Optimization of the Salvo code on the Origin 2000

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Part 1: Architecture of the Origin 2000

Part 2: Performance tools on the Origin 2000

Part 3: Performance optimization for salvo

Part 4: Shared Memory version of salvo

Performance tools on the Origin 2000

- **perfex** for an overal view on computational costs
- **speedshop** for detailed analysis on source code level
- **-S compiler option** for software pipelining

perfex: description

perfex prints the values of 32 hardware performance counters of the R10000.

- 21 = Graduated floating point instructions
- 25 = Primary data cache misses
- 26 = Secondary data cache misses

Options:

- -a Multiplex over all events, projecting totals.
- -y Report statistics and ranges of estimated times per event.
- -x Count at exception level (as well as the default user level).

```
SGI> perfex -x -y -a a.out
```

perfex: example

```
SGI>  mpirun -np 1 perfex -x -y -a -o output salvo < shot.prm

                                                               Typical
   Event Counter Name                             Counter Value   Time (sec)
21 Graduated floating point instructions.....   28920012288   148.307755
25 Primary data cache misses.................    1430674576    66.104502
26 Secondary data cache misses...............      37043312    14.342411

Statistics
=======================================================================
L1 Cache Line Reuse.........................      14.362031
L2 Cache Line Reuse.........................      37.621670
L1 Data Cache Hit Rate......................       0.934904
L2 Data Cache Hit Rate..... ................       0.974108
Time accessing memory/Total time............       0.673777
```

Note that for salvo there are no 'strange' things reported by perfex.

speedshop: description

Integrated package of performance tools to run performance experiments on executables, and to examine the results of those experiments.

- ssrun - set up and run a process to collect SpeedShop performance data
  - **-[f]pcsampc** emphasizes functions that cause cache misses
  - **-[f]gfp_hwc** *statistical* PC sampling, of the graduated floating-point instruction counter
  - **-ideal** uses basic-block counting, by instrumenting the executable
- prof - analyze SpeedShop performance data

```
SGI> ssrun -fgfp_hwc a.out
SGI> prof -h -b .ideal
```

speedshop: example

```
SGI> mpirun -np 1 ssrun -fgfp_hwc salvo < shot.prm

-------------------------------------------------------------------------
Function list, in descending order by counts
-------------------------------------------------------------------------
[index]      counts     %   cum.%   samples  function (dso: file, line)

  [1]   11446256160  39.8%  39.8%   1746720  pipe_single (salvo: pipe_single.F, 99)
  [2]    5106851195  17.8%  57.6%    779315  PASSF4 (salvo: fftpack.f, 1221)
  [3]    5087585375  17.7%  75.2%    776375  PASSB4 (salvo: fftpack.f, 909)
  [4]    2332999060   8.1%  83.4%    356020  phase_correction (salvo: filter_li.F, 259)
  [5]    1754526432   6.1%  89.5%    267744  PASSB5 (salvo: fftpack.f, 961)
  [6]    1747560593   6.1%  95.5%    266681  PASSF5 (salvo: fftpack.f, 1273)
  [7]     723313587   2.5%  98.0%    110379  thin_lens (salvo: thin_lens.F, 36)
  [8]     306202031   1.1%  99.1%     46727  __cosf (libm.so: fcos.c, 93)
  [9]     155050533   0.5%  99.6%     23661  image (salvo: image.F, 34)
 [10]      36133242   0.1%  99.8%      5514  __vcosf (libm.so: vfcos.c, 77)
 [11]      30654934   0.1%  99.9%      4678  __vsinf (libm.so: vfsin.c, 77)
 [12]       9678781   0.0%  99.9%      1477  RADF5 (salvo: fftpack.f, 225)
 [13]       9174200   0.0%  99.9%      1400  RADF3 (salvo: fftpack.f, 135)
 [14]       4442934   0.0% 100.0%       678  vel_interp (salvo: vel_interp.c, 47)
 [15]       4148049   0.0% 100.0%       633  RADF4 (salvo: fftpack.f, 171)
 [16]       3158546   0.0% 100.0%       482  CFFTI1 (salvo: fftpack.f, 664)
 [17]       1690674   0.0% 100.0%       258  apply_encoding (salvo: apply_encoding.F, 31)
 [18]        878102   0.0% 100.0%       134  scatterFrequencies (salvo: scatterFreq.c, 74)
 [19]        203143   0.0% 100.0%        31  __pow (libm.so: pow.c, 198)
 [20]        183484   0.0% 100.0%        28  filter_li (salvo: filter_li.F, 50)
 [21]        150719   0.0% 100.0%        23  RFFTI1 (salvo: fftpack.f, 36)
 [22]         72083   0.0% 100.0%        11  hdr_get (salvo: segyhdr.c, 80)
 [23]         32765   0.0% 100.0%         5  segy_getxyz (salvo: segyio.c, 545)
 [24]         32765   0.0% 100.0%         5  scatterData (salvo: scatterData.c, 62)
 [25]         19659   0.0% 100.0%         3  fftData (salvo: fftData.c, 151)
 [26]         13106   0.0% 100.0%         2  __libm_dcis (libm.so: dcis.c, 179)
 [27]          6553   0.0% 100.0%         1  memcpy (libc.so.1: bcopy.s, 329)
 [28]          6553   0.0% 100.0%         1  timeline_ (salvo: timeline.c, 73)
 [29]          6553   0.0% 100.0%         1  seis_fftlen (salvo: seifft.c, 87)
 [30]          6553   0.0% 100.0%         1  initvars (salvo: initvars.F, 76)
```

compiler -S option: description

Compile the specified source programs and leave the symbolic assembly language output in corresponding files suffixed with .s.

Usefull to check how effectively the processor's hardware resources are being used in the schedule generated by the compiler. Specially software pipelining and loop unrolling are reported.

```
SGI> f77 -O3 -S file.f
```

compiler -S option: example

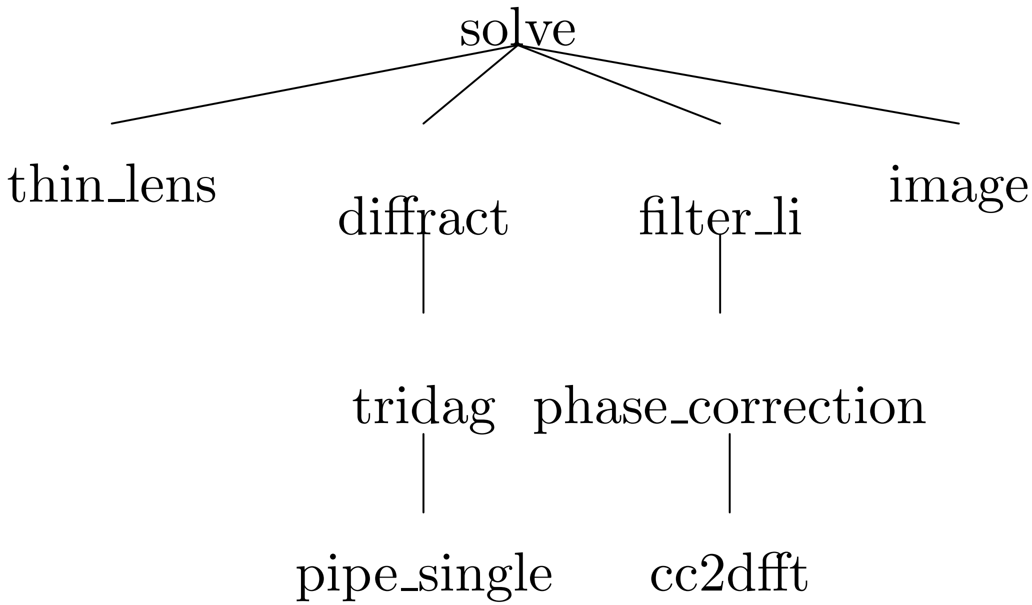
```
SGI> f77 -O3 -S pipe_single.f
```

```
 #<swps> Pipelined loop line 678 steady state
 #<swps>
 #<swps>   100 estimated iterations before pipelining
 #<swps>       Not unrolled before pipelining
 #<swps>     8 cycles per iteration
 #<swps>     8 flops        ( 50% of peak) (madds count as 2)
 #<swps>     6 flops        ( 37% of peak) (madds count as 1)
 #<swps>     2 madds        ( 25% of peak)
 #<swps>     6 mem refs     ( 75% of peak)
 #<swps>     3 integer ops  ( 18% of peak)
 #<swps>    15 instructions ( 46% of peak)
 #<swps>     1 short trip threshold
 #<swps>     4 integer registers used.
 #<swps>     6 float registers used.
 #<swps>
 #<swps>     6 min cycles required for resources
 #<swps>     8 cycles in minimum schedule found
......
 #<swps> Pipelined loop line 387 steady state
 #<swps>
 #<swps>    50 estimated iterations before pipelining
 #<swps>     2 unrollings before pipelining
 #<swps>     8 cycles per 2 iterations
 #<swps>     8 mem refs     (100% of peak)
 #<swps>     4 integer ops  ( 25% of peak)
 #<swps>    12 instructions ( 37% of peak)
 #<swps>     2 short trip threshold
 #<swps>     9 integer registers used.
 #<swps>     8 float registers used.
```

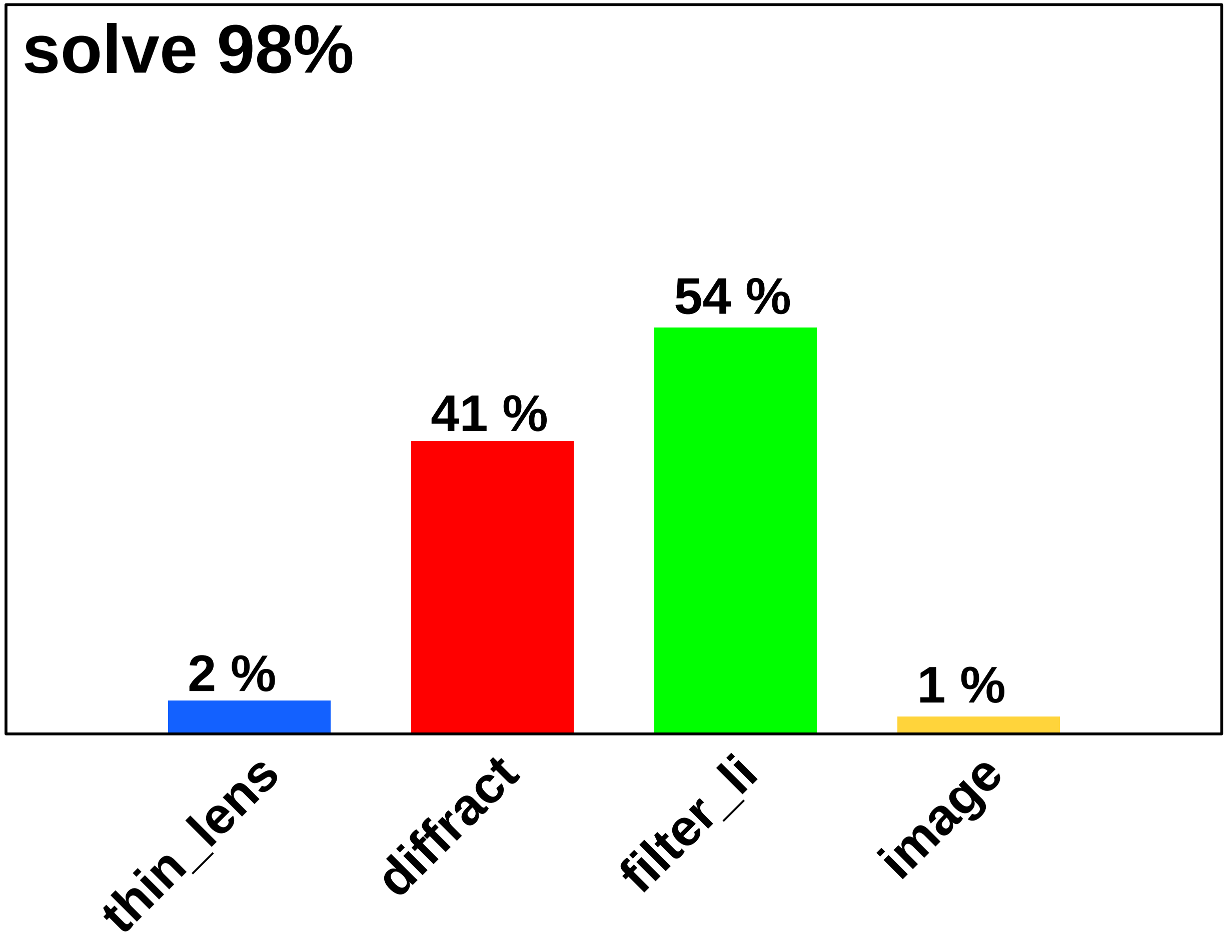
Note that loops which include a function call are not pipelined.

Performance optimization for salvo

Computational scheme:

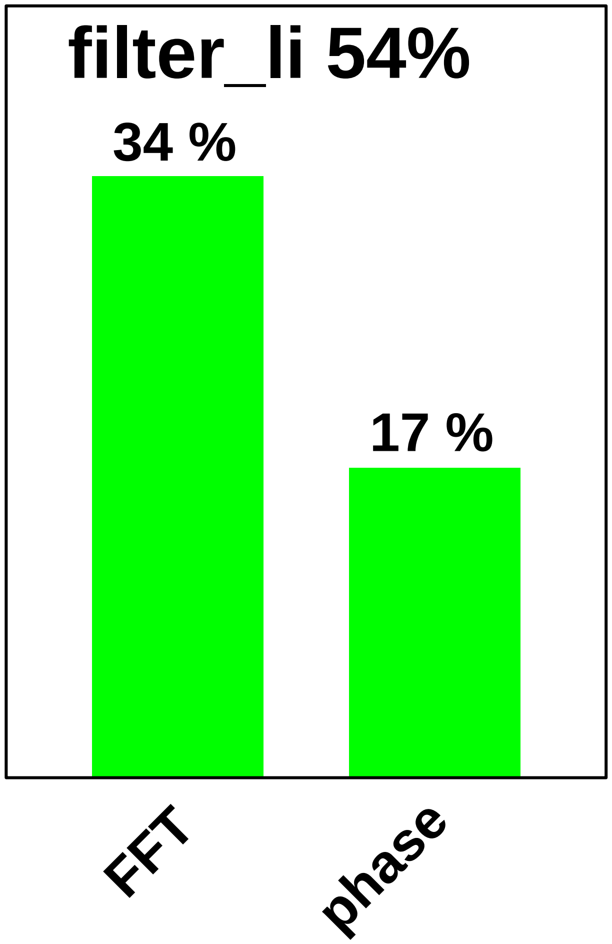


Performance optimization for salvo



profiled with *ssrun -ideal* experiment

Performance optimization for salvo



Performance optimization for salvo

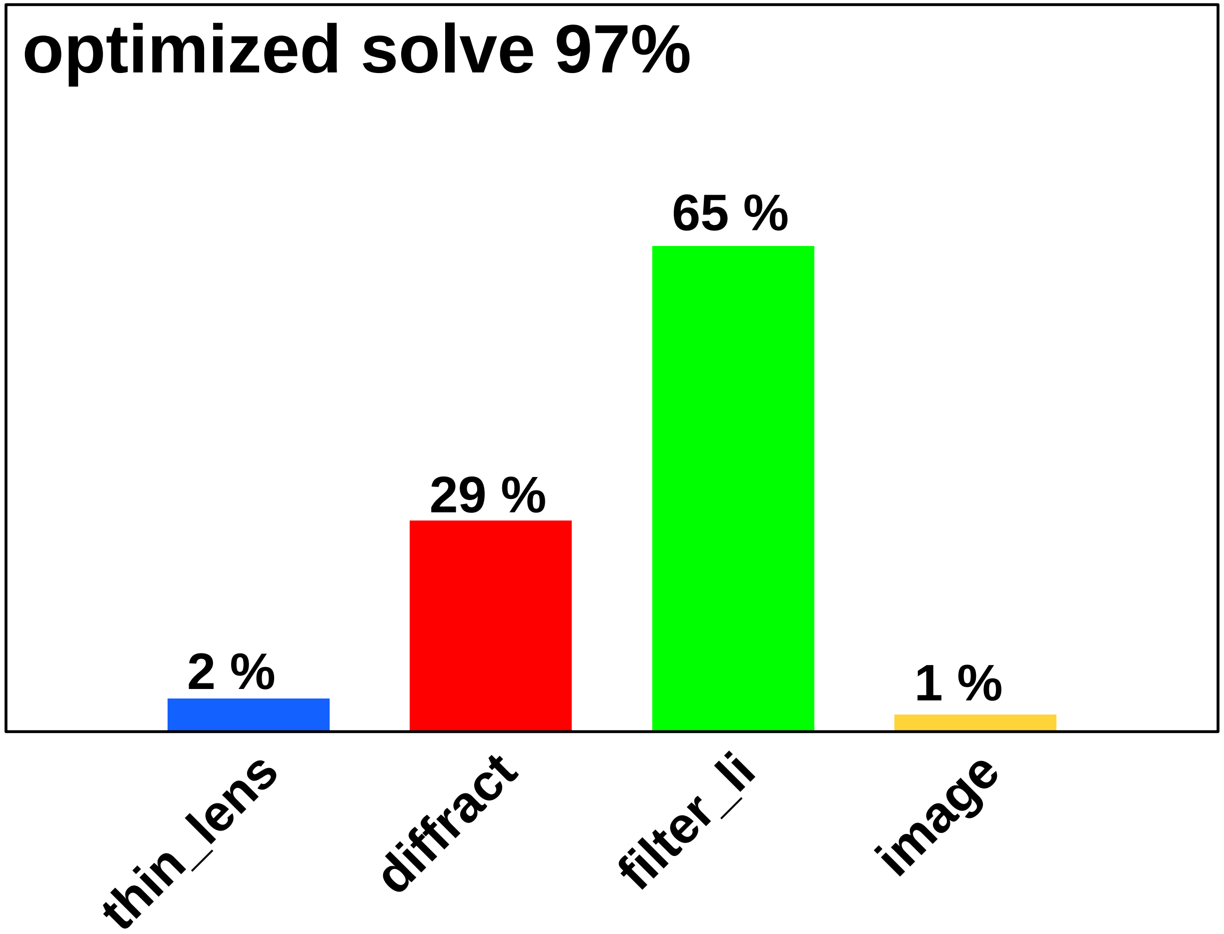
- use SGI's **SCS** library (-lscs_mp) to do the FFT's
- rearrange calculations in pipe_single.f
- replace complex arrays with real arrays (*to be done*)
- loop level optimization (*to be done*)

Performance optimization for salvo

	Time (s)	instructions	Gflop*	Gintop	Mflop/s
Original	206	69.10^9	37	11	143
replaced FFT's	137	67.10^9	37	10	146
rearrange calc's	116	62.10^9	35	10	172
shared memory	113	59.10^9	35	9	180

The times given are for one CPU; computing one depth step of the migration of one shot record of the Sandia_OBC data-set in the frequency range [7.5, 90.0] Hz. One depth slize is 295x295 (nx$x$ny) points and 297 frequencies are calculated. $*$ Note that one floating point cycle may consist of one add and a mult.

Performance optimization for salvo



profiled with *ssrun -ideal* experiment

Performance optimization for salvo

Scaling of frequency parallelism (MPI partially code-optimized)

# CPU's	Time (s)
1	116
2	58.9
4	30.8
8	15.6
16	8.2
32	4.7
64	-

Note that these results were obtained by running on a non-dedicated machine.

Shared memory version of salvo

Migration algorithm:

```
for (iz=0; iz<nz; iz++) {
    for (ifreq=0; ifreq<nw; ifreq++) {
        copy freq slices data[ifreq][ny][nx] to local array[ny][nx]
        extrapolate source and receiver fields (call salvo)
        imaging condition (call image)
        store extrapolated freq slice back in data[ifreq][ny][nx]
    }
    add all images from all frequencies
    write total image for iz to disk
}
```

Note that the depth loop can be moved inside the frequency loop without rewriting the code.

Single CPU performance

Method	total time [s]		time/depth_step [s/m]	
	195 Hz	250 Hz	195 Hz	250 Hz
Original	1867	-	203	-
Optimized	1066	-	114	-
Shared Memory	969	743	107	85

For the shared memory version a smaller FFT length 320 =¿ 300 is used.

Using the Sandia_OBC data set and the following parameters:

Output image: nx*ny*nz = 295*295*10 (size of the output image) dy=82 dx=82 dz=25 filter_type=1 image_type=0 (=Correlation)

velocity input file: nxv=102 xvmin=24272 dxv=656 nyv=75 yvmin=76096 dyv=656 nzv=97 zvmin=0 dzv=150

frequency range: fmin=7.5 fmax=90 (nf=297) compiler: 7.2.1 with -O3 -mips4 -n32 OS: IRIX 6.5 CPU: MIPS r10000 at 195 MHz and 4 MB secondary cache

Scaling of frequency parallelism

# CPU's	SMP^1	SMP^2	MPI	MPI(original)
1	969		1066	1867
2	511		544	962
4	268		284	505
8	134		141	257
16	71		77	128
32	44		44	74
64	-	-	-	-
128	-	-	-	-

Total wallclock time (user+system) is shown. 1) 195 Mhz R10k with 4 MB of secondary cache 2) 250 Mhz R10k with 4 MB of secondary cache 3) 300 Mhz R12k with 8 MB of secondary cache

Concluding remarks

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