Program Development Tools

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Topics

- *Source code management*
- *Make*
- *System Monitoring Tools*
- *The SpeedShop profiler*
- *Performance Boosters*

Using these tools will save you time and frustration

Source Code Management

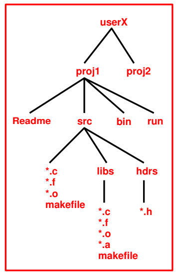
RCS/SCCS

Source Files

* Tree Organization

* Small Modules
  * fsplit / split
  * Faster Compile
  * Less Resources To Compile
  * Code Study
  * Optimization Flexibility

* Documentation
  * RCS/SCCS
  * Make
    * Readme



RCS (Revision Control System)

- *Automatic Documentation*
- *Roll–back*
- *100% "Oops" free*
- *Easy to use*

```
ruud@emmen 86% mkdir RCS
ruud@emmen 87% ls -lt main.f
-rw-r--r--    1 ruud     user    72 Mar 21 19:02 main.f
ruud@emmen 88% ci main.f
RCS/main.f,v  <--  main.f
enter description, terminated with single '.' or end of
file:
NOTE: This is NOT the log message!
>> Key new application
>> .
initial revision: 1.1
done
ruud@emmen 89% co main.f
RCS/main.f,v  -->  main.f
revision 1.1
done
ruud@emmen 90% rcsdiff main.f
===================================================================
RCS file: RCS/main.f,v
retrieving revision 1.1
diff -r1.1 main.f
ruud@emmen 91%
```


RCS Commands

- **creation:** (mkdir RCS) ci <file>
- **versions:** rlog <file>
- **add new:** ci <file>
- **retrieve:** co –r<version> <file>
- **edit:** co –l<version> <file>
- **diff:** rcsdiff –r<version> –r<version> <file>

SCCS

- **Automatic Documentation**
- **Roll Back**
- **100% "oops free"**
- **admin / get / delta / prs**
- **Make Integrated**

```
admin -ifile1.c  s.file1.c
make -g t
```


SCCS Commands

- **creation:** admin –i<file> s.<file>
- **versions:** prs s.<file>
- **add new:** delta s.<file>
- **retrieve:** get –r<version> s.<file>
- **edit:** get –e –r<version> s.<file>
- **diff:** sccsdiff –r<version> –r<version> s.<file>

Make

Make

- Automatic Documentation
- Minimizes compiles + compiles in parallel (!)
- 100% "oops free"

```
pgm: main.o sub1.o sub2.o
<tab>    f77 -o pgm main.o sub1.o sub2.o \
         -64 -lm

sub1.o:  sub1.f:
<tab>    f77 -c -O3 -64 -mips4 sub1.f

sub2.o:  sub2.f
<tab>    f77 -c -O3 -64 -mips4 -static sub2.f

clean:
<tab>   -rm -f pgm main.o sub1.o sub2.o
```


Make – Example

```
# This make file uses symbols

EXE     = pgm
OBJECTS = main.o sub1.o sub2.o
FFLAGS  = -O3 -mips4 -64
LDFLAGS = -lm -64

default: $(EXE)

$(EXE): $(OBJECTS)
<tab>    f77 -o $(EXE) $(OBJECTS) $(LDFLAGS)

.f.o:
<tab>    f77 -c $(FFLAGS) $*.f

sub2.o: sub2.f
<tab>    f77 -c $(FFLAGS) -static $*.f

clean:
<tab>   @rm -f $(OBJECTS) $(EXE) core
```


Make – A More Elaborate Example

```
#
FC      = $(TOOLROOT)/usr/bin/f77
CC      = $(TOOLROOT)/usr/bin/cc
LD      = $(FC)
F77     = $(FC)
SWP     = swplist
RM      = /bin/rm -f
MP      =
ABI     = -n32
ISA     = -mips4
PROC    = ip27
ARCH    = $(MP) $(ABI) $(ISA)
OLEVEL  = -Ofast=$(PROC)
FOPTS   = -OPT:IEEE_arithmetic=3
COPTS   = -OPT:IEEE_arithmetic=3
FFLAGS  = $(ARCH) $(OLEVEL) $(FOPTS)
CFLAGS  = $(ARCH) $(OLEVEL) $(COPTS)
LIBS    = -lfastm
LDFLAGS = $(ARCH) $(OLEVEL)
PROF    =

FOBJS   = f1.o f2.o f3.o
COBJS   = c1.o c2.o c3.o
OBJS    = $(FOBJS) $(COBJS)
EXEC    = executable

$(EXEC):        $(OBJS)
        $(LD) -o $@ $(PROF) $(LDFLAGS) $(QV_LOPT) $(OBJS) $(LIBS)

clean:
        $(RM) $(EXEC) $(OBJS)
        $(SWP) -c $(CFLAGS) $(QV_OPT) $(DEFINES) $<
```

```
.SUFFIXES:
.SUFFIXES: .o .F .c .f .swp

.F.o:
        $(FC)  -c $(FFLAGS) $(QV_OPT) $(DEFINES) $<

.f.o:
        $(FC)  -c $(FFLAGS) $(QV_OPT) $(DEFINES) $<

.c.o:
        $(CC)  -c $(CFLAGS) $(QV_OPT) $(DEFINES) $<

.F.swp:
        $(SWP) -c $(FFLAGS) $(QV_OPT) $(DEFINES) -WK,-cmp=$*.m $<

.f.swp:
        $(SWP) -c $(FFLAGS) $(QV_OPT) $(DEFINES) -WK,-cmp=$*.m $<

.c.swp:
        $(SWP) -c $(CFLAGS) $(QV_OPT) $(DEFINES) $<
```

Make has been parallelised

Speed–up your compiles:

make	old standard, serial compilation
smake	old standard, parallel compiles
pmake	many extensions on old standard, parallel compiles

```
% pmake -JN (make with "N" compile streams)
```

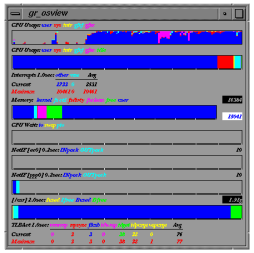

System Monitoring Tools

System Monitoring Tools

- *gr_osview (and osview)*
- *sar*
- *timex*

gr_osview

```
# Example configuration file
cpu strip
cpu
intr numeric max tracksum(10)
rmem tracksum
wait
netif
disk(/usr)
tlb numeric max tracksum(1)
```




```
Keywords:
strip        - display as a strip chart
numeric      - display numeric values
max          - add a maximum value numeric meter
max(n)       - add a maximum value meter with reset interval n
tracksum     - add an average value numeric meter
tracksum(n)  - add an average value meter with interval n
noborder     - suppress bar border
interval(n)  - set sample interval in base units
samples(n)   - set number of samples in strip chart

attack(f)      - set attack speed of bar
colors(c,...)  - set bar colors to use
maxcolor(b,f)  - set maximum value display colors
limcolor(b,f)  - set scale limit value display colors
sumcolor(b,f)  - set tracking sum display colors
lockscale(x)   - lock the scale value
creepscale     - autoscaling will only increase the scale
ticks(i,n)     - set strip chart tick marks
```

osview

```
 Osview 2.1 : One Second Average   eo2k3      04/22/97 11:54:30 #197   int=5s
 Load Average           %sys         0.40    %idle      100.00    %sys          0.00    Phys         8.0G
   1 Min       9.081    %intr        0.00  CPU 20 Usage           %intr         0.00     kernel    257.9M
   5 Min       7.598    %sxbrk       0.00    %user         0.00   %sxbrk        0.00      heap      27.2M
   15 Min      7.891    %idle       99.60    %sys          0.00   %idle       100.00       stream   64.0K
*CPU 0 Usage          CPU 14 Usage           %intr         0.00 CPU 27 Usage              zones    106.5M
*CPU 1 Usage            %user        0.00    %sxbrk        0.00   %user         0.00      ptbl       4.5M
*CPU 2 Usage            %sys         0.00    %idle       100.00   %sys          0.00     fs ctl     30.2M
*CPU 3 Usage                                                                    0.00     fs data   340.6M
*CPU 4 Usage                                                                    0.00      delwri        0
*CPU 5 Usage                                                                  .00.00     free        6.7G
*CPU 6 Usage                                                                             userdata  729.9M
*CPU 7 Usage                                                                    0.00     pgallocs       0
*CPU 8 Usage                                                                    0.00  Node[0]
 CPU 9 Usage                                                                    0.00      Totalmem502.9M
   %user                                                                        0.00      freemem 428.2M
   %sys                                                                       .00.00      64k page  1.6K
   %intr                                                                                  256k pages 402
   %sxbrk                                                                       0.00      1MB pages  100
   %idle                                                                        0.00      4MB pages   25
 CPU 10 Usage                                                                   0.00      16MB pages   0
   %user                                                                        0.00  Node[1]
   %sys        0.00     %idle       99.60    %sys          0.00   %idle       100.00      Totalmem506.5M
   %intr       0.00   CPU 17 Usage           %intr         0.00 CPU 30 Usage              freemem 401.7M
   %sxbrk      0.00     %user        0.00    %sxbrk        0.00   %user       100.00      64k page  1.5K
   %idle     100.00     %sys         0.00    %idle       100.00   %sys          0.00      256k pages 405
 CPU 11 Usage           %intr        0.00  CPU 24 Usage           %intr         0.00      1MB pages  101
   %user       0.20     %sxbrk       0.00    %user        99.80   %sxbrk        0.00      4MB pages   25
   %sys        8.03     %idle      100.00    %sys          0.20   %idle         0.00      16MB pages   0
   %intr       0.00   CPU 18 Usage           %intr         0.00 CPU 31 Usage          Node[2]
   %sxbrk      0.00     %user        0.20    %sxbrk        0.00   %user         0.00      Totalmem506.5M
   %idle      91.77     %sys         0.00    %idle         0.00   %sys          0.00      freemem 448.6M
 CPU 12 Usage           %intr        0.00  CPU 25 Usage           %intr         0.00      64k page  1.6K
   %user       0.00     %sxbrk       0.00    %user         0.00   %sxbrk        0.00      256k pages 405
   %sys        0.00     %idle       99.80    %sys          0.00   %idle       100.00      1MB pages  101
   %intr       0.00   CPU 19 Usage           %intr         0.00 Wait Ratio                4MB pages   25
   %sxbrk      0.00     %user        0.00    %sxbrk        0.00   %IO            0.0      16MB pages   0
   %idle     100.00     %sys         0.00    %idle       100.00   %Swap          0.0  Node[3]
 CPU 13 Usage           %intr        0.00  CPU 26 Usage           %Physio        0.0      Totalmem506.5M
   %user       0.00     %sxbrk       0.00    %user         0.00 System Memory             freemem 176.2M
```

Use the "h,j,k,l" keys to move around

Use "D" to delete a section

Use "I" to expand a section

SAR (System Activity Reporter)

Options to SAR

–u	(cpu)
–b	(buffer)
–d	(disks)
–w	(swap & switch)
–q	(run queues)
–p	(paging)
–r	(virtual memory)
–I	(interrupts)
(etc...)	
–A	(everything)

```
sar -r 1 3

IRIX 5.1.1.1 IP20 01/04/94

10:34:53 freemem freeswp
10:34:54      323   36752
10:34:56      320   36752
10:34:57      321   36752


10:34:57 freemem freeswp
Average       321   36752
```


Timex

```
timex -s date
Tue Jan  4 10:39:59 MET 1994

real         0.07
user         0.01
sys          0.03


IRIX dope 5.1.1.1 10011611 IP20    01/04/94

10:39:59  %usr  %sys %intr  %wio %idle %sbrk  %wfs %wswp %wphy %wgsw %wfif
10:40:00    10    70     0    10    10     0   100     0     0     0     0

10:39:59  device   %busy  avque  r+w/s  blks/s    w/s wblks/s  avwait  avserv
10:40:00  dks0d1      30    1.0     15     360      5     160     0.0    20.0
          dks0d2       0    0.0      0       0      0       0     0.0     0.0


(etc...)
```


The SpeedShop Profiler

Profiling Tools

`perfex`: first–pass detection of program–wide performance issues

What is the problem?

SpeedShop: source–procedure annotation for focused experiments

Which procedures have the problems?

`dprof`: virtual memory data space profiling to discover access patterns

Which arrays are involved

SpeedShop

- **Speedshop provides the following profiling experiments:**
  - *PC sampling*
  - *Ideal time*
  - *Usertime*
  - *Hardware counter profiling*
  - *Floating point exception tracing*
  - *Heap tracing*
- **Does not require any special compilation or re–linking**
- **Usage:**

```
% ssrun -exp experiment [options] program [flags]
% prof "ssrun_output_file(s)"
```

- **Modes of counting on some experiments:**
  - **f for more fine–grained sampling**
  - **x for a 32 bit bin size, instead of the default of 16**

Example: `% ssrun -exp [f]pcsamp[x] ./a.out`

PC–sampling experiment

```
% ssrun -pcsamp adi2

 Time:       7.619 seconds
 Checksum:   5.6160428338E+06

% prof adi2.pcsamp.4885

-------------------------------------------------------------------------------
Profile listing generated Sat Jan  4 10:28:11 1997
    with:       prof adi2.pcsamp.4885
-------------------------------------------------------------------------------

samples   time    CPU    FPU   Clock   N-cpu  S-interval Countsize
   8574   8.6s R10000 R10010 196.0MHz   1      1.0ms     2(bytes)

Each sample covers 4 bytes for every  1.0ms ( 0.01% of 8.5740s)

-------------------------------------------------------------------------------
  -p[rocedures] using pc-sampling.
  Sorted in descending order by the number of samples in each procedure.
  Unexecuted procedures are excluded.
-------------------------------------------------------------------------------

samples   time(%)      cum time(%)      procedure (dso:file)

   6688   6.7s( 78.0)  6.7s( 78.0)         zsweep (adi2:adi2.f)
    671  0.67s(  7.8)  7.4s( 85.8)         xsweep (adi2:adi2.f)
    662  0.66s(  7.7)    8s( 93.6)         ysweep (adi2:adi2.f)
    208  0.21s(  2.4)  8.2s( 96.0)       fake_adi (adi2:adi2.f)
    178  0.18s(  2.1)  8.4s( 98.1)         irand_ (/usr/lib32/libftn.so:../../libF77/rand_.c)
    166  0.17s(  1.9)  8.6s(100.0)          rand_ (/usr/lib32/libftn.so:../../libF77/rand_.c)
      1 0.001s(  0.0)  8.6s(100.0)      __oserror (/usr/lib32/libc.so.1:oserror.c)

   8574   8.6s(100.0)  8.6s(100.0)          TOTAL
```


Ideal Time experiment

For ideal time, speedshop must first "pixify" the executable and DSOs:

```
% ssrun -ideal adi2

Beginning libraries
        /usr/lib32/libssrt.so
        /usr/lib32/libss.so
        /usr/lib32/libfastm.so
        /usr/lib32/libftn.so
        /usr/lib32/libm.so
        /usr/lib32/libc.so.1
Ending libraries, beginning "adi2"
 Time:       8.291 seconds
 Checksum:   5.6160428338E+06
```

Ideal Time experiment (continued)

```
% prof adi2.ideal.4920

  Prof run at: Sat Jan  4 10:34:06 1997
 Command line: prof adi2.ideal.4920


         285898739: Total number of cycles
          1.45867s: Total execution time
         285898739: Total number of instructions executed
             1.000: Ratio of cycles / instruction
               196: Clock rate in MHz
            R10000: Target processor modelled


---------------------------------------------------------
Procedures sorted in descending order of cycles executed.
Unexecuted procedures are not listed. Procedures
beginning with *DF* are dummy functions and represent
init, fini and stub sections.
---------------------------------------------------------

        cycles(%)  cum %     secs    instrns    calls procedure(dso:file)

  68026368(23.79)  23.79     0.35   68026368 32768 xsweep(adi2.pixie:adi2.f)
  68026368(23.79)  47.59     0.35   68026368 32768 ysweep(adi2.pixie:adi2.f)
  68026368(23.79)  71.38     0.35   68026368 32768 zsweep(adi2.pixie:adi2.f)
  35651584(12.47)  83.85     0.18   35651584 2097152 rand_(./libftn.so.pixn32:../../libF77/rand_.c)
  27262976( 9.54)  93.39     0.14   27262976 2097152 irand_(./libftn.so.pixn32:../../libF77/rand_.c)
  18874113( 6.60)  99.99     0.10   18874113     1 fake_adi(adi2.pixie:adi2.f)
     11508( 0.00)  99.99     0.00      11508     5 memset(./libc.so.1.pixn32:/slayer_xlv0/ficussg-nov05/work/irix/lib/libc/libc_n32_
      3101( 0.00)  99.99     0.00       3101    55 __flsbuf(./libc.so.1.pixn32:_flsbuf.c)
```


Operation Counts

```
% prof -op adi2.ideal.4920

  Prof run at: Wed Jan 15 14:42:54 1997
 Command line: prof -op adi2.ideal.4920


         285898739: Total number of cycles
          1.45867s: Total execution time
         285898739: Total number of instructions executed
             1.000: Ratio of cycles / instruction
               196: Clock rate in MHz
            R10000: Target processor modelled


---------------------------------------------------------
pixstats summary
---------------------------------------------------------
          56590456: Floating point operations (38.796 Mflops @ 196 MHz)
         105500230: Integer operations (72.3265 M intops @ 196 MHz)

                              .
                              .
                              .
```


Gprof

```
% prof -gprof adi2.ideal.4920

                                        .
                                        .
                                        .
        All times are in milliseconds.
--------------------------------------------------------------------------------
        NOTE: any functions which are not part of the call
              graph are listed at the end of the gprof listing
--------------------------------------------------------------------------------

                            self          kids       called/total    parents
index       cycles(%)      self(%)       kids(%)    called+self     name     index
                            self          kids       called/total    children

  [1]  285895481(100.00%)    57( 0.00%)  285895424(100.00%)     0       __start [1]
                             50          285895369         1/1          main [2]
                              3                  0         1/1          __istart [112]
                              2                  0         1/1          __readenv_sigfpe [113]

--------------------------------------------------------------------------------

                             50          285895369         1/1          __start [1]
  [2]  285895419(100.00%)    50( 0.00%)  285895369(100.00%)    1       main [2]
                       18874113          267020445         1/1          fake_adi [3]
                            205                606         5/5          signal [44]

--------------------------------------------------------------------------------

                       18874113          267020445         1/1          main [2]
  [3]  285894558(100.00%) 18874113( 6.60%) 267020445(93.40%)   1      fake_adi [3]
                       68026368                  0   32768/32768        zsweep [4]
                       68026368                  0   32768/32768        ysweep [5]
                       68026368                  0   32768/32768        xsweep [6]
                       35651584           27262976 2097152/2097152        rand_ [7]
                             28              13486         2/2          s_wsfe64 [9]
                             26               5368         2/2          e_wsfe [17]
                             22               2610         1/1          do_fioxr4v [25]
                             22               2610         1/1          do_fioxr8v [24]
                             23               2428         1/1          s_stop [28]
                            114                 44         2/2          dtime_ [68]

--------------------------------------------------------------------------------
                                        .
                                        .
                                        .
```


Usertime Experiment

```
% ssrun -usertime adi2

% prof adi2.usertime.19572
-------------------------------------------------------------------------------
Profile listing generated Wed Jan 15 16:57:10 1997
    with:       prof adi2.usertime.19572
-------------------------------------------------------------------------------

        Total Time (secs)      : 9.99
        Total Samples          : 333
        Stack backtrace failed: 0
        Sample interval (ms)   : 30
        CPU                    : R10000
        FPU                    : R10010
        Clock                  : 196.0MHz
        Number of CPUs         : 1


-------------------------------------------------------------------------------

index  %Samples     self descendents  total        name
[1]    100.0%    0.00         9.99     333         __start
[2]    100.0%    0.00         9.99     333         main
[3]    100.0%    0.09         9.90     333         fake_adi
[4]     80.8%    8.07         0.00     269         zsweep
[5]      7.5%    0.75         0.00      25         xsweep
[6]      6.9%    0.69         0.00      23         ysweep
[7]      3.9%    0.12         0.27      13         rand_
[8]      2.7%    0.27         0.00       9         irand_
```

Hardware Counter Profiling

The most commonly used counters are named:

[f]gi_hwc:	graduated instructions
[f]cy_hwc:	cycle counter
[f]ic_hwc:	primary icache misses
[f]isc_hwc:	secondary icache misses
[f]dc_hwc:	primary dcache misses
[f]dsc_hwc:	secondary dcache misses
[f]tlb_hwc:	TLB misses
[f]gfp_hwc:	graduated floating point instructions

Can use any counter as follows:

prof_hwc: get counter from environment variable

```
% setenv _SPEEDSHOP_HWC_COUNTER_NUMBER <cntr>
% setenv _SPEEDSHOP_HWC_COUNTER_OVERFLOW <ovfl>
```


Hardware Counter Profiling (cont'd)

```
% ssrun -tlb_hwc adi2
 Time:       7.887 seconds
 Checksum:   5.6160428338E+06
% prof adi2.tlb_hwc.18520
-------------------------------------------------------------------------------
Profile listing generated Wed Jan 15 19:27:52 1997
    with:       prof adi2.tlb_hwc.18520
-------------------------------------------------------------------------------

        Counter                 : TLB misses
        Counter overflow value: 257
        Total numer of ovfls    : 21181
        CPU                     : R10000
        FPU                     : R10010
        Clock                   : 195.0MHz
        Number of CPUs          : 1


-------------------------------------------------------------------------------
  -p[rocedures] using counter overflow.
  Sorted in descending order by the number of overflows in each procedure.
  Unexecuted procedures are excluded.
-------------------------------------------------------------------------------

  overflows(%)  cum overflows(%)      procedure (dso:file)

  21169( 99.9)      21169( 99.9)         zsweep (adi2:adi2.f)
      4(  0.0)      21173(100.0)         ysweep (adi2:adi2.f)
      4(  0.0)      21177(100.0)         xsweep (adi2:adi2.f)
      4(  0.0)      21181(100.0)       fake_adi (adi2:adi2.f)

  21181(100.0)                         TOTAL
```


Floating Point Exceptions

Trace with SpeedShop's –fpe experiment

Excessive underflows can cause large system time

Use libfpe to flush them to zero

```
% ld -o program ... -lfpe
% setenv TRAP_FPE "UNDERFL=ZERO"
% program ...
```

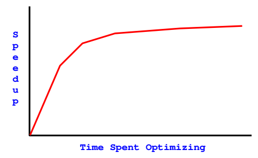
```
#include <sys/fpu.h>

void
flush_to_zero(int on_off)
{
union fpc_csr   n;

     n.fc_word = get_fpc_csr();
     if ( on_off == 0 ) {
          n.fc_struct.flush = 0;
     } else {
          n.fc_struct.flush = 1;
     }
     set_fpc_csr(n.fc_word);
}
```

See handle_sigfpes(3C)

Profiling

Optimization Methodology

- **Optimize one loop/routine at a time**
- **Start with the most time consuming routines**
- **Then the second most ...**
- **Then the third most ...**
- **Parallelize your program**



Performance Boosters

Feedback Compilation

Provides run–time execution frequencies for better compiler optimization decisions

1. Compile the program –O0
2. "Pixify" the program: `pixie foo`
3. Run the `.pixie` executable using "representative" input data

`.Counts` file will be produced
rename `.Counts` file before each run
2 & 3 can be replaced by `ssrun -ideal`

Feedback Compilation (continued)

4. Run prof with –feedback –pixie:

```
% prof -feedback -pixie foo foo.1.counts {foo.2.counts, ...}
```

produces .fb file for cord
.cfb file for feedback compilation

5. Recompile the program:

```
% cc|f77 -c -fb foo.cfb + optimization flags
```

Notes:

The.cfb file can be reused if the source is not changed

Non–representative input data can mislead the compiler

Benefits of Feedback Compilation

Better decisions on:

- *Inlining*
- *Register allocation*
- *Unrolling and software pipelining*
- *If–conversion*
- *Loop–invariant code motion*
  (not moved out of loop if executed less than n% of iterations, where n is set by the following compiler option: `–WOPT:aggcm_thresh=n` [default 70])

The Cord Utility

- **Reduces instruction cache misses and virtual paging**
- **Works by rearranging order of procedures in executable or library**

  Procedures invoked together are located near each other

- **How to use it:**

```
% cord foo.exe foo.fb {foo.2.fb, ...}
```

One can use multiple files to provide temporal proximity information to cord, e.g., in a phase–structured program, one .fb file for each phase