Coding for Multiple Threads on a CMT System

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Outline

- Multiple processes
- Simple problem
- fork - multi-process
- pthreads - multi-thread
- OpenMP - multi-thread
- Autopar - multi-thread
- Compiler options
- Supporting tools

Options for parallelism

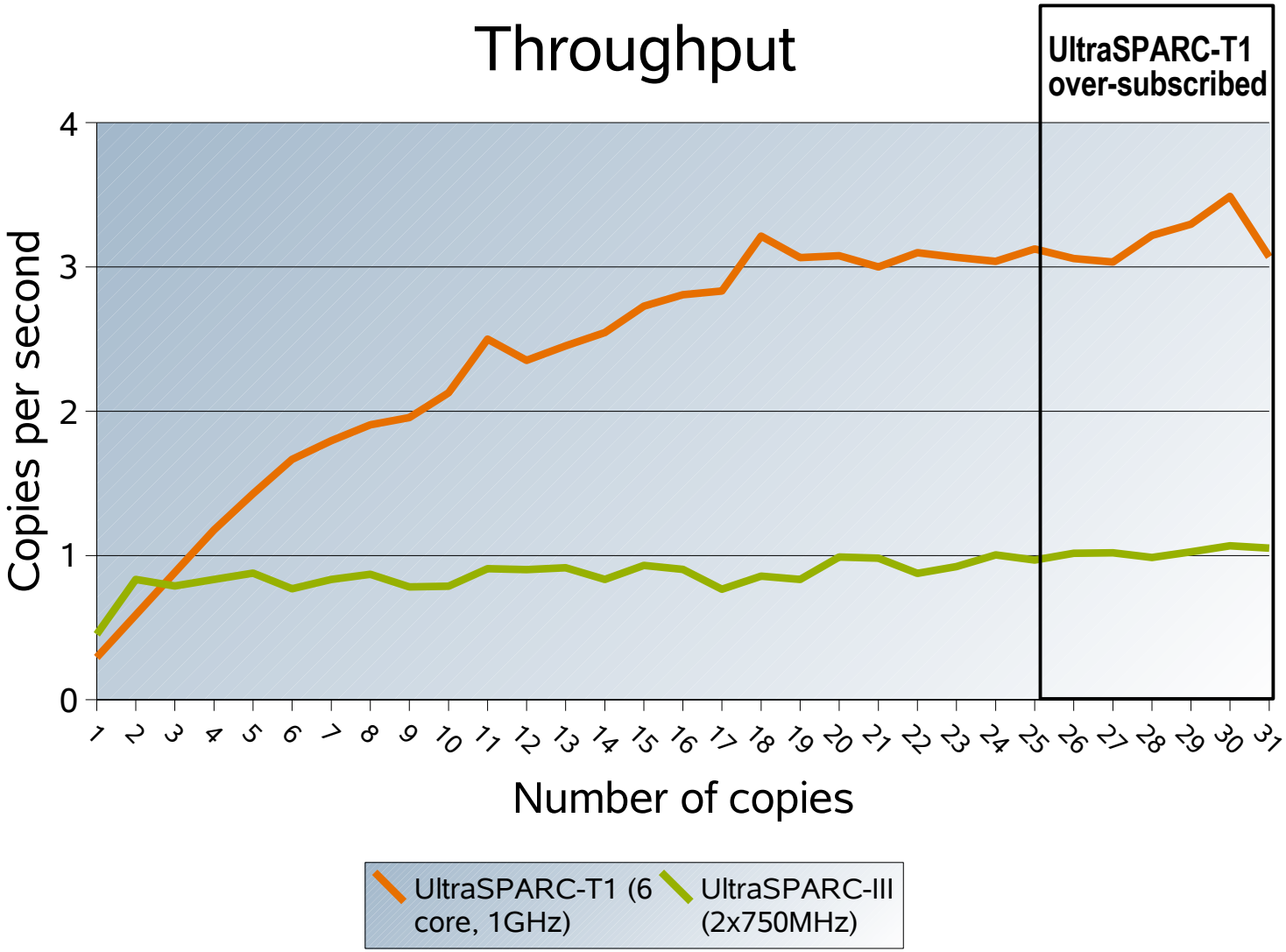
	Style	Task description	Example
Less Collaboration	Multiple Processes	Independent Heterogeneous	Consolidation
	Multi-process	Independent Homogeneous	Web server
	Pthreads	Shared tasks	Web browser
	OpenMP	Shared tasks Splitting	Array Manipulation
More Communication	Autopar	Shared tasks Splitting	Array Manipulation

Multiple processes

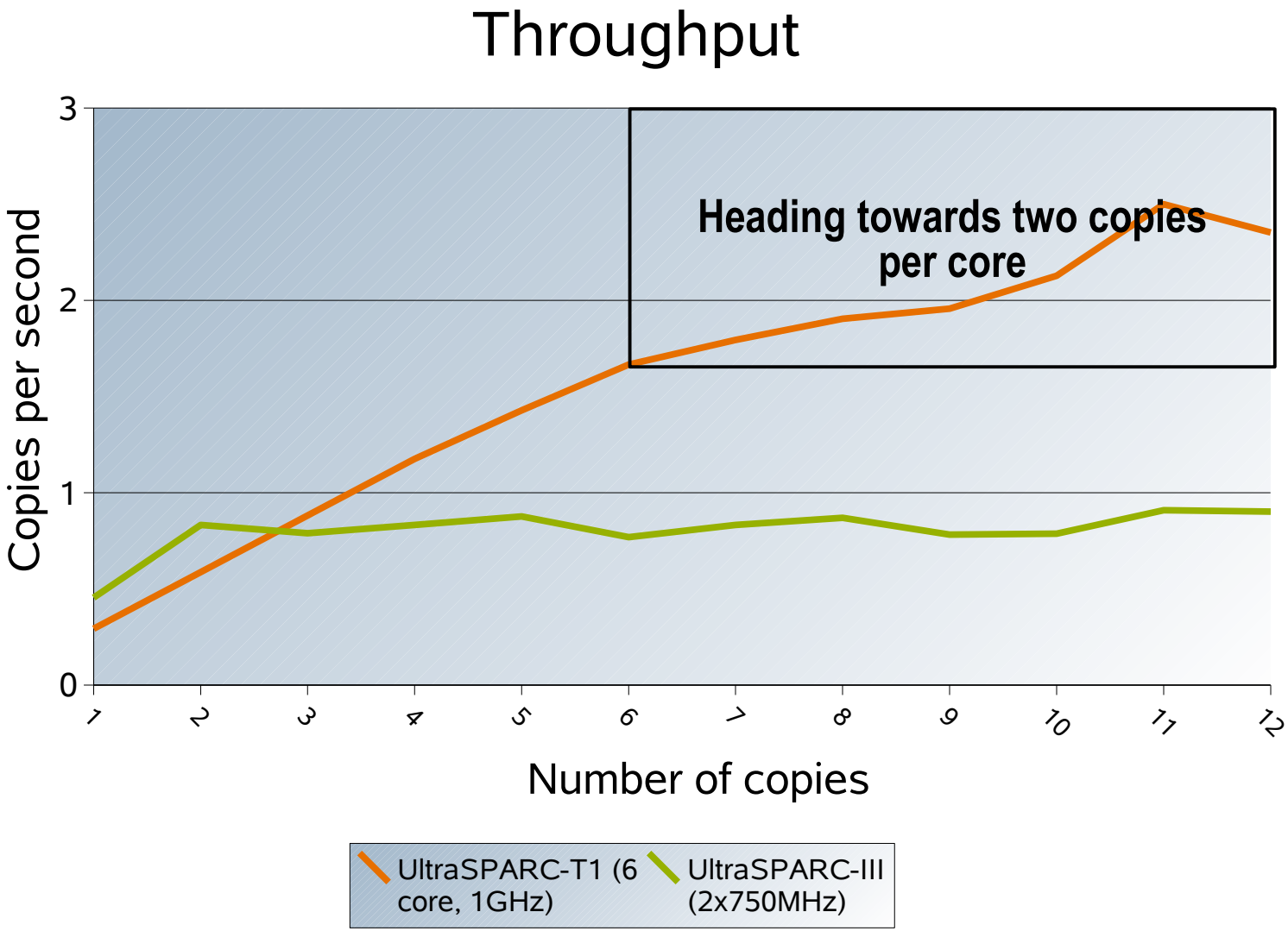
- Comparing
  - 6 core, 1 Ghz UltraSPARC-T1
  - 2x 750 Mhz UltraSPARC-III
- N copies of:

```
$ time gzip -c --best myfile | gunzip -c - >/dev/null
```

Multiple processes scaling



Scaling - zoom



Observations

- Scaling beyond number of cores.
- How CMT is implemented is not important
- Even over-subscribed performance doesn't drop

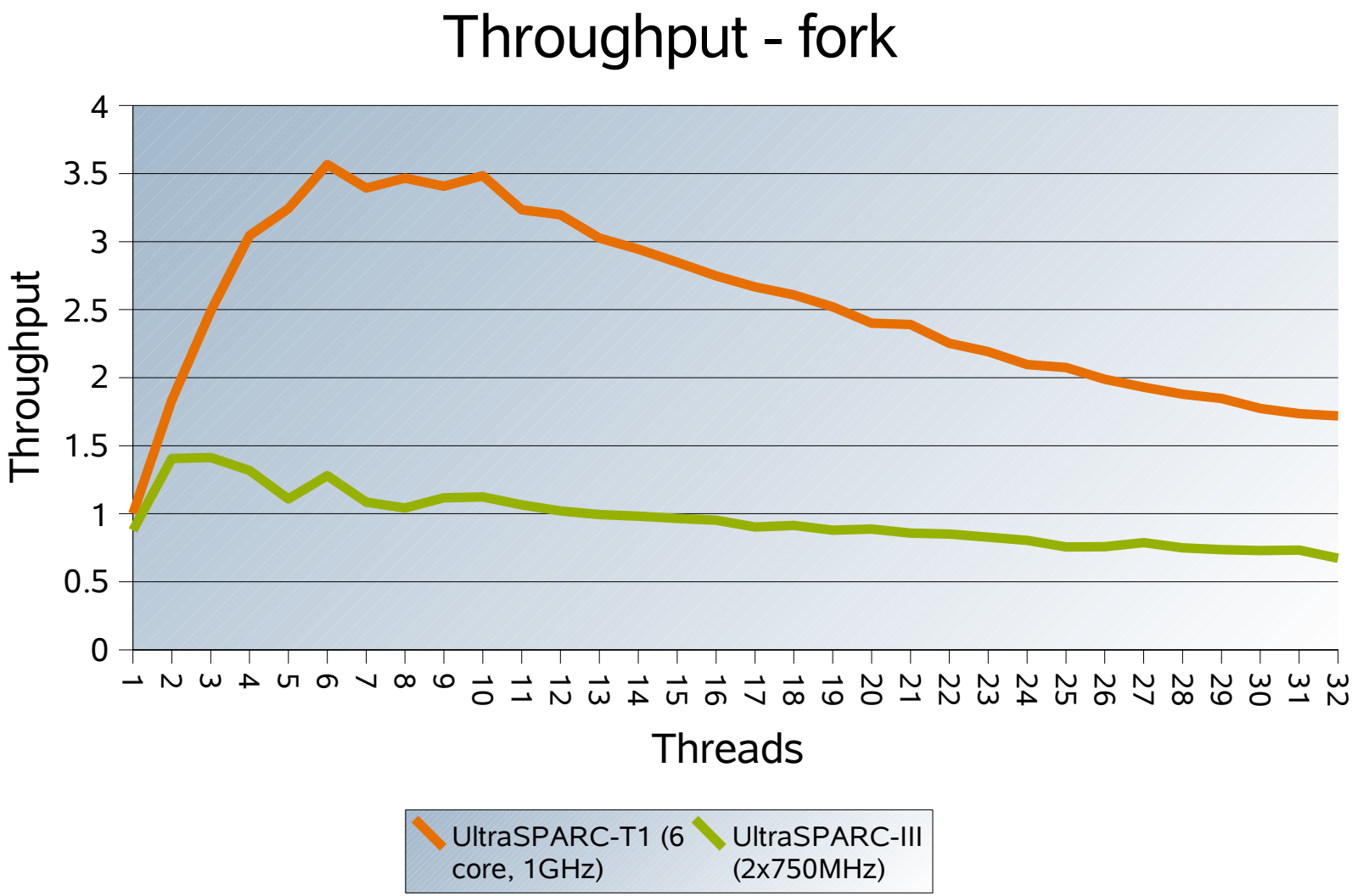
A simple problem

```
void main(int argc,const char** argv)
{
  int i;
  hrtime_t start_time;

  array=(int*)malloc(sizeof(int)*SIZE);
  int sum=0;

  for (i=0; i<SIZE;i++) { array[i]=1; }

  start_time=gethrtime();
  for (i=0; i<SIZE; i++)
  {
    sum+=array[i];
  }
  printf("Elapsed time (seconds)=%5.3f ",
        (gethrtime()-start_time)/1000000000.0);
  printf("Total is %i\n",sum);
}
```

Using fork()

```
rtn=1;
start_time=gethrtime();
for (id=0;id<threads;id++)
{
  if (rtn !=0) {rtn=fork();} /*Fork main thread*/
  else {break;}              /*Don't fork child*/
}

if (rtn==0)
{
 sum=0;/* Child thread*/
 for (i=(id-1)*array_length; i<id*array_length; i++)
 {
   sum+=array[i];
 }
 exit(0);
}
for (id=0; id<threads; id++) { wait(0); }
printf("Elapsed time (seconds)=%5.3f \n",
       (gethrtime()-start_time)/1000000000.0);
```

Scaling using fork()



Problems using fork() in this case

- (By default) No data shared between children
- Large footprint
- Lots of overhead
- Hard to pass results back. Solutions:
  - Message passing
  - Doors
  - Pipes
  - Shared memory

Using pthreads - create and join

```
start_time=gethrtime();
for (id=0;id<threads;id++)
{
  pthread_create(&thread_array[id]NULL,&thread_code,(void
  *)id);
}

/*Join the threads*/
for (id=0;id<threads;id++)
 { pthread_join(thread_array[id],NULL); }

for (id=0;id<threads;id++)
 {  global_sum+=results[id];  }

printf("Elapsed time (seconds)=%5.3f ",
       (gethrtime()-start_time)/1000000000.0);
```

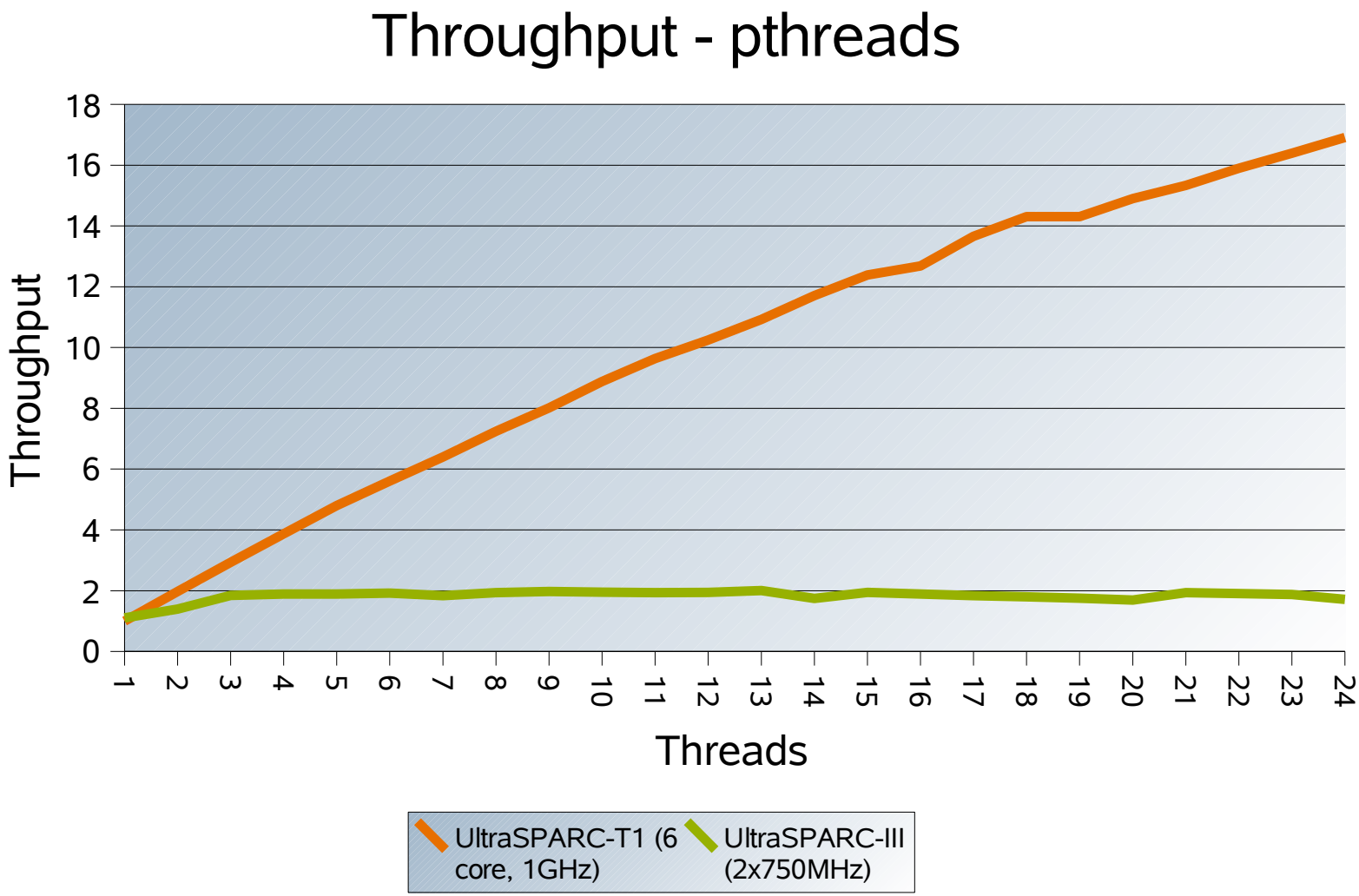
Using pthreads - doing work

```
void* thread_code(void* v)
{
  int i;
  int sum = 0;
  int id = (int)v;
  for (i=(id)*array_length; i<(id+1)*array_length; i++)
  {
    sum+=array[i];
  }

  results[id]=sum;
  return 0;
}
```

Compiling

```
cc -O -mt example.c -lpthread
```

pthread scaling



Comments on pthreads

- Good scaling
- Control over activities of threads
- Significant coding overhead

False sharing

```
void* thread_code(void* v)
{
  int i;
  int sum = 0;
  int id = (int)v;
  for (i=(id)*array_length; i<(id+1)*array_length; i++)
  {
    sum+=array[i];
  }

  results[id]=sum;
  return 0;
}
```

False sharing is when two or more threads try to update different parts of the same cacheline.

Not called often - so not an issue.

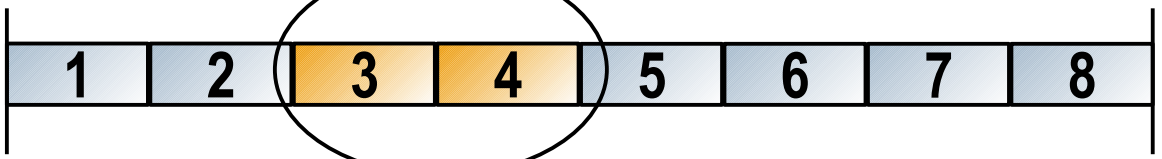
False sharing - example

```
volatile int * results;
                              ...

void* thread_code(void* v)
{
  int i;
  int results[id] = 0;
  int id = (int)v;
  for (i=(id)*array_length; i<(id+1)*array_length; i++)
  {
    results[id]+=array[i];
  }

  /*results[id]=sum;   */
  return 0;
}
```

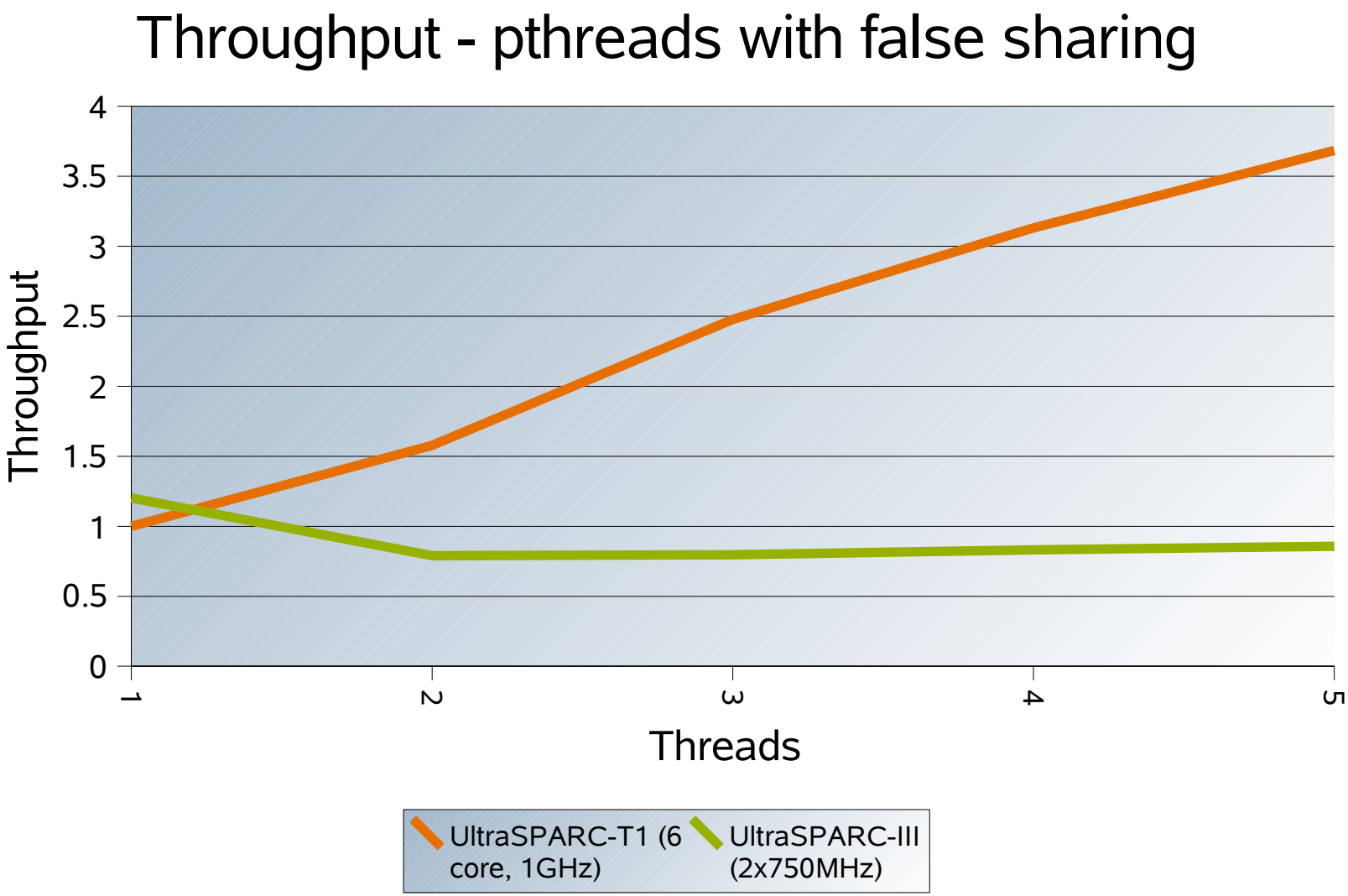
Threads update different variables on the same cacheline

Called frequently - so is an issue!

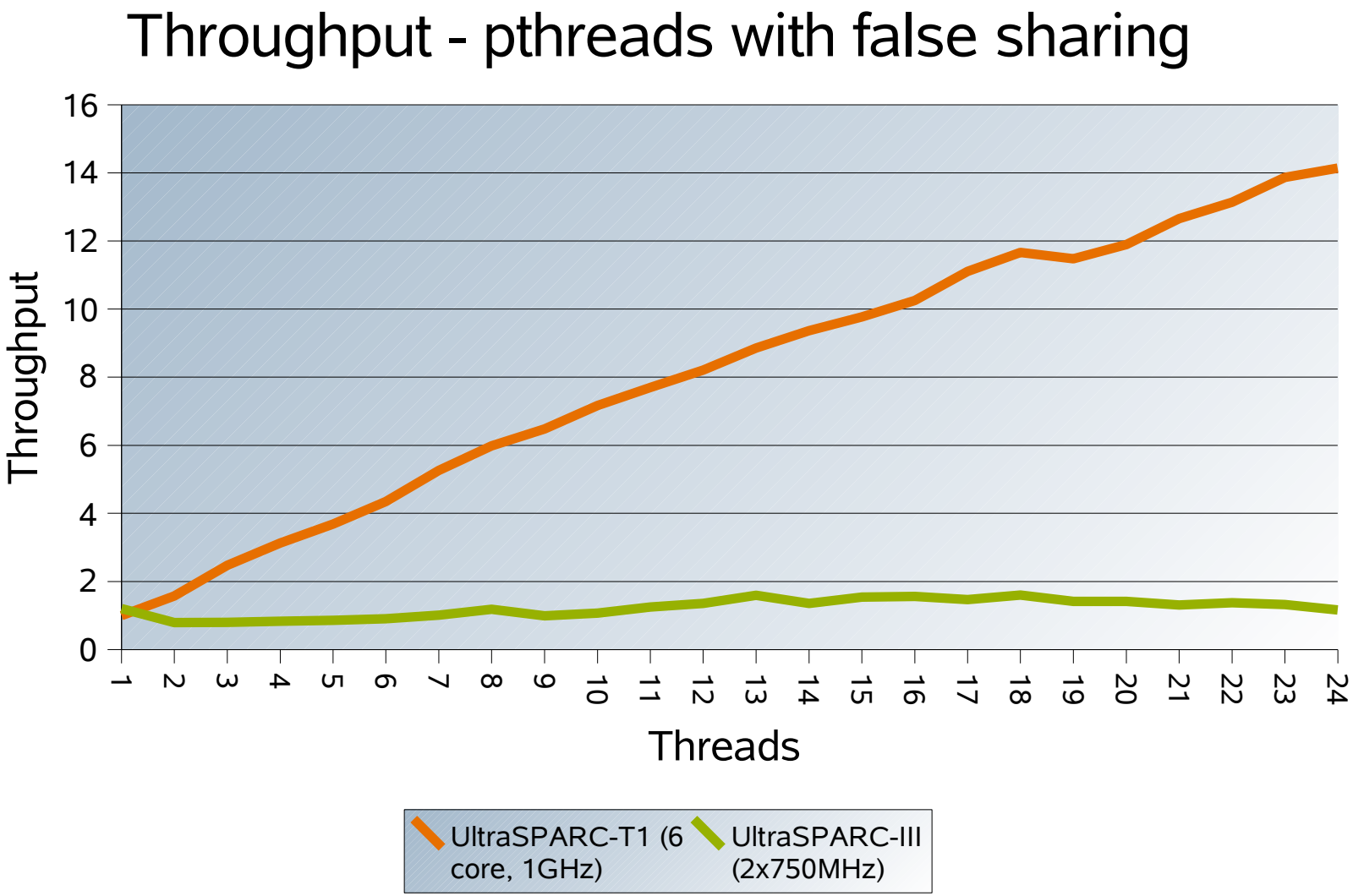
Two threads trying to update the same cacheline



False sharing performance



False sharing performance



Comments on false sharing

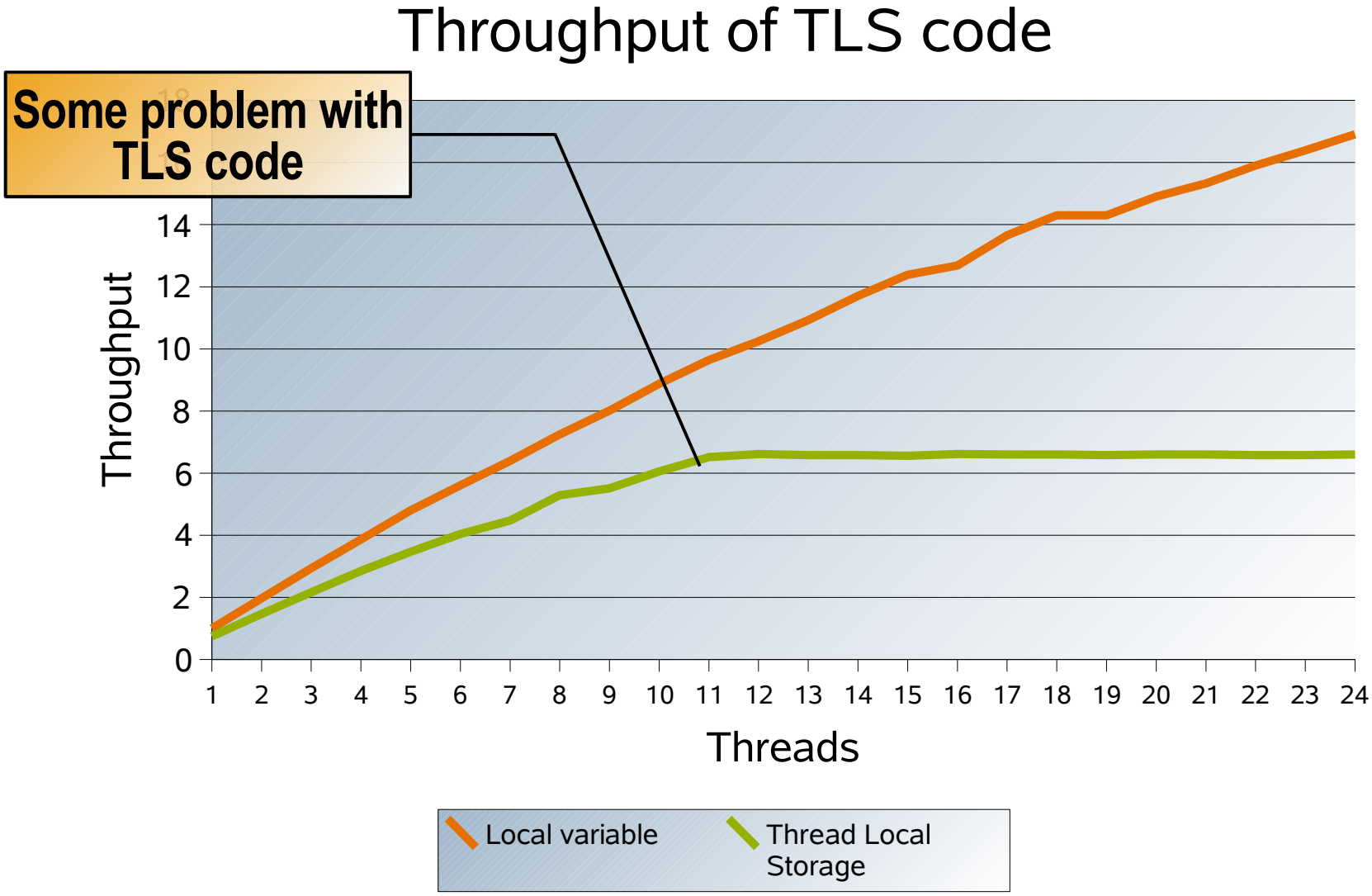
- Multiple processors write to different parts of the same cacheline
- Causes significant performance impact on MP systems
- Avoid by padding structures to cacheline (64-byte) boundaries
- Not a problem for single chip CMT

Thread Local Storage -TLS

```
int results=0;
pthread_mutex_t results_mutex;
__thread int sum = 0;
__thread int id;
...

void* thread_code(void* v)
{
  int i;
  int id = (int)v;
  for (i=(id)*array_length; i<(id+1)*array_length; i++)
  {
    sum+=array[i];
  }
  pthread_mutex_lock(&results_mutex);
  results += sum;
  pthread_mutex_unlock(&results_mutex);

  return 0;
}
void main()
{... pthread_mutex_init(&results_mutex,NULL); ...}
```

Reduction

TLS Throughput On UltraSPARC-T1



TLS - aliasing issue

```
__thread int sum;
         int* array;
....

for (i=(id)*array_length; i<(id+1)*array_length; i++)
{
    sum+=array[i];
}

...
10f88:  ac 05 a0 01  inc      %l6
10f8c:  ba 07 40 05  add      %i5, %g5, %i5
10f90:  fa 27 20 00  st       %i5, [%i4] //Store sum
10f94:  aa 05 60 04  inc      4, %l5
10f98:  80 a5 80 17  cmp      %l6, %l7
10f9c:  24 4f ff fb  ble,a,pt %icc, 0x10f88
10fa0:  ca 05 60 00  ld       [%l5], %g5 //Load array
...
```

Sum "could be" an element in the array

Restrict pointers

- Need to tell compiler that array does not point to sum
- The keyword `restrict` can be applied to pointer to mean that they point to their own memory

```
int * restrict array;
```

- Performance restored!

Thread Local Storage

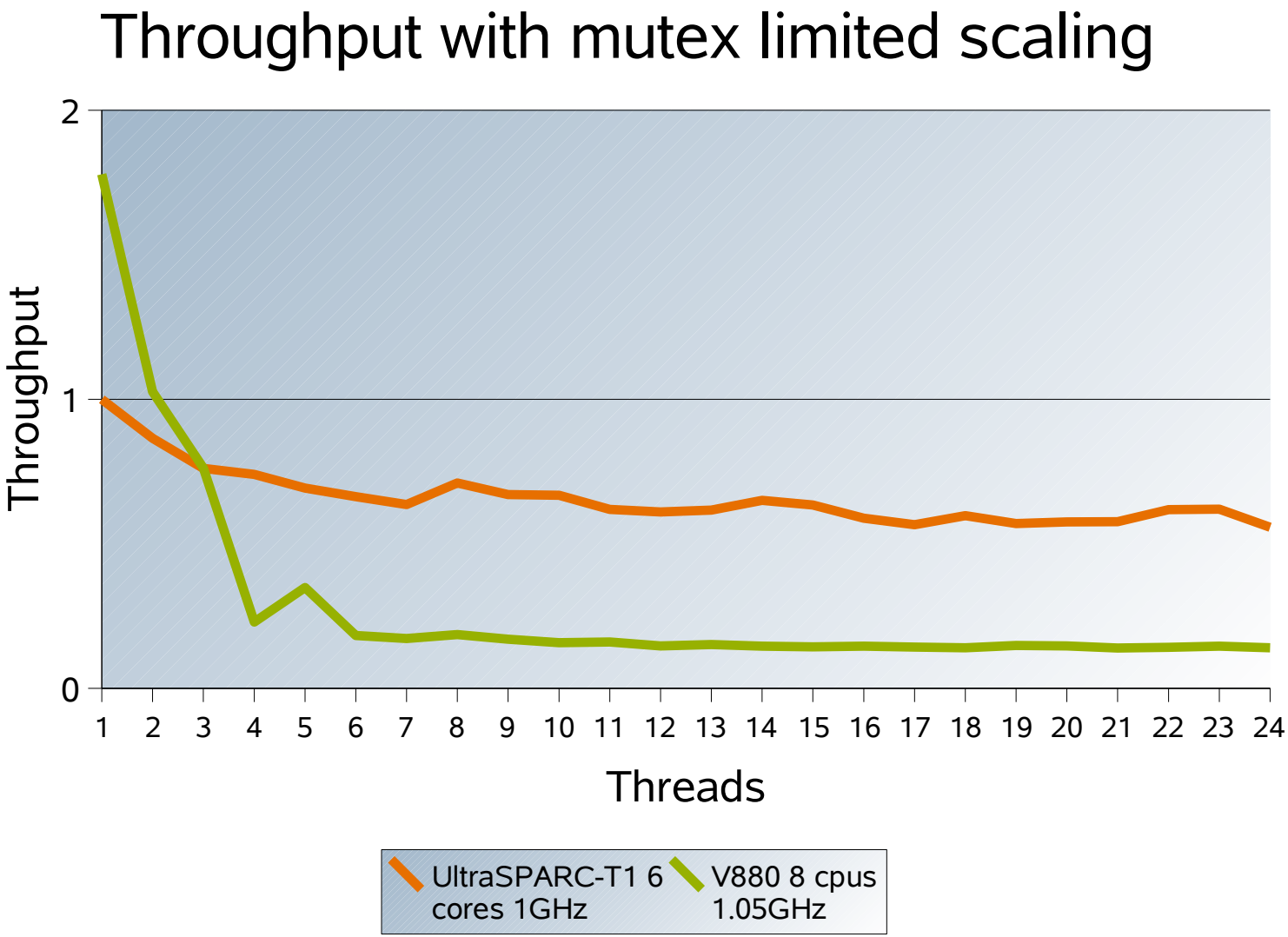
- TLS mechanism to have “thread-global” variables
- Easier than setting up structures
- Non-local variables can potentially alias:
  - `restrict` keyword
  - `-xrestrict` compiler flag
  - `-xalias_level=<>` compiler flag

Mutex - making a scaling problem

```
void* thread_code(void* v)
{
   int i;
   int id = (int)v;
   for (i=(id)*array_length; i<(id+1)*array_length; i++)
   {
   pthread_mutex_lock(&results_mutex);
   results+=array[i];
   pthread_mutex_unlock(&results_mutex);
   }

   return 0;
}
```

All loop iterations are mutexed

Mutex constrained scaling



Mutex observations

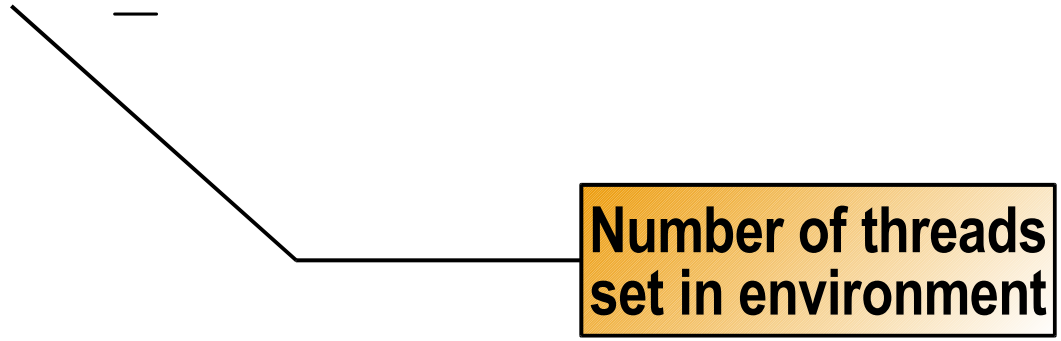
- Using mutexes limits scaling
- Less impact on CMT processor

OpenMP

```
void main(int argc,const char** argv)
{
  int i;
  hrtime_t start_time;

  array=(int*)malloc(sizeof(int)*SIZE);
  int sum=0;

  for (i=0; i<SIZE;i++) { array[i]=1; }
  start_time=gethrtime();

  #pragma omp parallel for reduction(+:sum)
  for (i=0; i<SIZE; i++)
  {
    sum+=array[i];
  }
  printf("Elapsed time (seconds)=%5.3f ",
         (gethrtime()-start_time)/1000000000.0);
  printf("Total is %i\n",sum);
}
```

OpenMP compiling and running

- Compile with:
  - `> cc -O -xopenmp example.c`
- Run with:
  - `> export OMP_NUM_THREADS=2`
  - `> a.out`



OpenMP comments

- Same scaling as pthread version.
- OpenMP implemented on pthreads.
- Much easier to add: single line added to source file.
- Incremental parallelisation possible.

OpenMP: sleep or spin?

- Idle thread behaviour controlled by:
  `SUNW_MP_THR_IDLE=SLEEP`
  `SUNW_MP_THR_IDLE=SPIN`
- `SLEEP` idle threads consume no resources, so better for other processes on machine. (Current default is to sleep after short delay.)
- `SPIN` idle threads instantly ready to do work, but consume processor resources. Causes lower performance on over-subscribed systems.

OpenMP: binding to core

- Avoids process migration
- Can cause oversubscription
- Environment setting:
  - `SUNW_MT_PROCBIND="true"`
  - `SUNW_MT_PROCBIND="0 2 4 6"`

Autopar: Original code

```
void main(int argc,const char** argv)
{
  int i;
  hrtime_t start_time;

  array=(int*)malloc(sizeof(int)*SIZE);
  int sum=0;

  for (i=0; i<SIZE;i++) { array[i]=1; }

  start_time=gethrtime();

  for (i=0; i<SIZE; i++)
  {
    sum+=array[i];
  }
  printf("Elapsed time (seconds)=%5.3f ",
         (gethrtime()-start_time)/1000000000.0);
  printf("Total is %i\n",sum);
}
```

Compiling with autopar

- Compiler flags:

```
cc -O -xautopar -xreduction -xloopinfo test.c

"test.c", line 24: not parallelized, unsafe
  dependence (array)
"test.c", line 30: PARALLELIZED, reduction
```

- `-xautopar` Enable autoparallelisation
- `-xreduction` Perform reduction optimisations
- `-xloopinfo` Report on parallelisation

Autopar: aliasing issue

- Problem:

```
int * array;
...
for (i=0; i<SIZE;i++) { array[i]=1; }

"example.c", line 24: not parallelized,
unsafe dependence (array)
```

- Solutions:

```
int * restrict array;
```

or

compiler flag: `-xalias_level=basic`

Compiling and optimising

- Optimisation still important
  Total throughput = Single thread throughput * Threads
- Reduce instruction count
- **NEW**: Useless speculation steals from other threads
- So....
  - No big change

Compiling recap

- Always use optimisation (at least `-O`)
- `-xtarget=generic[64]` for 1 binary to many processors
- Debug doesn't hurt (`-g`, but `-g0` for C++)
- Crossfile optimisation (`-xipo=2`) particularly C++
- Use large pages (eg `-xpagesize=64K`)
- Always profile the application

Profiling the mutex code

- Using Sun Studio Performance Analyzer

```
collect <application> <arguments>
analyzer test.1.er
```

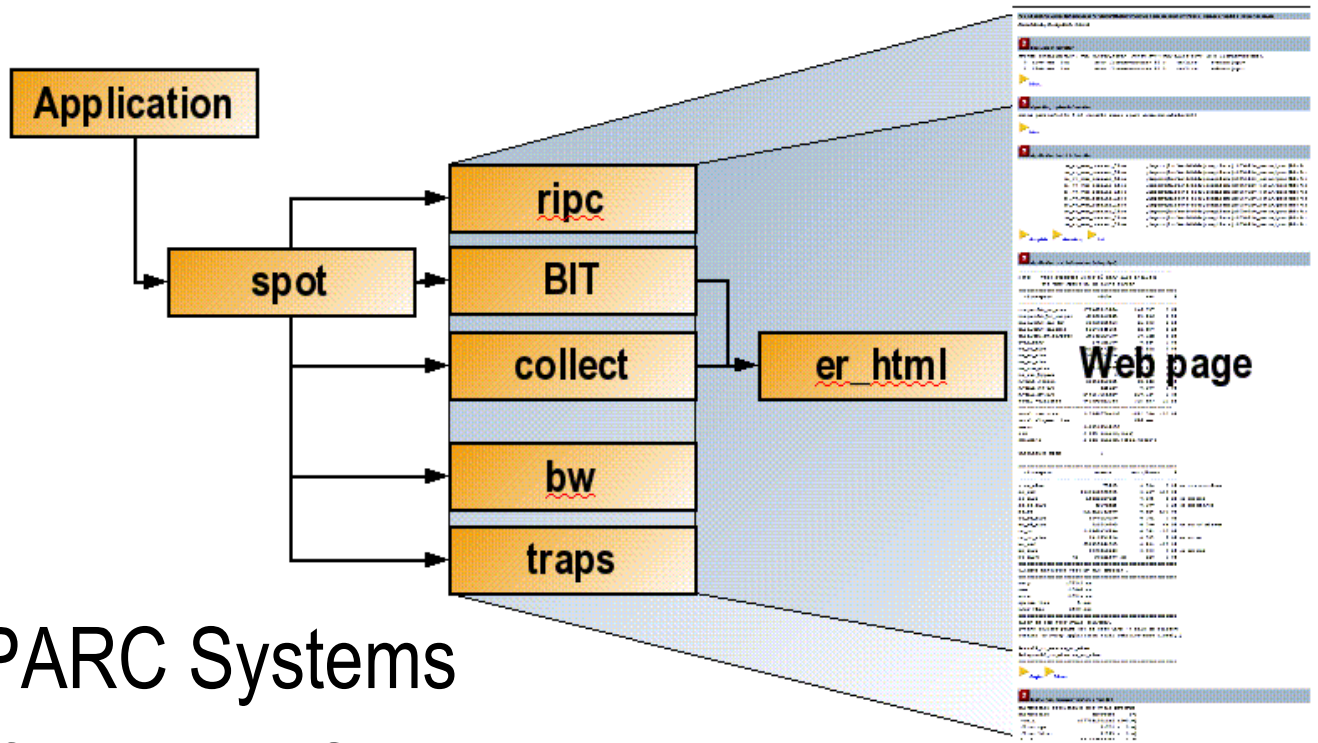
User CPU (sec.)	User CPU (sec.)	Source File: ./mutex.c Object File: ./mutex Load Object: <mutex>
		Loop could not be pipelined because it contains calls
1.401	1.401	30. for (i=(id)*array_length; i<(id+1)*array_length; i++)
		31. {
0.140	23.947	32. pthread_mutex_lock(&results_mutex);
0.020	0.020	33. results+=array[i];
0.120	8.676	34. pthread_mutex_unlock(&results_mutex);
		35. }
		36. return 0;
		37. }
		38.
		39.

Time in called routines

Time in this routine

Cool tools for SPARC systems

http://cooltools.sunsource.net/



- GCC for SPARC Systems
- Simple Performance Optimisation Tool
- Automatic Tuning and Troubleshooting Tool
- …

Concluding remarks

- Many ways to utilise a CMT processor
- Impact of traditional scaling limiters reduced on CMT - therefore easier to extract scaling opportunities
- Traditional compiler optimisation still works
- Issues are aliasing and locking

Coding for Multiple Threads on a CMT System.

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