figure 5: Optimal Algorithm Selection on Niagara2

(32 cores, 256 threads)

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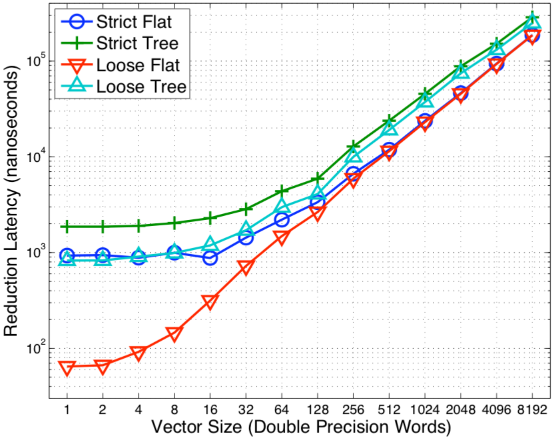

Figure 6: Optimal Algorithm Selection on Clovertown

(8 cores, 8 threads)

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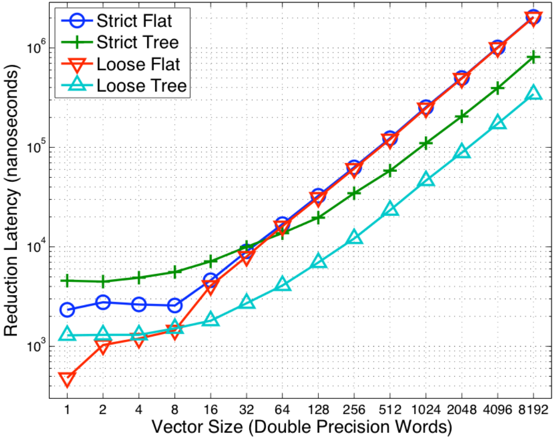

Figure 4: Optimal Algorithm Selection on Barcelona

(32 cores, 32 threads)

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Summary

- Best strategy depends on the hardware and on the problem
- Using a library that can automatically adapt to a given situation can bring a great performance improvement, since hand tuning takes far too long

Words on the Paper

- Very high level
- Description of the problem without concrete solution
- No implementation
- Plots aren't always clear and precise