Maximizing the Benefits of CMT with Sun's Compilers and Tools

Partha Tirumalai
Distinguished Engineer
Scalable Systems Group, Sun Microsystems

Multicore Expo
Santa Clara, CA, USA
March 21-23, 2006

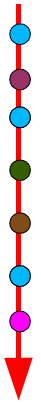
Introduction to CMT

What is CMT?

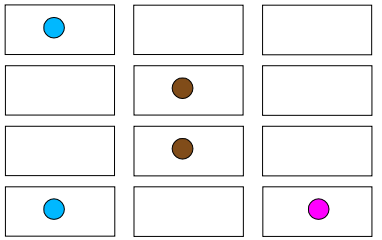
- Chip-MultiThreading (CMT) refers to a processor design that allows a single silicon chip to simultaneously execute more than one software thread (instruction stream).
- CMT includes:
  - Multi-core designs
  - Multi-threaded designs
    - Vertical, Horizontal, or other forms of threading in a core
  - Combinations of the above
    - I.e., multiple multi-threaded cores on one chip

Why CMT? - The "old" approach

- Microprocessors have focussed on improving single thread performance for the last 25 years
  - Pipelined functional units
  - Multiple-instruction issue
  - Out-of-order execution
  - Hardware prefetching
  - Large, complex cache hierarchies



Single, serial thread



3-issue, 4-stage pipe
Up to 12 ops in flight
Very low efficiency
Rarely operates at peak

- Technology trends have made this approach increasingly difficult
  - Complex designs, low efficiency (perf/$, perf/W, ...)

Modest CMT Designs

- Largely retain focus on extracting performance from a single thread of execution
  - Use Moore's law to put 2 cores on 1 die
  - Add incremental features like Simultaneous Multi-threading
- Benefits
  - Leverages investment in old cores already designed
  - Good single thread performance
  - Some (but limited) gain on multi-threaded workloads
    - Use large SMP's or clusters to handle more threads
  - Examples: US IV, Dual-core Opteron

Aggressive CMT Designs

- Reduce focus on single thread performance
  - Recognize memory accesses as the chief bottleneck and tolerate these by exploiting thread level parallelism (TLP)
- Design from scratch for multiple parallel threads
  - Zero or very low thread-switch overhead
  - High associativity, high bandwidth on-chip cache
  - Very high bandwidth to memory
- Benefits
  - Excellent throughput and efficiency (perf/$, perf/W)
- Examples: US T1

CMT Outlook

- Every major vendor in the industry is working on CMT designs
- CMT is expected to be ubiquitous in the near future
  - Multiple threads even in laptops
    - In Apple's MacBook Pro Now!
  - Threads – cheap, everywhere, for everyone

CMT - Synergies Beyond the Chip

- Hardware
  - Adequate cache/memory, I/O, and networking bandwidth, plus RAS for large, parallel workloads
- Operating System
  - Reliable and scalable OS for optimal management of parallel threads
- Developer Tools
  - Compilers and tools to make application development easy and efficient

Focus of this talk: Sun Studio 11 C/C++/Fortran Compilers & Tools

Sun Studio 11 Compilers and Tools

developers.sun.com/sunstudio

Free!

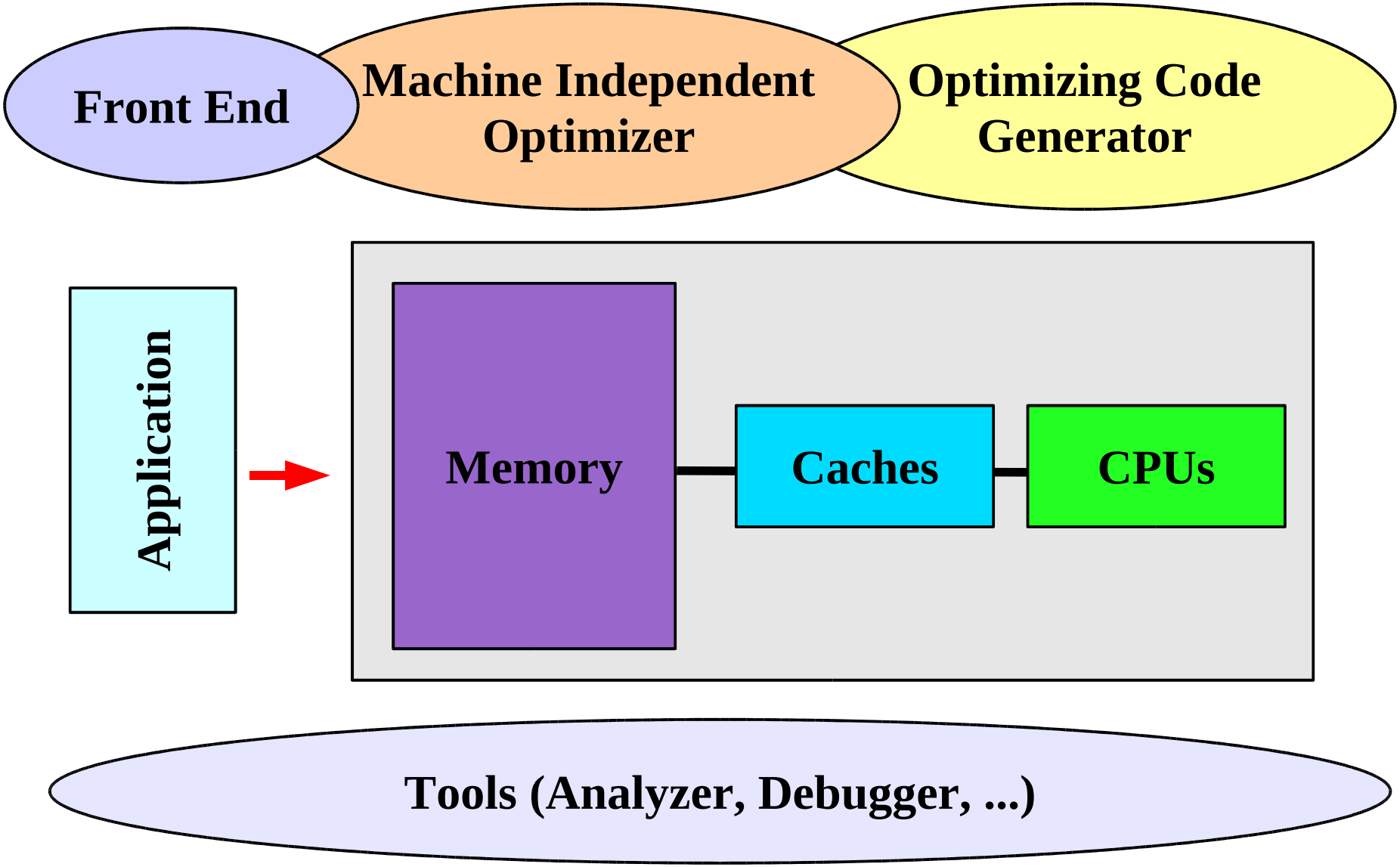
SPARC

Solaris

Sun Studio 11 – From 50K Feet

- Reliable
  - >100M lines of tests routinely run on compute farm
    - Huge, complex, mission-critical applications are built with our compilers
- Standards adherence
  - At the forefront of industry standards
    - C99, IEEE floating point, OpenMP ...
- Advanced optimizations, easy to use
  - Deliver high performance on a wide spectrum of codes
    - Tuned to the latest hardware

Compiler Components



Optimization & Commentary

What did it do to my code?

- The compiler commentary explains how the source code was optimized
  - Build with "-g" added (does not disable optimizations)
  - Get commentary with er_src command
  - See documentation for details
- Improves understanding and helps user optimize
  - User can derive hints on further options to use (or not use)
  - User can derive hints on adding pragmas that might help
  - User can derive hints on what reorganization might help

Example 1 – Loop Scheduling

```
for (j=1; j<n; j++)
  a[j] = a[j-1] + 4.0*b[j]*c[j] +
         b[j]*b[j] + c[j]*c[j] + 6.0;
```

- 1 load eliminated
- 1 fpmul eliminated
- unrolled 4 times
- optimally scheduled
  - resource limit = 4
  - dependence limit = 4
  - achieved schedule = 4
- 3 prefetches inserted

cc -fast -g -c loop.c
er_src -source foo 1 loop.o

```
L-unknown scheduled with steady-state cycle count = 4
L-unknown unrolled 4 times
L-unknown has 2 loads, 1 stores, 3 prefetches, \
  4 FPadds, 3 FPmuls, and 0 FPdivs per iteration
L-unknown has 0 int-loads, 0 int-stores, 5 alu-ops, \
  0 muls, 0 int-divs and 0 shifts per iteration
Source loop below has tag L1
     7.    for (j=1; j<n; j++)
     8.      a[j] = a[j-1] + 4.0*b[j]*c[j] +
                    b[j]*b[j] + c[j]*c[j] + 6.0;
```

Example 2 – IPO, Pointers, IF's

```
void propagate(int *p, int *q, int *r) {
  int x;
...

  x = *p;
...
  if (x < 50) {
    ...r1...
    split(p,q);
    ...r2...
    if (x < 100) {
      merge(q,r);
    }
  }
...
```

- Note x is a local variable
- If it can be proved that:
  - cond1 => cond2
  - x is not modifiable in split
  - x is not modified in r1
  - x is not modified in r2
- then:
  - the second if is eliminated

- Involves
  - Pointer analysis
  - Inter-procedural analysis
  - Conditional relationships

- **Complexity and "code rot" can cause such scenarios**
- **Second conditional optimized away by the compiler**

Example 3 – Profile Feedback

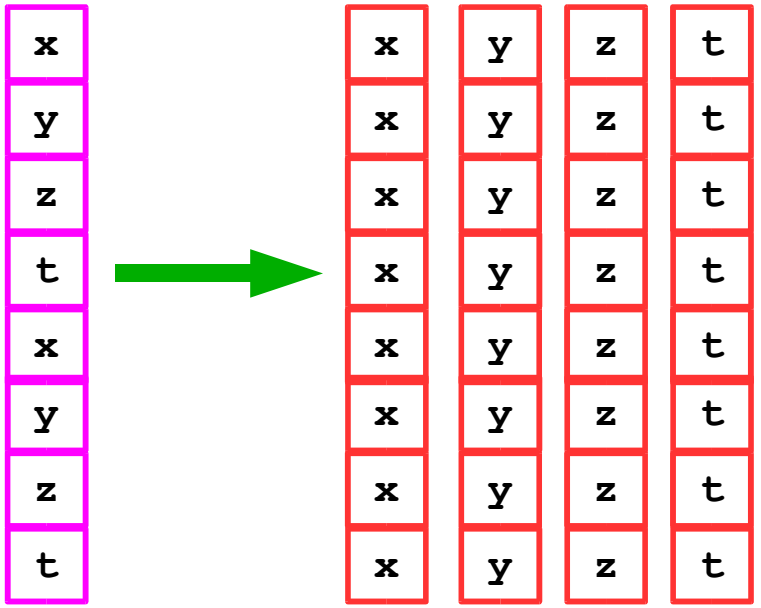
```
switch (var) {
  case   1: ...; break;
  case   2: ...; break;
  ...
  case  47: ...; break;
  ...
  case  59: ...; break;
  ...
  case 250: ...; break;
}
```

- Large switch statement (many cases)
- Without profile feedback
  - Jump table generated
- With profile feedback
  - Data shows a couple of hot cases
  - Other cases are cold
  - Test these two cases first
  - Then use a jump table
  - Results in
    - Faster dispatch of hot cases
    - Hot code uses I-cache better

```
$ cc -fast -xprofile=collect main.c process.c ...
$ a.out
$ cc -fast -xprofile=use main.c process.c ...
$ a.out
```

Example 4 – Whole Program Mode

```
setup(p);
for (i=0; i<STEPS; i++) {
   transform_x(p);
   transform_y(p);
   transform_z(p);
   transform_t(p);
}
report(p);
```



- Original source has 32 byte struct
- Program malloc's for large vector
- All hot segments touch one field
- Ends up with poor cache behavior
  - 32 byte stride, 25% utilization
- With whole program analysis
  - Compiler splits the vector
  - Generates four vectors
  - Hot segments get 8 byte stride
  - 100% cache block utilization
  - Performance is improved

Automatic Parallelization

Automatic Parallelization: Key Points

- Compiler does the parallelization *automatically*
  - Just use the -xautopar option
  - No other user action required
- Automatic parallelization targets loop nests
  - Works synergistically with loop transformations
  - Steadily improving - handles many complex cases now
- Thread count controlled by environment variable
- Two versions generated (if profitability cannot be statically determined)
  - Run time selection between serial and parallel versions
    - Serial version used if work/thread is too low (high overhead)

Example 1 – Matrix Addition

```
for (i=0; i<m; i++)
  for (j=0; j<n; j++)
    a[i][j] = b[i][j] + c[i][j];
```

Turns on auto-parallelization
Prints parallelization information

```
$ cc -xO4 -xautopar -xloopinfo main.o loop.c
"loop.c", line 7: PARALLELIZED, and serial version generated
"loop.c", line 8: not parallelized, not profitable
$ time a.out                        // Default is 1 thread

real    0m37.96s
user    0m36.64s
sys     0m0.97s
$ PARALLEL=2                       // For a two-way parallel run
$ time a.out

real    0m21.99s
user    0m41.07s
sys     0m2.23s
```

The same **binary can run with different numbers of threads.**

Example 2 – Multiple Transforms

```
...
first(m,n);
second(m,n);
...
```

- Top level routine has two calls

```
for (j=0; j<n; j++)
  for (i=0; i<m; i++)
    a[i][j] = b[i][j] + c[i][j];
```

- Loop in first()

```
for (i=1; i<m-1; i++)
  for (j=1; j<n-1; j++)
    b[i][j] = 0.5*c[i][j];
```

- Loop in second()

- Routines inlined
- Loop nest in first() interchanged
- Loop nest in first() peeled
- Fused with loop nest in second()
- Loops parallelized at outer level
- Inner loop pipelined
- Prefetches inserted

➔ Difficult to understand final code

➔ Use commentary, other options

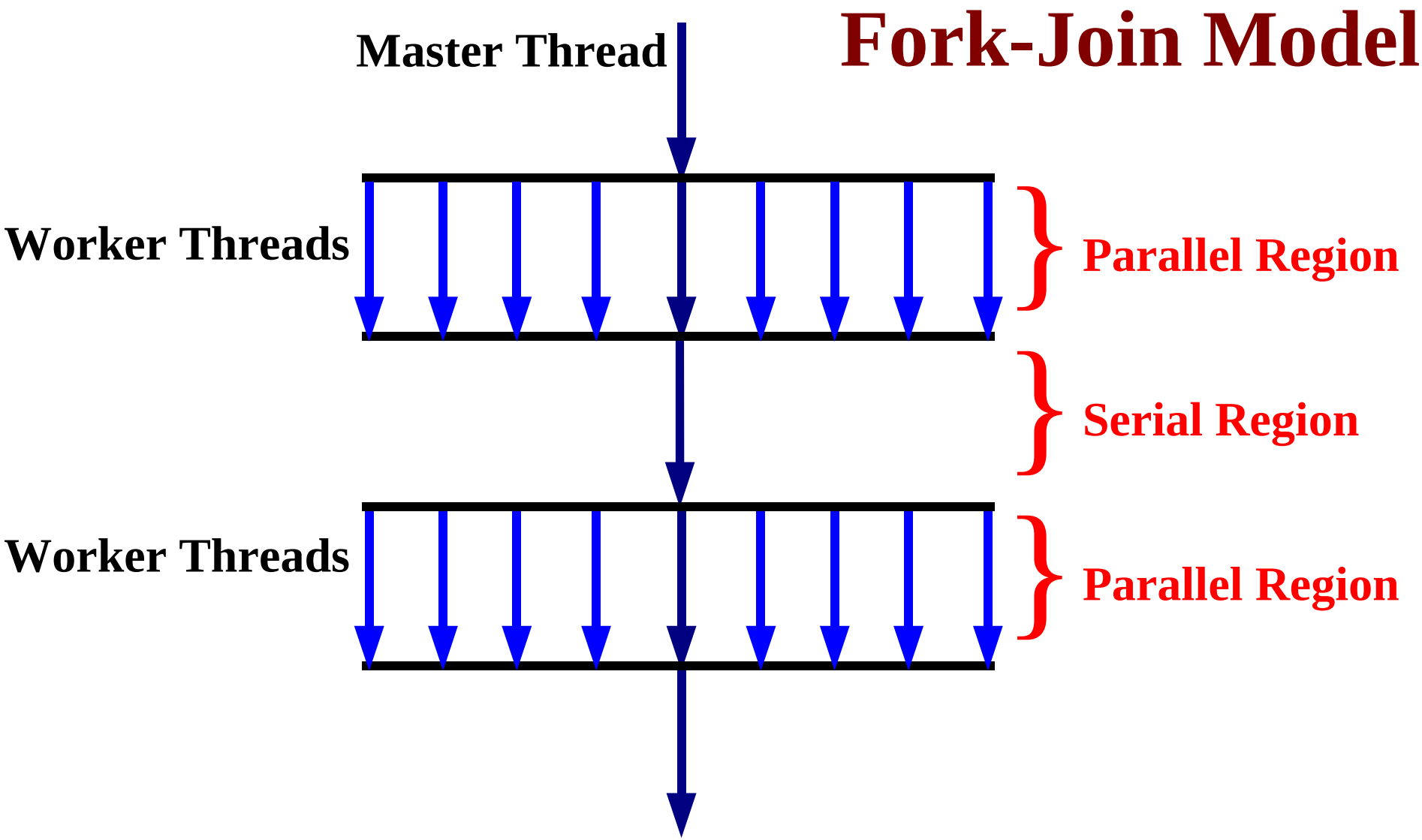
OpenMP

www.openmp.org

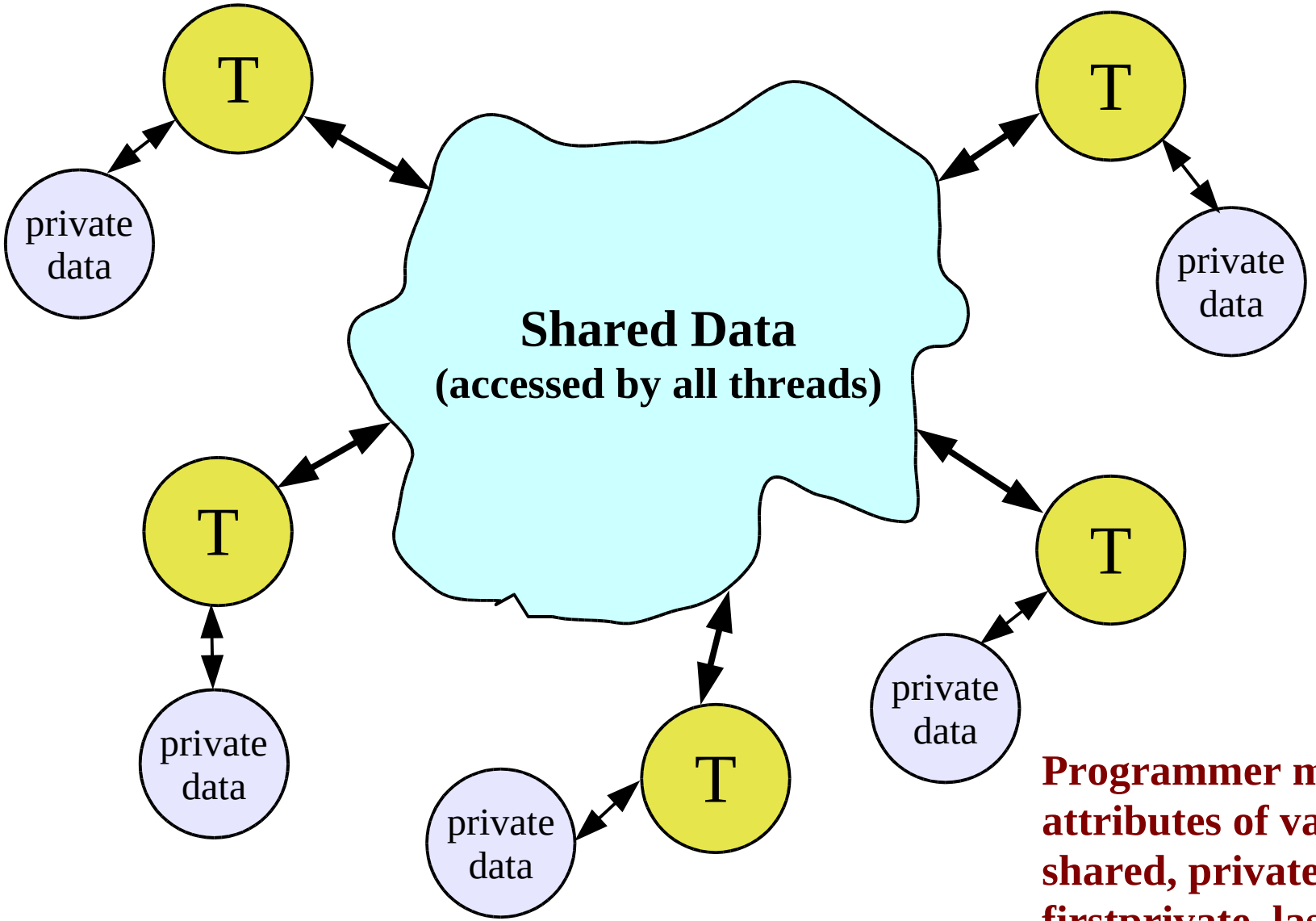
OpenMP for Parallelization

- It is an industry standard (www.openmp.org)
  - Supported by a large number of compilers
  - OpenMP code is portable
    - Directives can be ignored for serial or unsupported systems
- Requires little programming effort
  - Can start with just a handful of directives
  - Applications can be parallelized incrementally
- Good performance and scalability possible
  - Depends ultimately on the code, compiler, and system
    - Many excellent proof points on Sun's systems
    - CMT-friendly shared-memory parallelism leveraged

The OpenMP Execution Model



The OpenMP Memory Model



Programmer must decide attributes of variables: shared, private, firstprivate, lastprivate, ...

Example 1 - Loop

```
for (i=0; i<n; i++)
  a[index[i]] = a[i] + 2;
```

- -xautopar used
- Not parallelized
  - Unsafe

```
$ cc -xO4 -xautopar -xloopinfo loop.c
"loop.c", line 8: not parallelized, unsafe dependence (a)
```

```
#pragma omp parallel for shared(n,a) private(i)
for (i=0; i<n; i++)
  a[index[i]] = a[i] + 2;
```

- Pragma added
- -xopenmp used
- Parallelized

```
$ cc -xO4 -xopenmp -xloopinfo loop.c
"loop.c", line 9: PARALLELIZED, user pragma used
$ OMP_NUM_THREADS=4    // Controls number of threads
$ a.out
```

Example 2 - Sections

```
#pragma omp sections
    {
#pragma omp section
      foo1();
#pragma omp section
      foo2();
#pragma omp section
      foo3();
#pragma omp section
      foo4();
    }
```

- It is not just for loops
- Arbitrary pieces easily parallelized
- Must be legal, of course
- In this example:
  - foo1() - foo4() run in parallel

Sun Value-Added Features

- Version 2.5 fully supported
  - Includes support for nested parallelism
- Performance tuned for Solaris and Sun systems
- Idle thread behavior can be controlled
- Static and runtime error checking
- OpenMP debugging using dbx
- OpenMP performance profiling
- Autoscoping
  - The compiler can assist the user with scoping the variables

Original Code – CFD Application

```
...
!$omp & rusbpz, rusbmz, rustz, rusqz, rushz, ruzfz, rusbz
!$omp & rwsbpz, rwsbmz, rwstz, rwsqz, rwshz, rwzfz, rwsbz
!$omp & rxsbpz, rxsbmz, rxstz, rxsqz, rxshz, ryzfz, rysbz
!$omp & rysbpz, rysbmz, rystz, rysqz, ryshz, ryzfz, rysbz
!$omp & twsbpz, twsbmz, twstz, twsqz, twshz, twzfz, twsbz
!$omp & rusbpm, rusbm1, ruqtz, rpsqz, rsshz, pqzfz, rubsz
!$omp & rwsbpn, rwsbm2, rwrtz, r2sqz, wwshz, qpzfz, rwdqz
!$omp & rxsbpo, rxsbm3, rxetz, r7sqz, xxshz, ptzfz, ryfhz
!$omp & rysbpq, rysbm4, rydtz, r9sqz, ghshz, tpzfz, rylwz
!$omp & twsbpr, twsbm5, twgtz, tw4qz, flshz, rizfz, twkjz
!$omp & rysbps, rysbm6, ryctz, rys2z, koshz, irzfz, rrmwz
!$omp & twsbpt, twsbm7, twqtz, tws2qz, tw5shz, lqzfz, twqqz
...
!$omp do
   do i = is, ie
      [...]   1949 lines omitted
   end do
!$omp end do
!$omp end parallel
```

Code with Autoscoping

```
!$omp parallel DEFAULT(__AUTO)
!$omp do
   do i = is, ie
      [...]   1949 lines omitted
   end do
!$omp end do
!$omp end parallel
```

C Autoscoping Example

```
$ cc -fast -g -c -xopenmp -xloopinfo -xvpara loop.c
$ er_src -cc parallel -src loop.c loop.o
...
...
   Source OpenMP region below has tag R1
   Variables autoscoped as SHARED in R1: b, c, n, a
   Private variables in R1: i
   Shared variables in R1: a, b, c, n
     8. #pragma omp parallel for default(__auto)

   L1 parallelized by explicit user directive
     9.    for (i=0; i<n; i++)
    10.      a[i] = a[i] + 2*b[i] + c[i];
    11. }
```

- **Compiler commentary lists the autoscoping done**

Libraries

The Basic Math Library

- Includes functions such as exp(), log(), sin(), ...
- Part of Solaris, but developed by the compiler team
- Adhere to IEEE 754
- If gradual underflow is not important
  - Use -fns (implied by -fast)
- All C99 functions available in libm
- Vector versions of common functions included in libmvec
  - Can be recognized automatically by the compiler

Example 1 – Vector exp()

```
for (i=0; i<n; i++)
    a[i] = exp(b[i]);
```

- Normal compile calls exp

```
$ cc -fast -S loop.c
$ grep call loop.s
/* 0x0030              */          call    exp
```

- With -xvector, calls __vexp
- Vexp() runs in parallel
  - If idle processors available

```
$ cc -fast -xvector -S loop.c
$ grep call loop.s
/* 0x002c              */          call    __vexp_
```

Loops may be split to enable calling vector functions.

The Sun Performance Library

- Collection of linear algebra routines
  - LAPACK 3.0, BLAS 1-3
  - Standard routines from www.netlib.org
- Enhanced collection in Sun Performance Library
- Highly optimized for Sun systems
- Parallelized versions of the most important functions
- Run time selection of best version for execution platform
  - Provides portable high-performance

Example 2 – Matrix Multiply

```
do jj = 1,n,nb
   call zip(b(1,jj),%val(nb))
   do ii = 1,n,na
      call zip(a(1,ii),%val(na))
      do jjj = jj,jj+nb-1,3
         do iii = ii,ii+na-1,3
             call getts()
            call foo(a,b,c,iii,jjj)
             call gette()
         end do
      end do
       call gettp()
   end do
end do
```

+ There's more code behind!

```
$ f90 -fast main.f \
  hrtime.o -lsunperf
$ a.out
 Mflops:  2640
$ PARALLEL=8
$ a.out
 Mflops:  19736
```

- No coding sweat
- No debugging pains
- No tuning headaches
- Great performance!
- Portable!
- And parallel!

```
call dgemm('T','N',n,n,n,1.d0,a,num,b,num,0.d0,d,num)
```

mediaLib

- Part of Solaris, but developed by the compiler team
- Makes it easy to use available SIMD instructions
  - Collection of library routines provided for:
    - Imaging
    - Signal and Audio
    - Video processing
    - Graphics
    - ... and more
  - Portability across SPARC and x64
    - Plain “C” versions exist for additional portability
  - Performance tuned for Sun systems
  - Parallelized versions available for many functions

Example 3 – FIR Filter

```
for (n = 0; n < dlen; n ++) {
  tmp = 0;
  for (k = 0; k < flen; k ++)
    tmp += fir[k] * src[n+k];
  dst[n] = (vis_s16) (tmp >> 16);
}
```

```
vis_write_gsr(0);
da = (vis_u8 *) dst;
dp = (vis_d64 *) ((vis_u32) da & (~7));
off = (vis_u32) dp - (vis_u32) da;
dend = da + 2 * dlen - 1;
emask = vis_edge16(da, dend);
sa = (vis_u8 *) src;
num = ((vis_u32)dend>>3) - ((vis_u32)da>>3) + 1;
for (n = 0; n < num; n ++) {
  ss = sa;
  rdh = vis_fzero(); rdl = vis_fzero();
  for (k = 0; k < flen; k ++) {
    sp = (vis_d64 *) vis_alignaddr(ss, off);
    s0 = sp[0]; s1 = sp[1];
    sd = vis_faligndata(s0,
    ...
```

+ There's more code!

- No need to write VIS
- No need to write MMX
- Just use mediaLib functions
- Perf. gain of ~6X (avg.)
- C version exists
  - Can be run on any system

The Sun Performance Analyzer

Features Overview

- Analyzer – an advanced performance analysis tool
- Intuitive GUI interface
- Clock based statistical profiling
- HW counter based statistical profiling
- Can relate data to function, source, assembly level
- Integrated with compiler commentary
- Dataspace and memoryspace profiling
- Enhanced OpenMP support

Example 1 – Where did the time go?

```
Excl.      Incl.      Name
User CPU   User CPU
  sec.       sec.
36.956     36.956     <Total>
36.956     36.956     loop
 0.         0.        __collector
 0.         0.        __open
 0.         0.        _exithandle
```

```
...compiler commentary here...
    8.036  8.036  8.    for (i=0; i<n; i++)
## 28.920 28.920  9.      a[i] = b[i]/alpha;
...
```

```
   0.690 0.690 [ 9]    10ce0:  ldd    ...
## 5.174 5.174 [ 9]    10ce4:  fdivd  ...
   3.522 3.522 [ 9]    10ce8:  std    ...
   0.941 0.941 [ 9]    10cec:  ldd    ...
## 5.064 5.064 [ 9]    10cf0:  fdivd  ...
```

Function view

One click

Source view, with commentary

One click

Assembly view, with line numbers

Example 1 – Tuning

```
$ cc -xO4 -g main.c loop.c
main.c:
loop.c:
$ time a.out

real     0m36.81s
user     0m36.67s
sys      0m0.00s
```

```
$ collect -p on a.out
$ analyzer
```

```
$ cc -xO4 -fsimple=2 -g main.c loop.c
main.c:
loop.c:
$ time a.out

real     0m10.09s
user     0m10.00s
sys      0m0.00s
```

First run, simple compile

Analyze - "Aha, it's the divide!"

Add -fsimple=2, changes div->multiply, nice speedup

Example 2 – The memory bottleneck

```
Excl.        Incl.        Excl.      Incl.      Name
Instr_cnt    Instr_cnt    L3_miss    L3_miss
Events       Events       Events     Events
2452671487   2452671487   96803274   96803274   <Total>
2327052822   2327052822   93803181   93803181   loop
 125618665   2452671487    3000093   96803274   main
         0   2452671487          0   96803274   _start
```

```
...compiler commentary here...
                0            0          0          0
  11.    for (i=0; i<n; i++)
## 2327052822  2327052822  93803181  93803181
  12.      t += a[index[i]];
```

```
      9200436      9200436          0          0
  [13]    10908:  ldd           [%o0 + %l0], %f4
                0            0          0          0
  [13]    1090c:  faddd         %f2, %f10, %f14
## 1154977323  1154977323  93803181  93803181
  [13]    10910:  sll           %g5, 3, %g4
```

Function view

One click

Source view, with commentary

One click

Assembly view, with line numbers

Example 2 – Tuning

```
$ cc -fast -g main.c loop.c
main.c:
loop.c:
$ time a.out

real     0m17.49s
user     0m16.24s
sys      0m0.97s
```

```
$ collect -h Instr_cnt,h,L3_miss,h a.out
$ analyzer
```

```
$ cc -fast -g -xprefetch_level=3 main.c loop.c
main.c:
loop.c:
$ time a.out

real     0m6.79s
user     0m5.54s
sys      0m0.97s
```

First run, simple compile

Analyze - "Aha, it's the indirect ldd's L3 miss"

Add -xprefetch_level=3, prefetch emitted, nice speedup

Example 3 – Database on US T1

- Symptom: Slower with 32 threads than 8
- Analysis:
  - Most traffic to one memory bank
  - All 32 processes: same VA, different PA,same cache line
- Solution:
  - Shatter the hot page into smaller ones
  - Changes mappings to go to different lines
- Result:
  - ~6X improvement on US T1 with 32 processes
  - Took 3 hours to get to the “Aha” point with Analyzer

Technology Previews

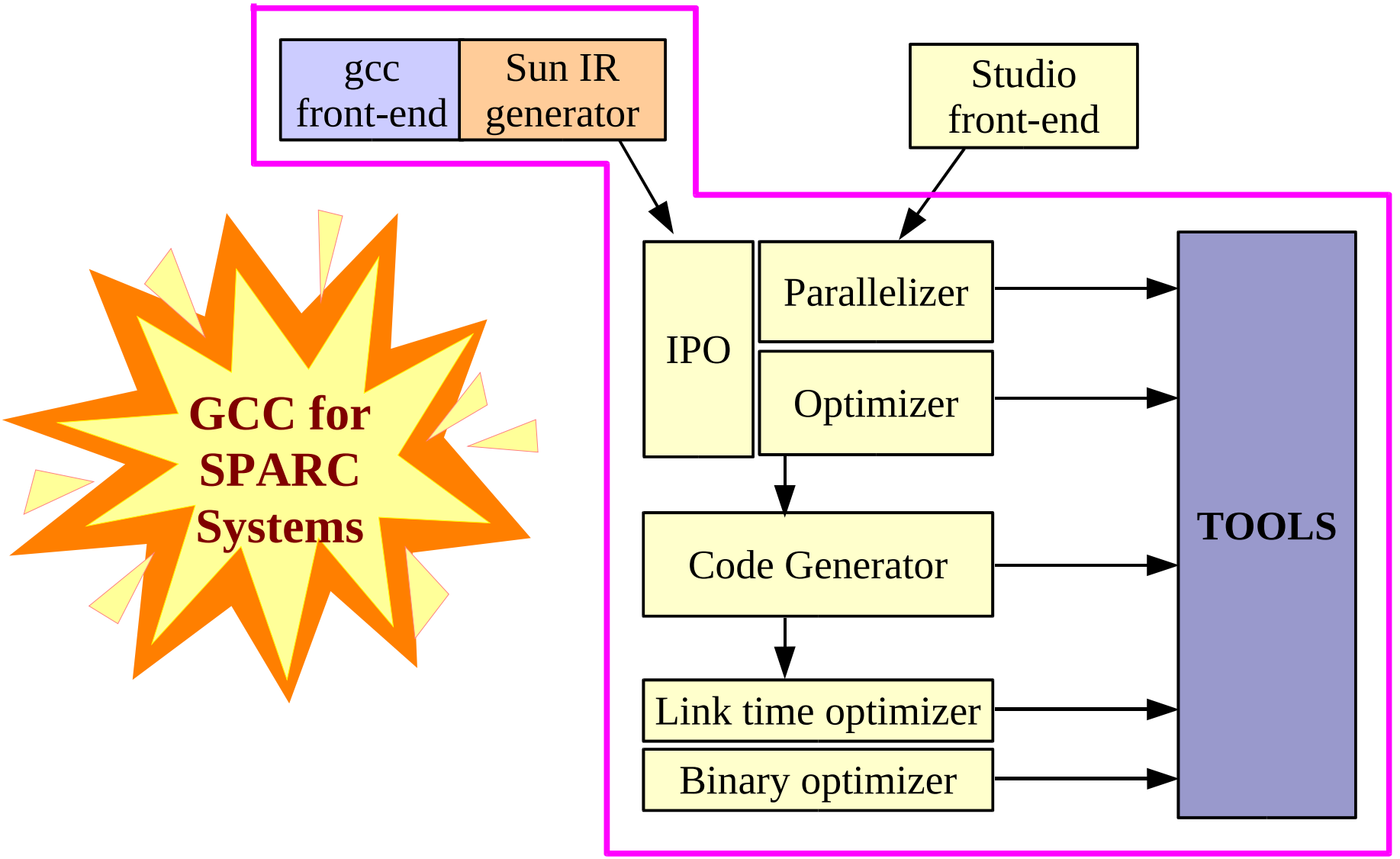
Some of the items in this section are available from the Sun Download Center now. Please stay tuned for updates regarding the others.

1. Embracing SPARC/gcc Users

- Many developers use gcc
  - Want to use the same compiler for different platforms
  - Use gcc language extensions
  - Familiar with & feel comfortable with gcc
  - Migration to Sun Studio is, or is viewed as being, difficult

Would be nice to bring the features of Sun Studio to these users.

How do we get there?



Goals of the Project

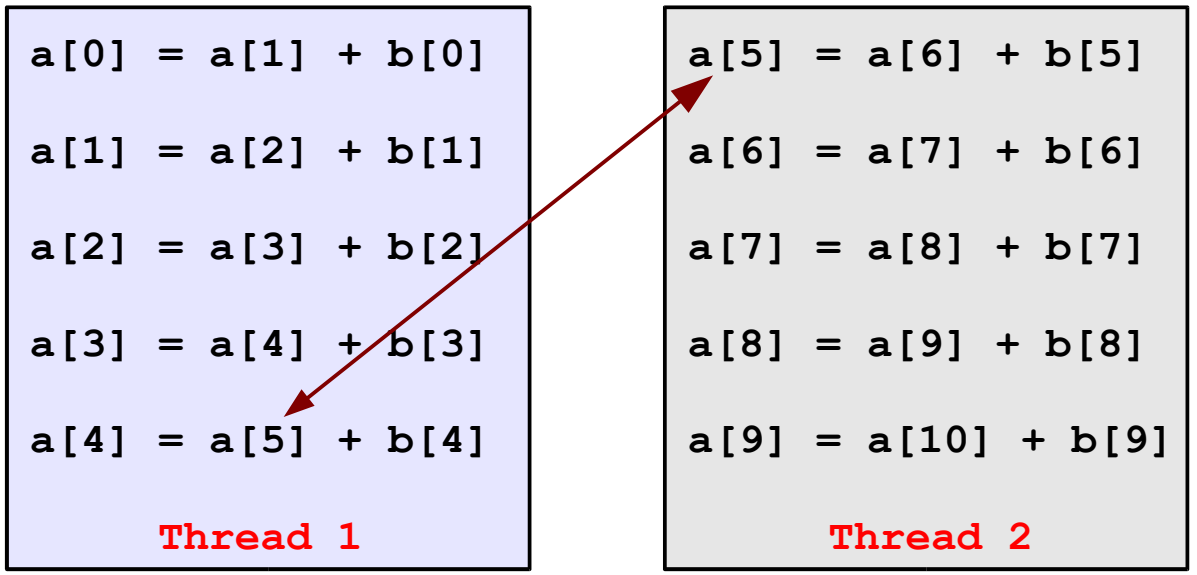
- Transparent to gcc users
  - Feature compatible with gcc
  - Debuggable with gdb and dbx
- Improved performance
  - Through advanced optimizations tuned to SPARC systems
  - Extra optimizations such as -xipo, -xprefetch, -xprofile
- Higher reliability

2. Enhancing Parallel Debugging

What is a race condition?

```
for (i=0; i<n; i++)
  a[i] = a[i+1] + b[i];
```

Sequential execution: Results are deterministic
Parallel execution: Results non-deterministic



Example:
Thread 1 executes i=0-4
Thread 2 executes i=5-9
Thread 2 might write a[5] before thread 1 reads it.
Final value of a[4] wrong!

This is a data race.

Race Detection Tool

- On-the-fly data race detection
- Two phases
  - Instrumentation phase
    - Instruments the executable (if not already instrumented)
  - Execution phase
    - Runs the executable, monitors memory accesses and thread synchronizations, and logs any data race condition detected
- Analysis phase
  - Displays the results gathered

Goals of the Race Detection Project

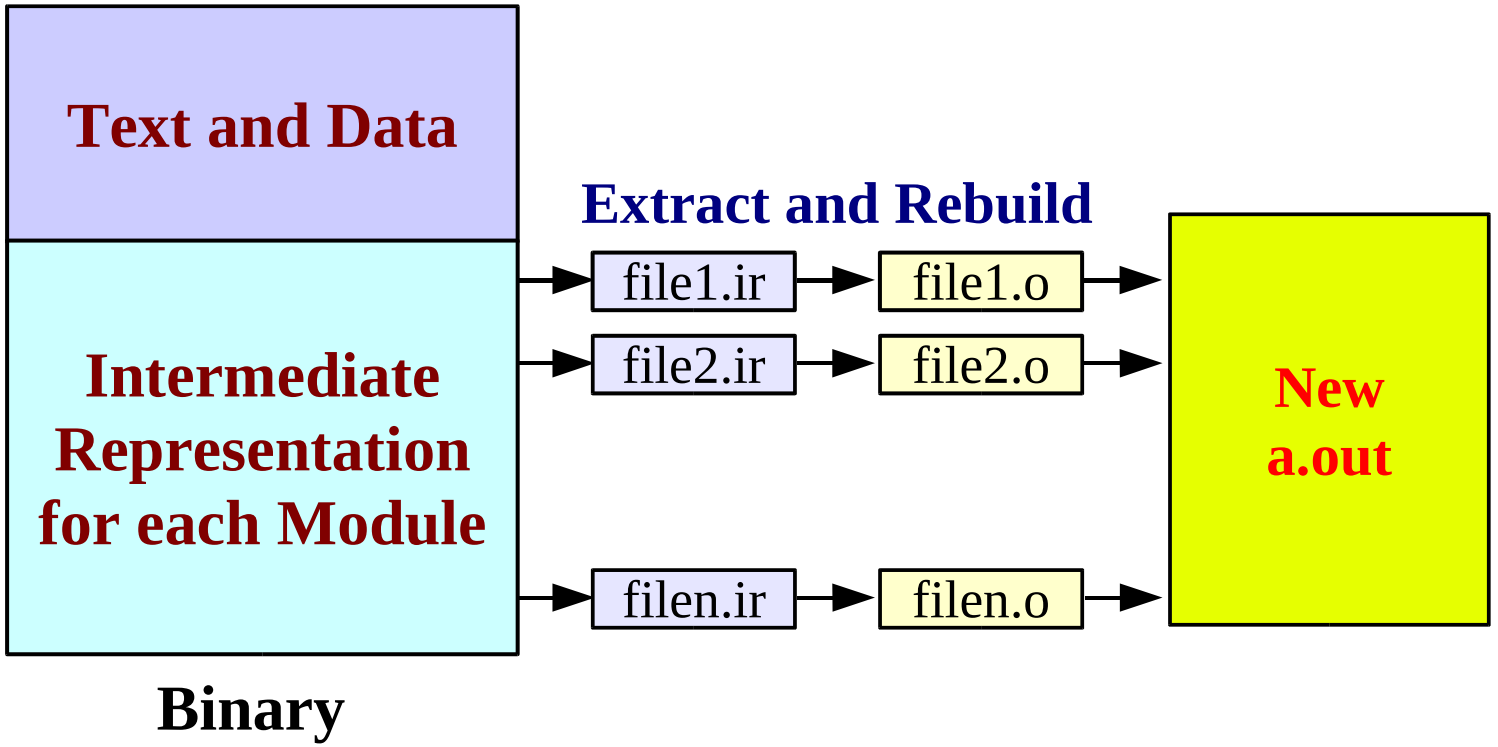
- Handle a variety of multi-threaded applications
  - Open MP
  - Posix threads
  - Solaris threads
  - Sun/Cray directives
  - Mixtures of the above
- Instrumentation at the IR or binary level
- Considering an open API
  - To support user annotations

3. Automating Tuning & Troubleshooting

- Why automate these tasks?
  - Performance tuning issues
    - Time consuming
    - Requires experienced staff
    - Functionality takes all the time, leaving little room for tuning
  - Debugging issues
    - Time consuming, often more than writing the “first cut” code
    - Requires expensive developer time
    - Main cause of schedule slips
  - With CMT, threads are cheap
    - Use computers to ease above tasks
      - ATS (Automatic Tuning System)

The Backbone of ATS - PEC

- Store the intermediate representation (IR) with the executable (object): Portable Executable Code (PEC)
  - The IR can be extracted and reprocessed



Previous Tuning Example with ATS

```
$ cc -fast -g <pecoption> main.c loop.c
main.c:
loop.c:
$ time a.out

real     0m17.49s
user     0m16.24s
sys      0m0.97s
```

```
$ collect -h Instr_cnt,h,L3_miss,h a.out
$ analyzer
```

~~$ cc -fast -g -xprefetch_level=3 main.c loop.c~~
~~main.c:~~
~~loop.c:~~

```
$ ats -i '-fast -g -xprefetch_level=3' \
>  -keepbin a.out
$ time a.out.1

real     0m6.83s
user     0m5.59s
sys      0m0.96s
```

First run, simple compile (with pec)

Analyze - “aha, it's the indirect ldd's L3 miss”

What if the source is unavailable?
With ATS & PEC, we can still tune the a.out!

Benefits of ATS+PEC

- Can operate on an a.out; source not required
- Faster recompilations because it starts with the IR
- Automatic tuning by searching for the best options
- Profile feedback can be applied by the user
- Can search for and find the offending module in the event of a failure; build a binary with a workaround
- Put those computers to good use instead of drawing circles on the screen!

4. Analyzing & Improving Binaries

- BIT - A tool that operates *reliably* on binaries
- Can instrument and collect information for analysis
- Can create a new binary with improved performance
  - Focusses on rearranging code to better use the I-cache
  - Works best on large, complex applications
- Build with
  - Sun Studio 11
  - Add -xbinopt=prepare
  - Use -O1 or higher optimization level

Analysis with BIT

```
$ cc -fast -xbinopt=prepare *.c -lm          // Build for BIT
...
and.c:
build-disjuncts.c:
extract-links.c:
...
$ bit instrument a.out                       // Instrument the a.out
$ a.out.instr 2.1.dict -batch < input        // Run a.out.instr
$ bit analyze -a ifreq a.out | more          // Analyze the run
Instruction frequencies for whole program
Instruction                Executed      (%)
 TOTAL                  18586774239 (100.0)
 float ops                      0 (  0.0)
 float ld st                    0 (  0.0)
 load store             4879117593 ( 26.3)
 load                   3794101701 ( 20.4)
 store                  1085015892 (  5.8)
-----------------------------------------
Instruction                Executed      (%)        Annulled   In Delay Slot
 TOTAL                  18586774239 (100.0)
 lduw                   2889942469 ( 15.5)        83993915       629750312
 br                     2797374496 ( 15.1)               0              0
 subcc                  2222270229 ( 12.0)               0       329895247
```

Examining Code Coverage

```
$ cc -fast -xbinopt=prepare *.c -lm          // Build for BIT
...
and.c:
build-disjuncts.c:
extract-links.c:
...
$ bit instrument a.out                       // Instrument the a.out
$ a.out.instr 2.1.dict -batch < input        // Run a.out.instr
$ bit coverage a.out                         // Analyze coverage
Creating experiment database test.1.er ...
BIT Code Coverage
Total Functions: 350
Covered Functions: 216
Function Coverage: 61.7%
Total Basic Blocks: 6,041
Covered Basic Blocks: 3,969
Basic Block Coverage: 65.7%
Total Basic Block Executions: 3,955,536,194
Average Executions per Basic Block: 654,781.69
Total Instructions: 27,606
Covered Instructions: 17,680
Instruction Coverage: 64.0%
Total Instruction Executions: 18,866,478,764
Average Executions per Instruction: 683,419.50
```

5. Simplifying Performance Optimisation

- SPOT – A Simple Performance Optimisation Tool
  - Produces a report on a code's execution
  - Exposes common causes of performance loss
  - Very easy to use
- SPOT reports contain hyperlinked profiles
  - Makes it easy to navigate from performance issue to source to assembly
  - For maximum information
    - Add -g (-g0 for C++)
    - Use -O1 or higher
    - Include -xbinopt=prepare

Using SPOT

```
$ cc -fast -xbinopt=prepare -g *.c -lm                    // Build the code
...
and.c:
build-disjuncts.c:
extract-links.c:
...
$ spot -X a.out 2.1.dict -batch < input > /dev/null      // Run SPOT
Copying spot resources
Collect machine statistics
Collect application details
Collect ipc data using ripc
Collect data using BIT
Output ifreq data from bit
Collect bandwidth data
Collect traps data
Collect HW counter profile data
Collect data for Rstall_IU_use & Re_DC_miss
Collect data for Rstall_storeQ & Cycle_cnt
Collect data for Dispatch0_2nd_br & Cycle_cnt
Generating html output for HW counter profile data
Collect clock-based profiling data
Generating html output for time profile data
Done collecting, tidying up reports
$
```

- SPOT runs the code many times
- Approx. 20X longer (in this mode)
- Invokes other tools to collect data
- Generates comprehensive report

SPOT Report Example

```
Application stall information (using ripc)
--------------------------------------------------
NOTE:   Time reported under D$ miss also includes
    the time spent in L2 cache misses
==================================================
  UltraSparc                  ticks          sec        %
==================================================
Dispatch0_IC_miss            78503999        0.065     0.3%
Dispatch0_br_target         323039451        0.267     1.1%
...
DTLB_miss                    11859795        0.010     0.0%
Re_DC_miss                 6402197760        5.296    22.1%
Re_EC_miss                  305913838        0.253     1.1%
Re_PC_miss                         99        0.000     0.0%
Re_RAW_miss                 56567038        0.047     0.2%
Re_FPU_bypass                      0        0.000     0.0%
Rstall_storeQ               678244916        0.561     2.3%
...
Total Stalltime           11545566208        9.551    39.8%
--------------------------------------------------
Total CPU Time            29010841600       24.000   100.0%
Total Elapsed Time                          24 Sec
Instr                     18990794752
IPC                     0.655 (instr/time)
```

- See full report
- Provides
  - HW info.
  - Build details
  - Stalls/IPC
  - Profiles
  - Traps data
  - Coverage
  - ...

Summary

- Sun has industry leading compilers and tools for CMT
  - Components are thread-aware and work synergestically
  - Reliable, with advanced optimizations and parallelization
  - Excellent multi-threaded analysis and debugging tools
    - Compiler commentary, automatic parallelization, OpenMP, tuned libraries, performance analyzer, ...
- Exciting new tools and enhancements are under-way
  - Embracing the SPARC/gcc community
  - Race detection in multi-threaded programs
  - Automation of the tuning and troubleshooting process
  - ...

More Information & Resources

- OpenSPARC information & community
  www.opensparc.net
- CoolTools site
  cooltools.sunsource.net
- Sun Forums (including developer forum)
  forum.sun.com
- Contacting Developer Tools Marketing
  Developer911@sun.com
- Sun Studio Product site
  sun.com/sunstudio11
- Sun Studio Developer site
  developers.sun.com/sunstudio

Thank You!

Partha .Tirumalai@Sun.Com