Performance Analysis and Tuning of Parallel Programs: Resources and Tools

PART1 - Introduction and Overview

Michael Gerndt (Forschungszentrum Jülich)

PART2 - Resources and Tools

Bernd Mohr (Forschungszentrum Jülich)

PART3 - Automatic Performance Analysis with Paradyn

Barton Miller (University of Wisconsin-Madison)
Brian Wylie (University of Wisconsin-Madison)

UNIVERSITY OF WISCONSIN MADISON

Contents

- Part 1 - Introduction and Overview
  - Parallel Systems
  - Programming Models
  - Common Performance Problems
  - Performance Measurement and Analysis Techniques
- Part 2 - Resources and Tools
  - Cray T3E, IBM SP2, SGI O2K Tools
  - 3rd Party Tools
  - Research Tools
  - Fall-back Tools
- Part 3 - Automatic Performance Analysis with Paradyn
  - Sample Analysis Session with Paradyn
  - Paradyn technologies and Architecture
  - On-going Research and Developments

Optimization Goals

- Execution Time
  - Get the answer as fast as possible.
- Throughput
  - Get as many happy users as possible.
- Utilization
  - Get the best exploitation of the invested money.

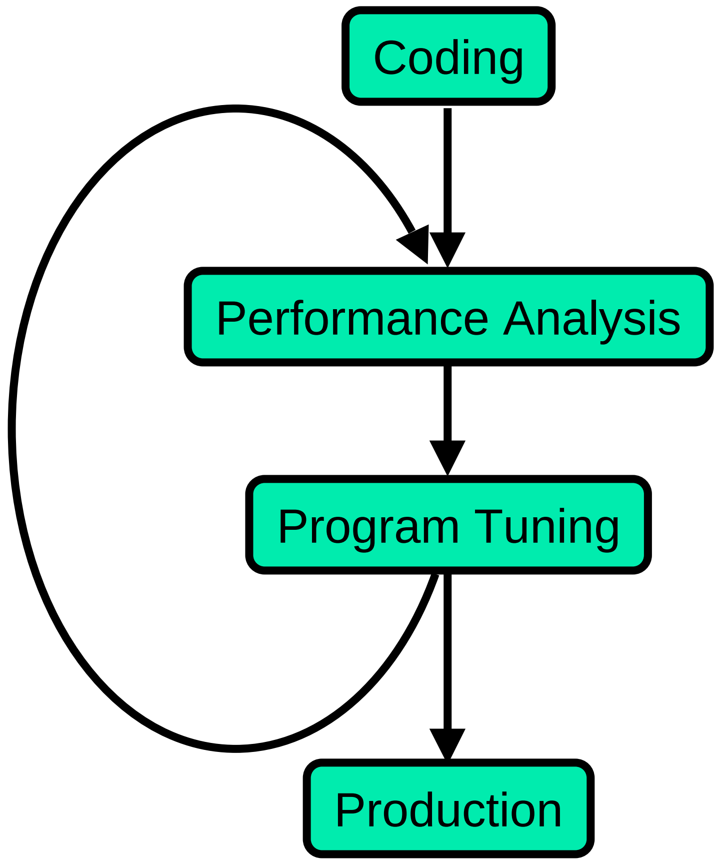
Performance of Application or Computer System

"How well is the goal achieved"

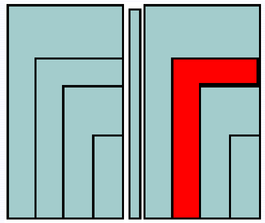
- Performance Analysis and Tuning is based on
  - measurements of performance data
  - evaluation of performance data
  - code or policy changes based on analysis results

Scenario: Parallel Computing

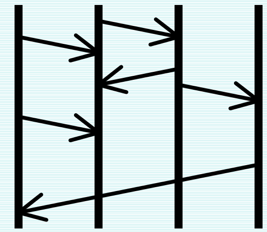
- Optimization goal: minimal execution time



Parallel Systems and Programming Models

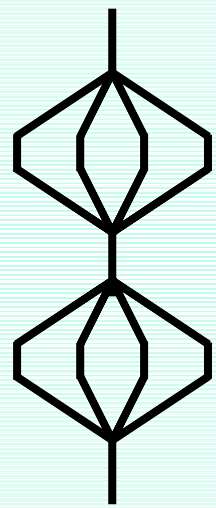


Cray T3E

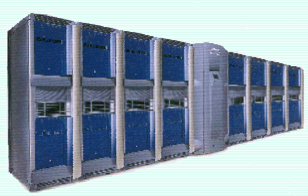


Message Passing

IBM SP2



Shared Memory



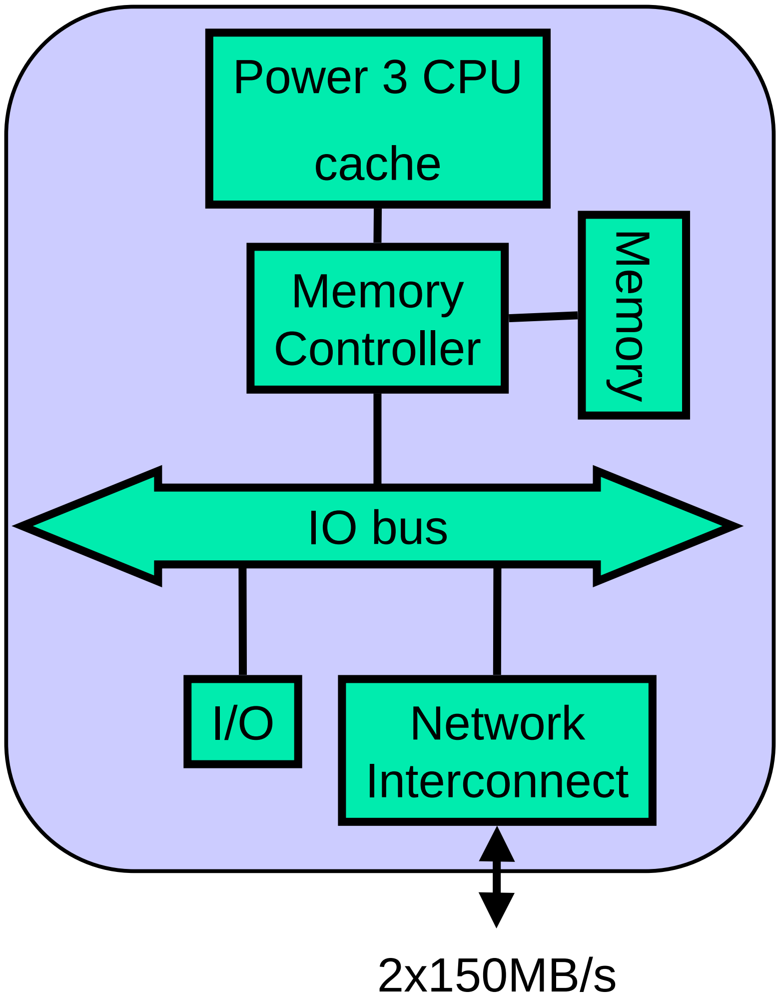
SGI Origin 2000

Contents

- Part 1 - Introduction and Overview
  - Parallel Systems
  - Programming Models
  - Common Performance Problems
  - Performance Measurement and Analysis Techniques
- Part 2 - Resources and Tools
  - Cray T3E, IBM SP2, SGI O2K Tools
  - 3rd Party Tools
  - Research Tools
  - Fall-back Tools
- Part 3 - Automatic Performance Analysis with Paradyn
  - Sample Analysis Session with Paradyn
  - Paradyn technologies and Architecture
  - On-going Research and Developments

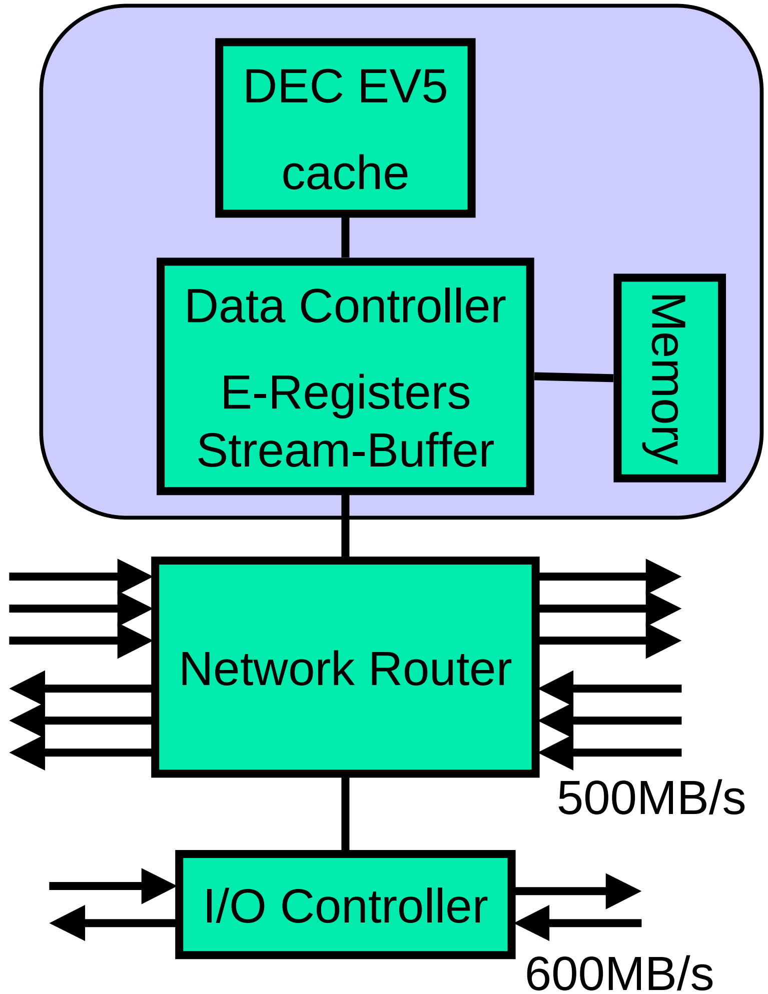
IBM SP2

- message passing system
- cluster of workstations
- 200 MHz Power 3 CPU
    - Peak 800 MFLOPS
    - 4-16 MB 2nd-level cache
    - sustained memory bandwidth 1.6 GB/s
- multistage crossbar switch
- MPI
    - latency 21.7 μsec
    - bandwidth 139 MB/s
- I/O hardware distributed among the nodes



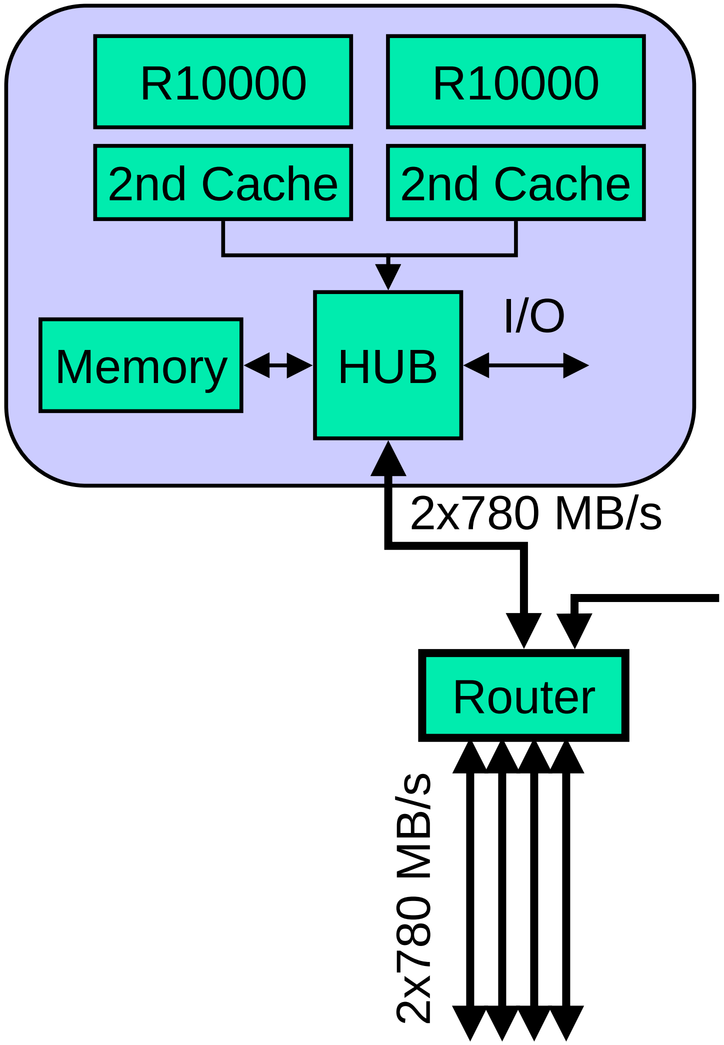
Cray T3E

- remote memory access system
- single system image
- 600 MHz DEC Alpha
  - peak performance 1200 MFLOPS
  - 2nd-level data cache 96 KB
  - memory bandwidth 600 MB/s
- 3D torus network
- MPI
  - latency 37 µsec
  - bandwidth 300 MB/s
- shmem
  - latency 4 µsec
  - bandwidth 400 MB/s
- SCI-based I/O network



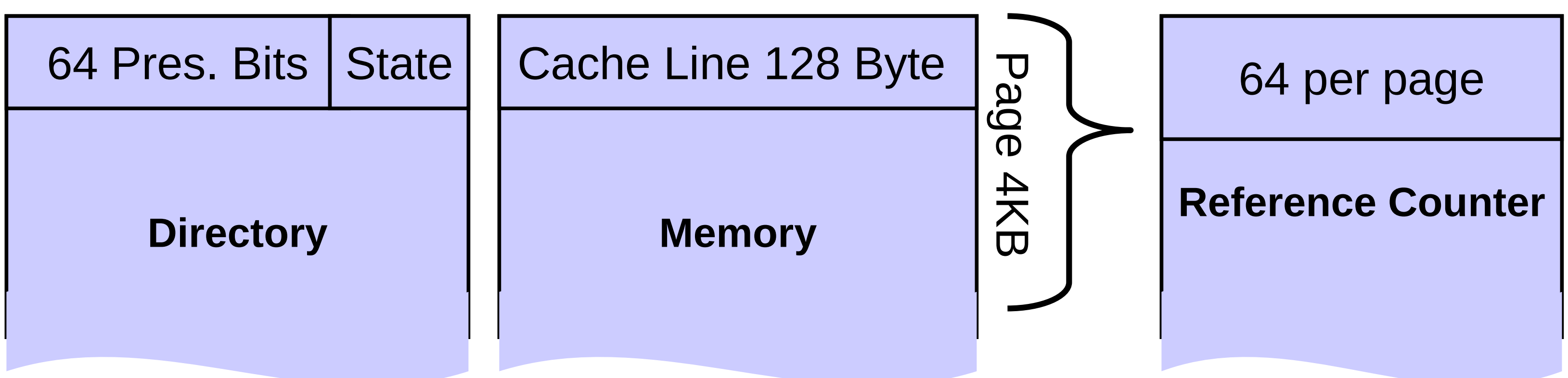
SGI Origin 2000

- cc-NUMA system
- single system image
- 250 MHz MIPS R10000
  - peak performance 500 MFLOPS
  - 2nd-level data cache 4-8 MB
  - memory bandwidth 670 MB/s
- 4D hypercube
- MPI
  - latency 16 μsec
  - bandwidth 100 MB/s
- remote memory access
  - latency 497 nsec
  - bandwidth 600 MB/s
- I/O hardware distributed among nodes but global resource

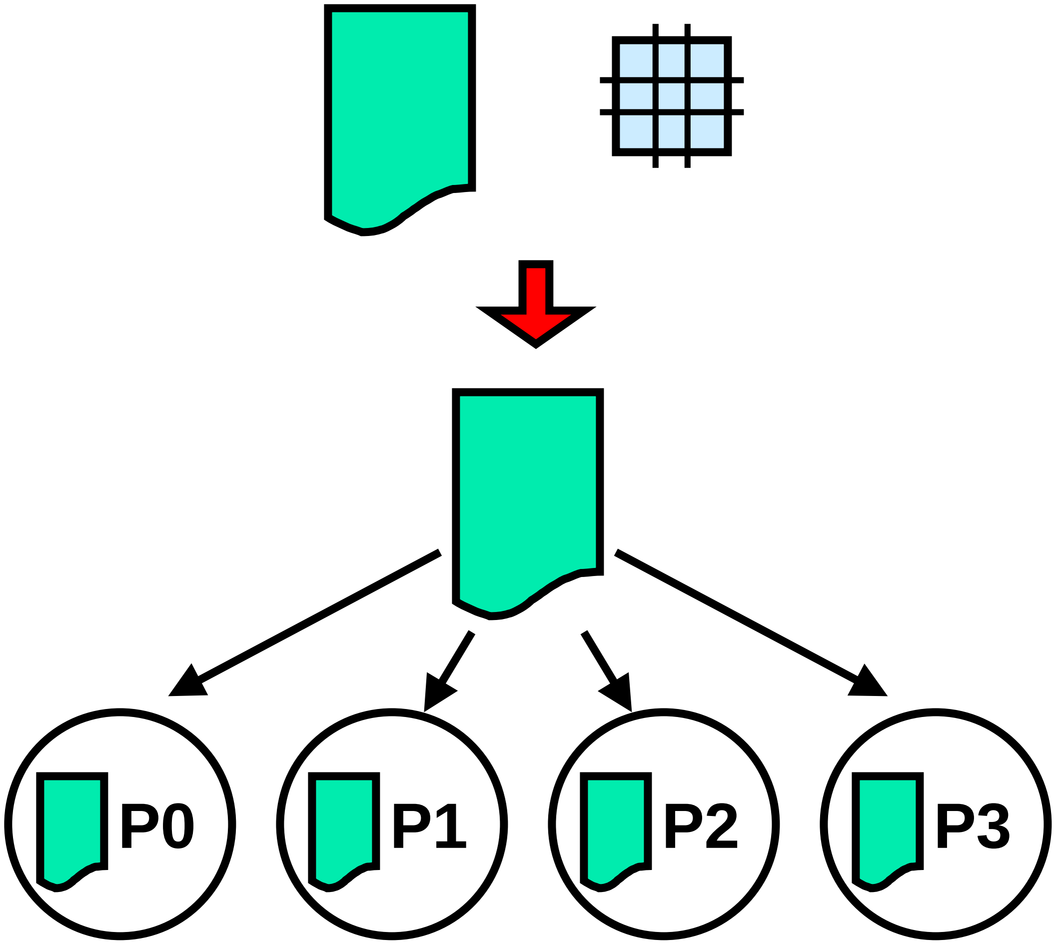


ccNUMA Implementation on SGI Origin 2000

- Access to remote data
  - read or write copy is transferred into the cache
  - coherence of copies and home location is maintained through directory
  - allocation of pages to node memories is by first touch
  - migration is possible based on reference counters



Single Program Multiple Data (SPMD)



sequential program
+ domain decomposition

node program
+ message passing

program replicated

MPI (Message Passing Interface)

- MPI is the standard programming interface
    - MPI 1.0 in 1994
    - MPI 2.0 in 1997
- Library interface (Fortran, C, C++)
- It includes
    - point-to-point communication
    - collective communication
    - barrier synchronization
    - one-sided communication (MPI 2.0)
    - parallel I/O (MPI 2.0)
    - process creation (MPI 2.0)

MPI Example

Node 0

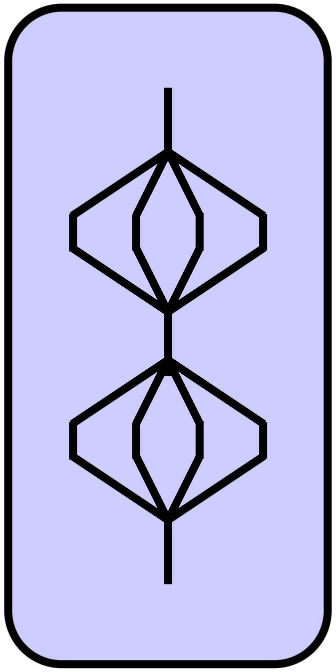
```
//local computation
for(i=0;i<10;i++) a(i)= f(i);

MPI_send(a(1), 10, MPI_INT, Node1, 20, comm)

//reduction
for (i=0;i<10;i++) s=s+a(i);
MPI_reduce(s, s1, 1, MPI_INT, SUM, Node1, comm)
```

Node 1

```
...

MPI_recv(b(1), 10, MPI_INT, Node1, 20, comm, status)

...
MPI_reduce(s, s1, 1, MPI_INT, SUM, Node1,comm)

printf(“Global sum: %d“,s1)
```

OpenMP: Directive-based SM Parallelization

- OpenMP is a standard shared memory programming interface (1997)
- Directives for Fortran 77 and C/C++
- Fork-join model resulting in a global program
- It includes:
  - Parallel loops
  - Parallel sections
  - Parallel regions
  - Shared and private data
  - Synchronization primitives
    - barrier
    - critical region



OpenMP: Example

```
!$OMP parallel do schedule(static, 10)
      do i=1,100
        a(i)=f(i)
      enddo
!$OMP end parallel do

!$OMP parallel do reduction(+:a),
!$OMP*            schedule(dynamic,10)
      do i=1,100
        s=s+a(i)
      enddo
!$OMP end parallel do

      write(*,*) 'Global sum:', s
```


Common Performance Problems with MPI

- Single node performance
  - Excessive number of 2^{nd}-level cache misses
  - Low number of issued instructions
- IO
  - High data volume
  - Sequential IO due to IO subsystem or sequentialization in the program
- Excessive communication
  - Frequent communication
  - High data volume

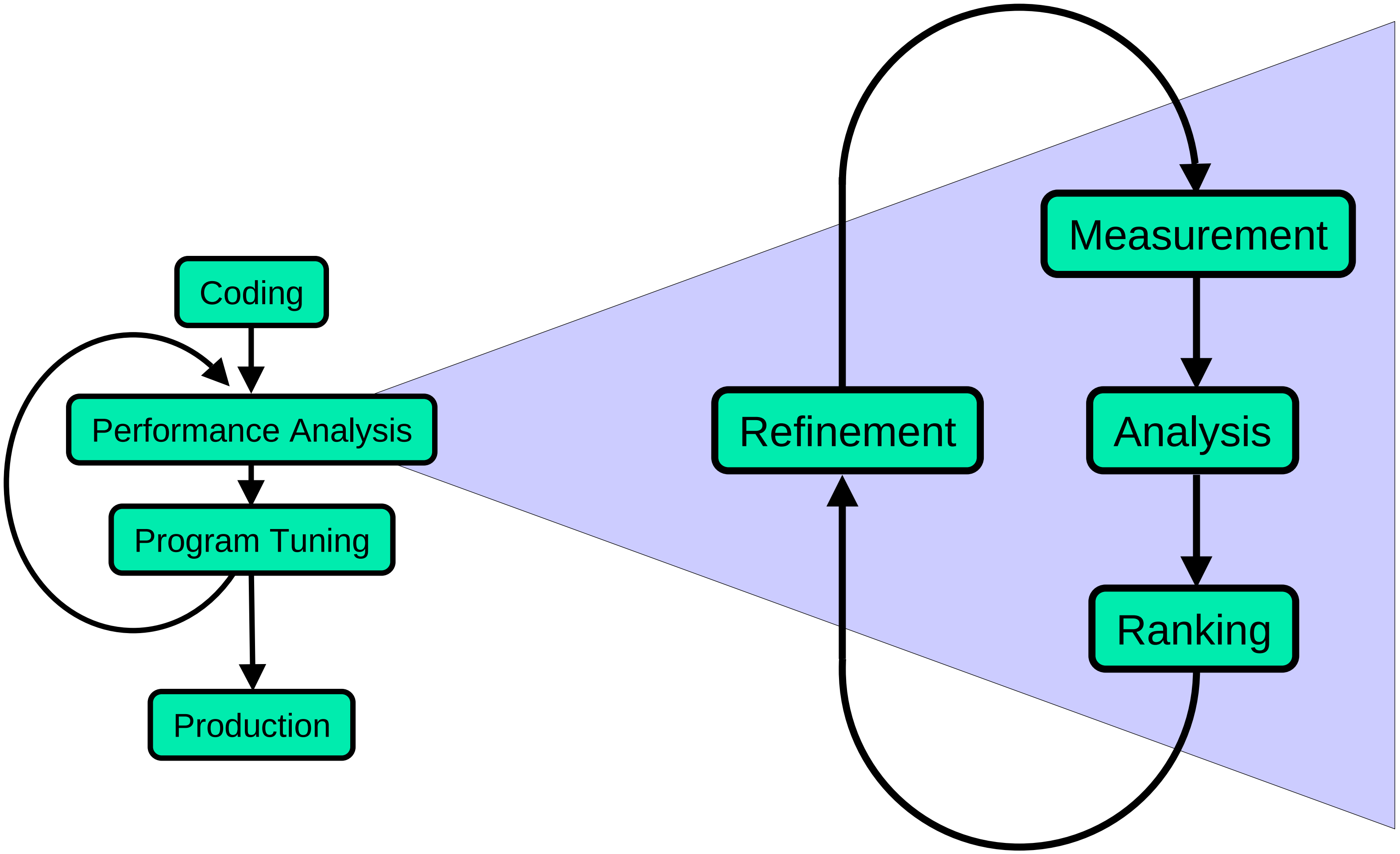
Common Performance Problems with MPI

- Frequent synchronization
  - Reduction operations
  - Barrier operations
- Load balancing
  - Wrong data decomposition
  - Dynamically changing load

Common Performance Problems with SM

- Single node performance
  - ...
- IO
  - ...
- Excessive communication
  - Large number of remote memory accesses
  - False sharing
  - False data mapping
- Frequent synchronization
  - Implicit synchronization of parallel constructs
  - Barriers, locks, ...
- Load balancing
  - Uneven scheduling of parallel loops
  - Uneven work in parallel sections

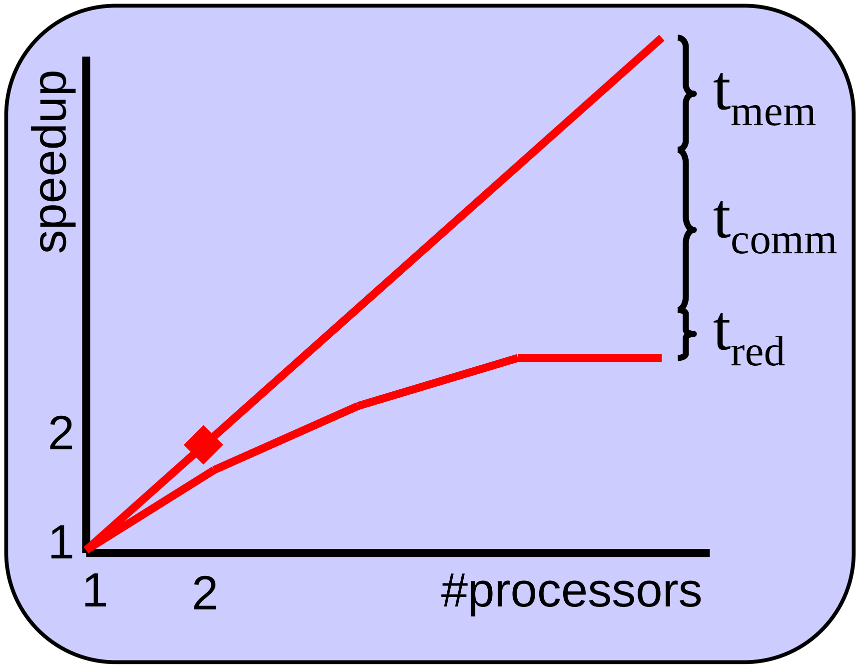
Performance Analysis Process



Overhead Analysis

- How to decide whether a code performs well:
  - Comparison of measured MFLOPS with peak performance
  - Comparison with a sequential version

$$\text{speedup}(p) = \frac{t_s}{t_p}$$



- Estimate distance to ideal time via overhead classes
  - t_{mem}
  - t_{comm}
  - t_{sync}
  - t_{red}
  - ...

Other Performance Metrics

- Scaled speedup: Problem size grows with machine size

$$\text{scaled\_speedup}(p) = \frac{t_s(n_p)}{t_p(n_p)}$$

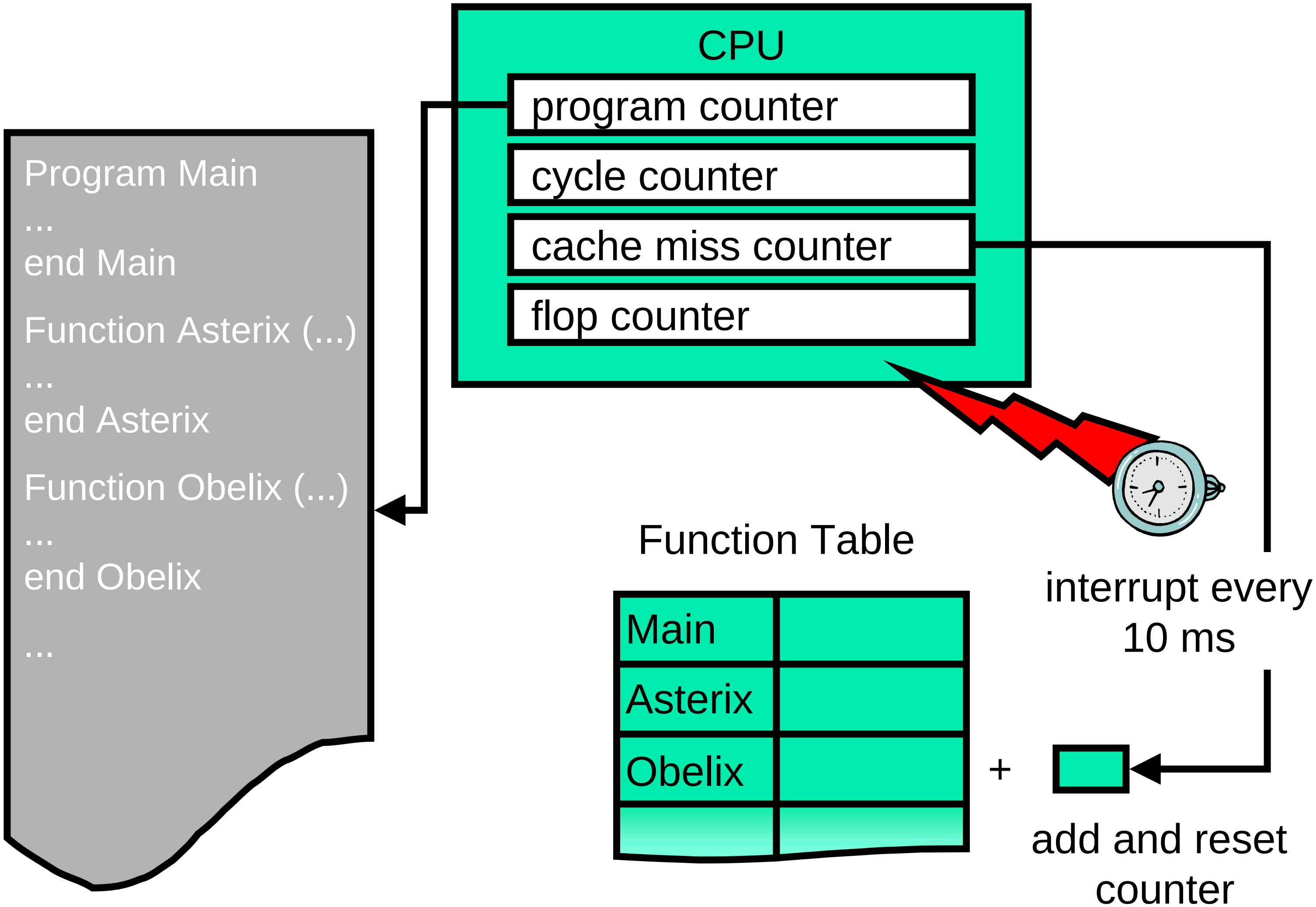
Parallel efficiency: Percentage of ideal speedup

$$\text{efficiency}(p) = \text{speedup}(p) / p = \frac{t_s}{t_p * p}$$

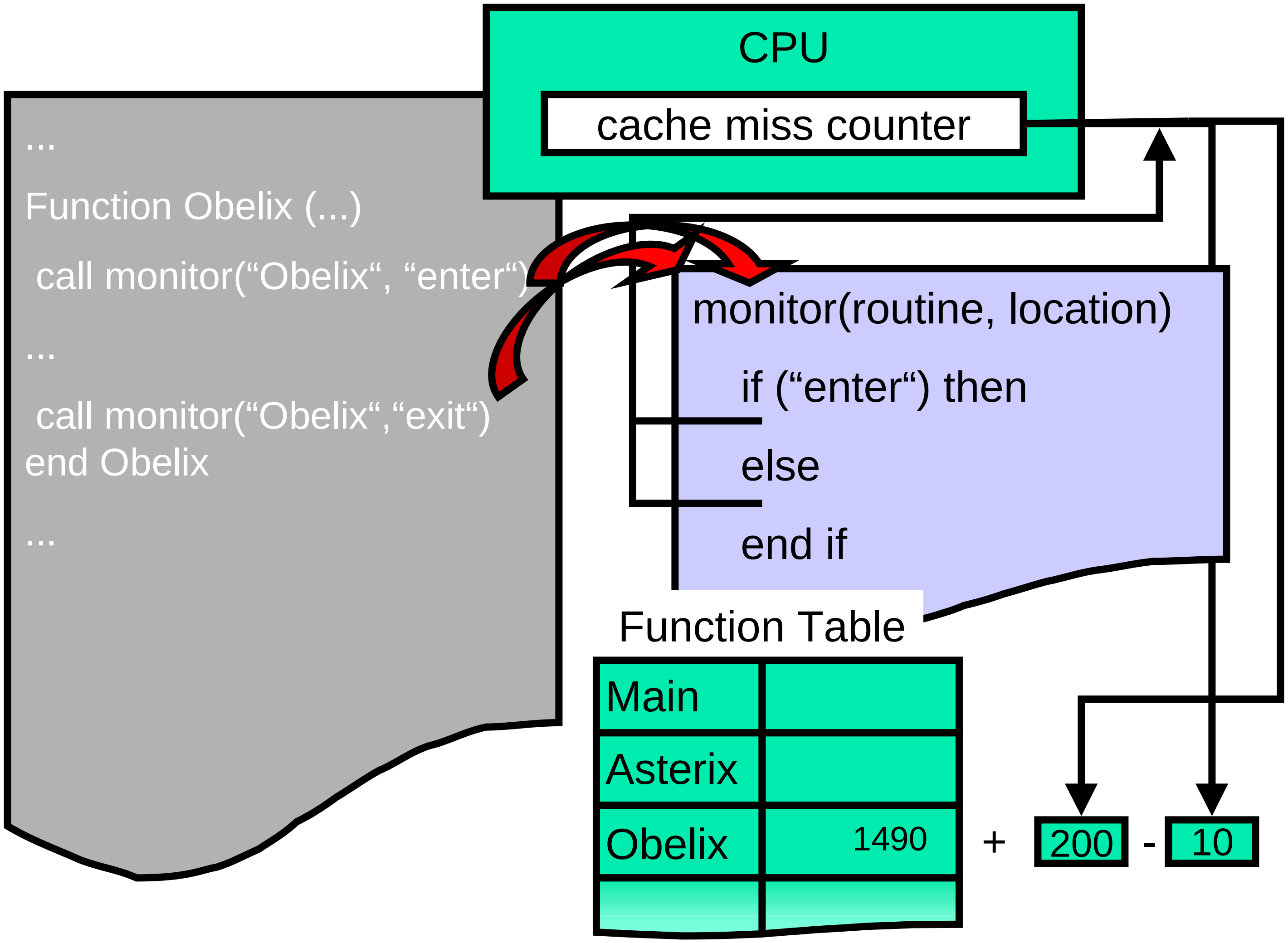
Performance Measurement Techniques

- Event model of the execution
  - Events occur at a processor at a specific point in time
  - Events belong to event types
    - clock cycles
    - cache misses
    - remote references
    - start of a send operation
    - ...
- Profiling: Recording accumulated performance data for events
  - Sampling: Statistical approach
  - Instrumentation: Precise measurement
- Tracing: Recording performance data of individual events

Sampling


CPU
program counter
cycle counter
cache miss counter
flop counter
Program Main
...
end Main
Function Asterix (...)
...
end Asterix
Function Obelix (...)
...
end Obelix
...
Function Table
Main
Asterix
Obelix
+
interrupt every
10 ms
add and reset
counter

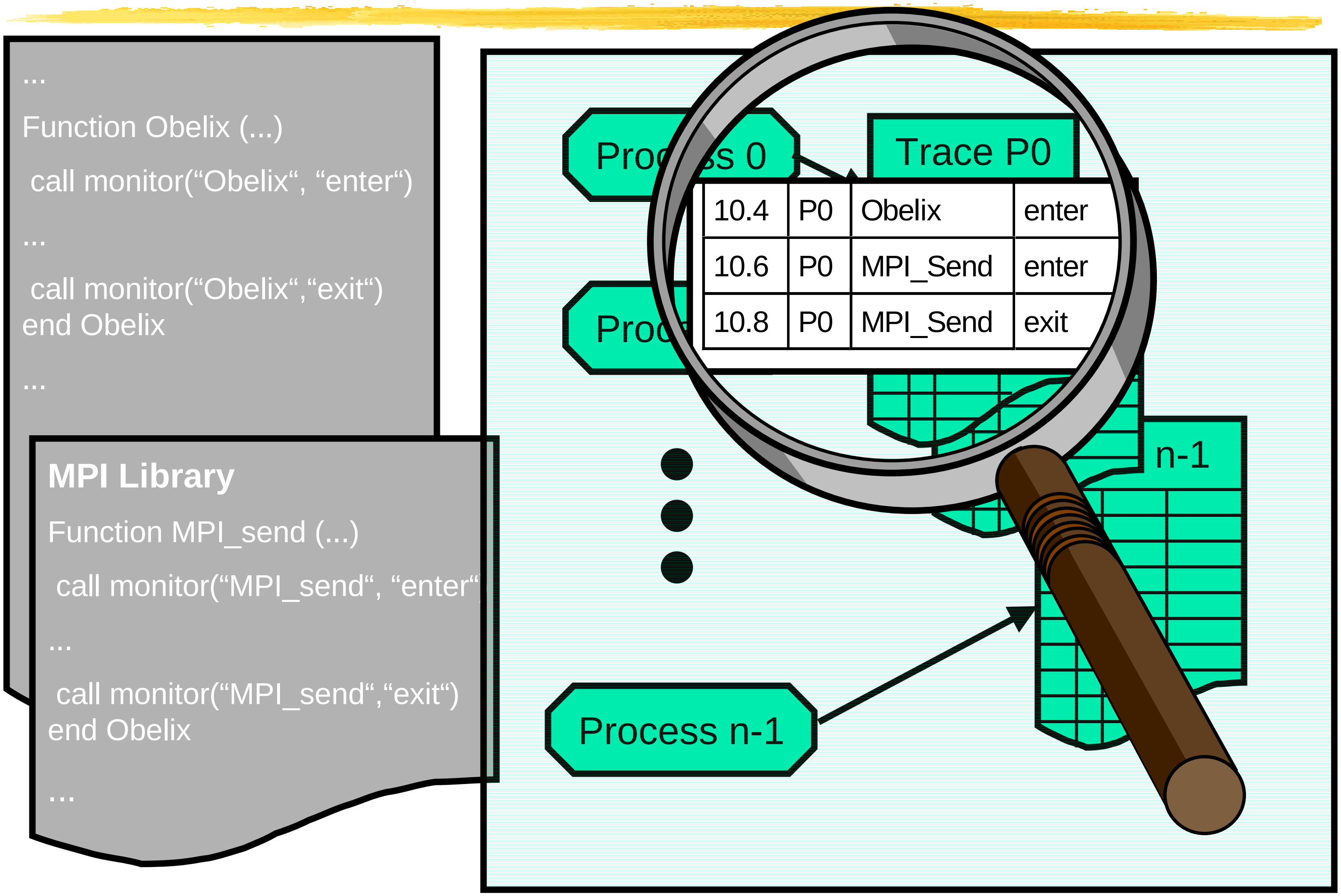
Instrumentation and Monitoring



Instrumentation Techniques

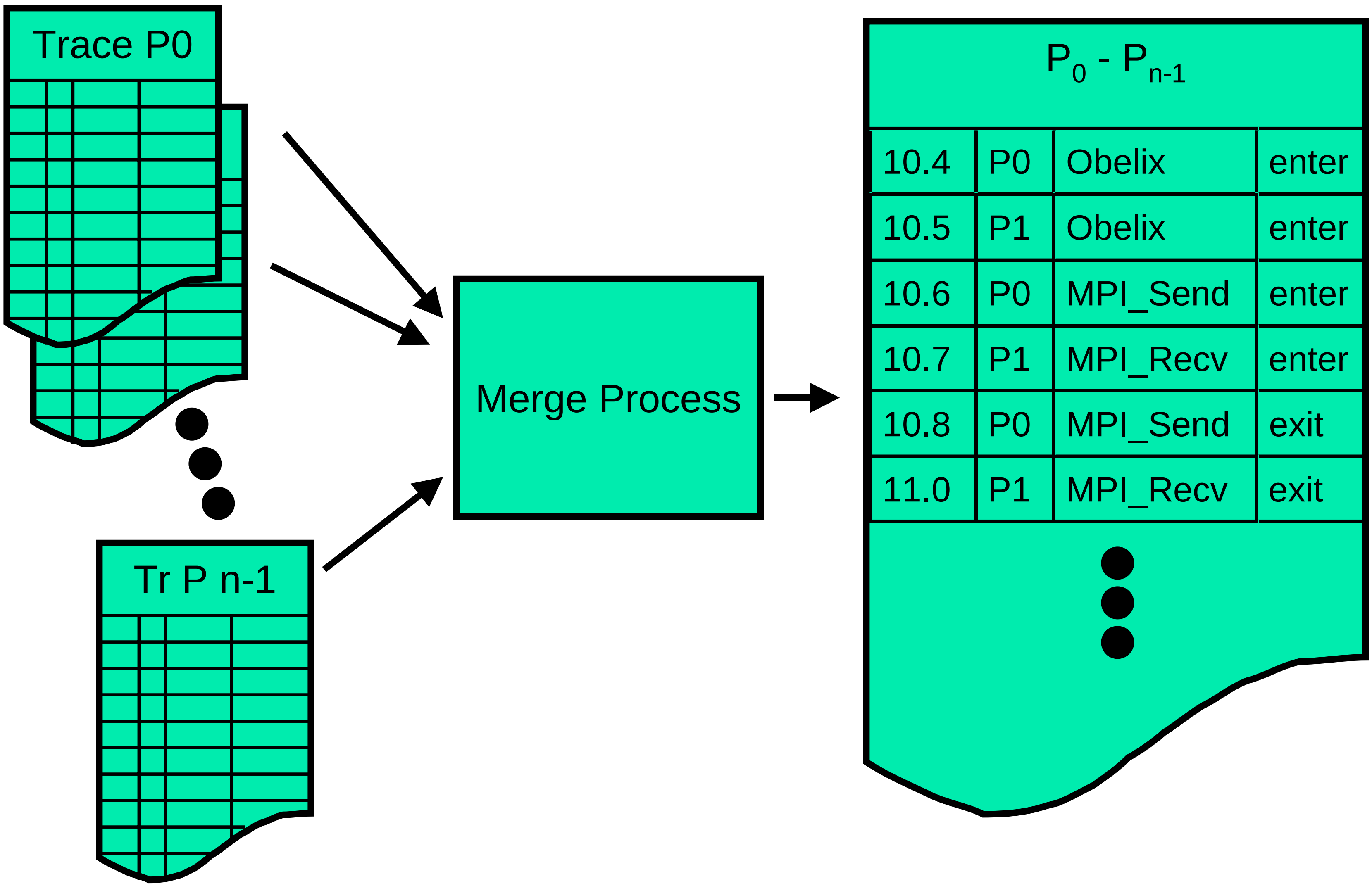
- Source code instrumentation
  - done by the compiler, source-to-source tool, or manually
    - \+ portability
    - \+ link back to source code easy
    - – re-compile necessary when instrumentation is changed
    - – difficult to instrument mixed-code applications
    - – cannot instrument system or 3rd party libraries or executables
- Object code instrumentation
  - "patching" the executable to insert hooks (like a debugger)
    - – inverse pros/cons
  - Offline
  - Online

Tracing



...
Function Obelix (...)
call monitor("Obelix", "enter")
...
call monitor("Obelix","exit")
end Obelix
...
MPI Library
Function MPI_send (...)
call monitor("MPI_send", "enter"
...
call monitor("MPI_send","exit")
end Obelix
...
Process 0
Proc
Trace P0
10.4 | P0 | Obelix | enter
10.6 | P0 | MPI_Send | enter
10.8 | P0 | MPI_Send | exit
n-1
Process n-1

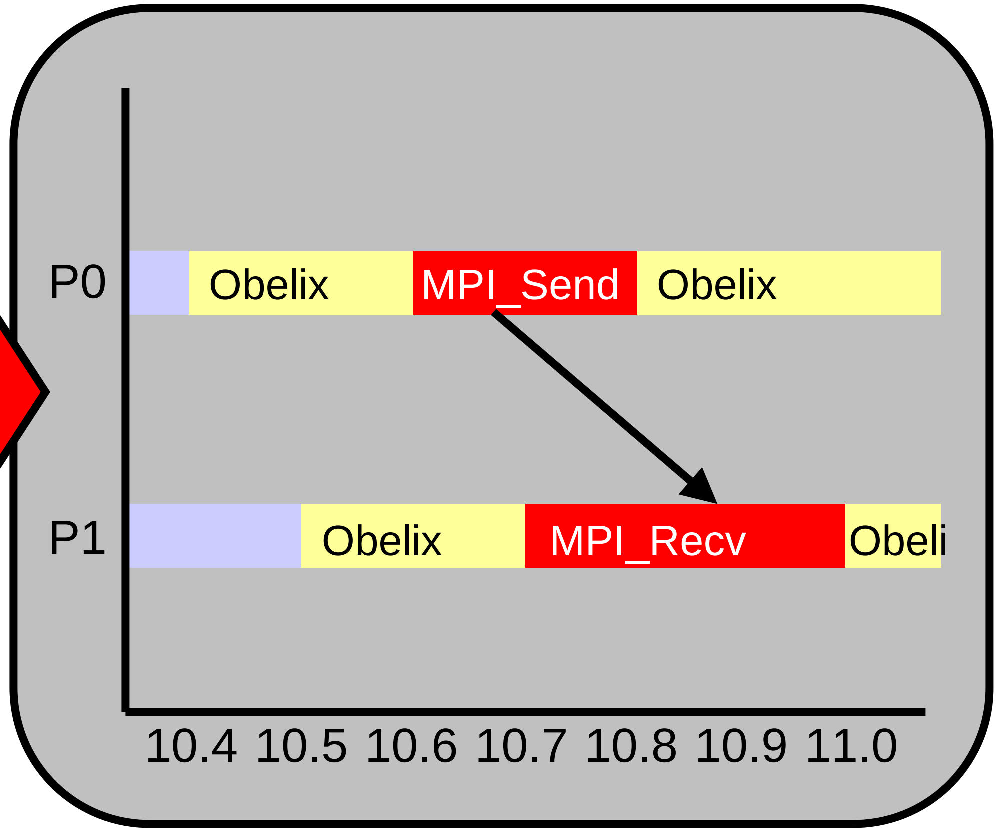
Merging


Trace P0
Tr P n-1
Merge Process
P_0 - P_{n-1}
10.4 P0 Obelix enter
10.5 P1 Obelix enter
10.6 P0 MPI_Send enter
10.7 P1 MPI_Recv enter
10.8 P0 MPI_Send exit
11.0 P1 MPI_Recv exit

Visualization of Dynamic Behaviour

P_0 - P_{n-1}			
10.4	P0	Obelix	enter
10.5	P1	Obelix	enter
10.6	P0	MPI_Send	enter
10.7	P1	MPI_Recv	e
10.8	P0	MPI_Send	exit
11.0	P1	MPI_Recv	exit

●
●
●

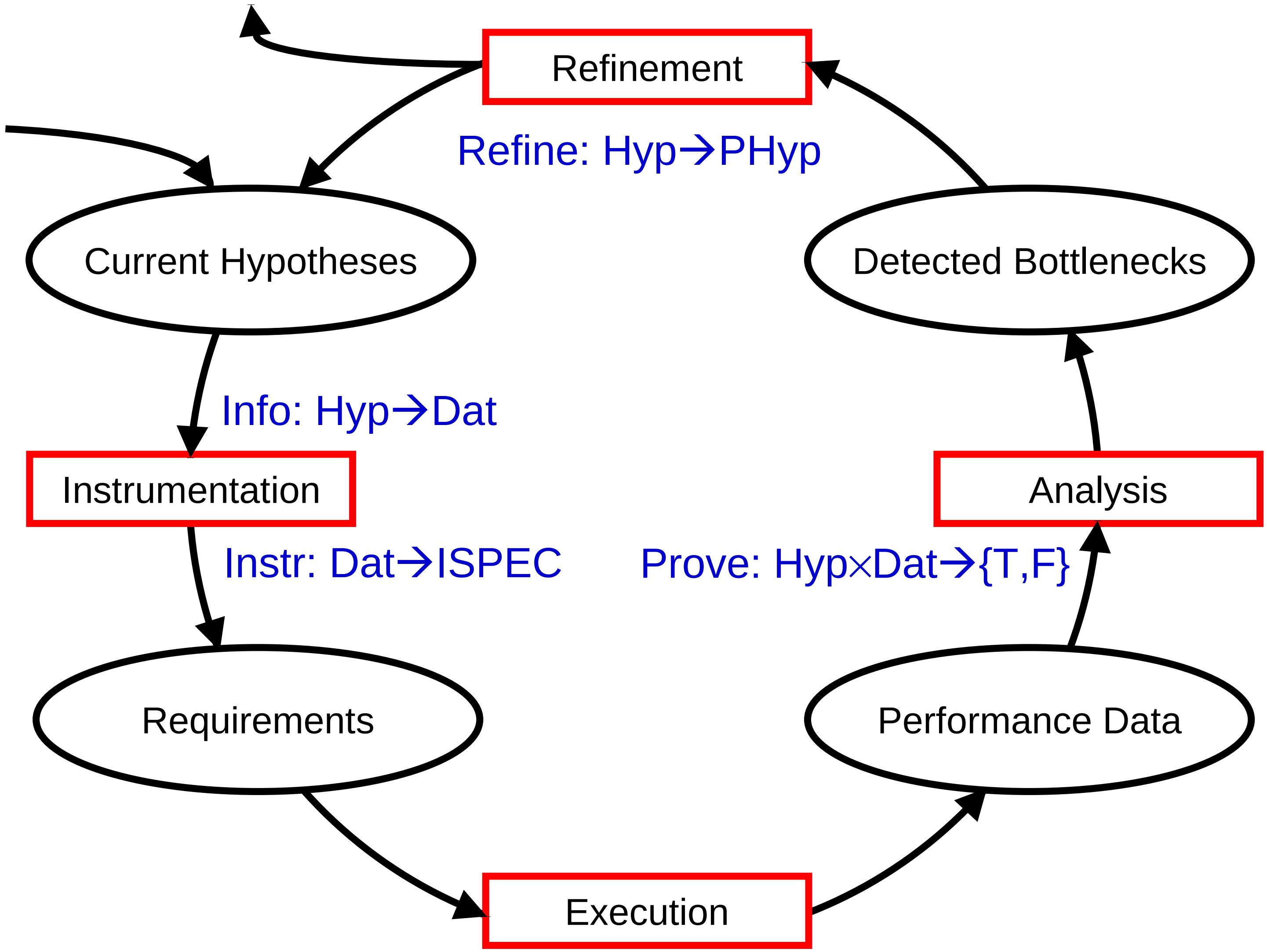


Timeline Visualization

Profiling vs Tracing

- Profiling
  - recording summary information (time, #calls, #misses...)
  - about program entities (functions, objects, basic blocks)
  - very good for quick, low cost overview
  - points out potential bottlenecks
  - implemented through sampling or instrumentation
  - moderate amount of performance data
- Tracing
  - recording information about events
  - trace record typically consists of timestamp, processid, ...
  - output is a trace file with trace records sorted by time
  - can be used to reconstruct the dynamic behavior
  - creates huge amounts of data
  - needs selective instrumentation

Performance Analysis



Performance Prediction and Benchmarking

- Performance analysis determines the performance on a given machine.
- Performance prediction allows to evaluate programs for a hypothetical machine. It is based on:
  - runtime data of an actual execution
  - machine model of the target machine
  - analytical techniques
  - simulation techniques
- Benchmarking determines the performance of a computer system on the basis of a set of typical applications.

Performance Analysis and Tuning of Parallel Programs: Resources and Tools

PART1 - Introduction and Overview

Michael Gerndt (Forschungszentrum Jülich)

PART2 - Resources and Tools

Bernd Mohr (Forschungszentrum Jülich)

PART3 - Automatic Performance Analysis with Paradyn

Barton Miller (University of Wisconsin-Madison)

Brian Wylie (University of Wisconsin-Madison)

UNIVERSITY OF WISCONSIN MADISON

Contents

- Practical Performance Analysis and Tuning
- Debugging
  - Totalview
- CRAY T3E Tools
  - Apprentice
  - PAT
- IBM SP2 Tools
  - Xprofiler
  - VT
  - Future Tools
- SGI O2K Tools
  - Perfex
  - SpeedShop
  - cvperf
- 3rd Party Tools
  - Vampir
  - Vampirtrace
  - Dimemas
  - GuideView
- Research Tools
  - Nupshot / Jumpshot
  - MPICL / Paragraph
  - TAU Profiling
  - AIMS
  - Other
- Fall-back Tools
  - Timer
  - HW Counter

Practical Performance Analysis and Tuning

- Peak and benchmark (Linpack, NAS) performance has nothing to do with 'real' performance
  - ⇒ The performance of your program is important
- 50% of 1 Gflop is better than 20% of 2GFlop
  - ⇒ the sustained fraction of peak performance is crucial
- Tuning is combination of
  - right algorithm and libraries
  - compiler flags and pragmas / directives
  - THINKING
- Measurement is better than reasoning / intuition (= guessing)
- It is easier to optimize a slow correct program

  than to debug a fast incorrect one
  - ⇒ Debugging before Tuning

Practical Performance Analysis and Tuning

- Don't optimize what doesn't matter

- Strategies for Speed
  - Use a better algorithm or data structure
  - Use optimized libraries (BLAS, Cray's libsci, IBM ESSL, ...)
  - Enable compiler optimizations (through options and pragmas)
  - Tune the code
    - Collect common subexpressions
    - Replace expensive operations by cheap ones
    - Write a special-purpose allocator
    - Unroll or eliminate loops
    - Cache frequently used values
    - Buffer input and output
    - Use approximate values

- Space Efficiency
  - Save space by using the smallest possible data type
  - Don't store what you can easily re-compute

Practical Performance Analysis and Tuning

- Typical Procedure
  - Do I have a performance problem at all?
    - time / HW counter measurements
    - speedup and scalability measurements
  - What is the main bottleneck (calculation / communication / synchronization) ?
    - flat profiling (sampling / prof)
  - Where is the main bottleneck?
    - call graph profiling (gprof)
    - detailed (basic block) profiling
  - Where is the bottleneck exactly and why is it there?
    - tracing of selected parts to keep trace files manageable
      - typically by using control functions to switch tracing on/off
      - select important parts only
      - for iterative programs: trace some iterations only
    - sometimes, trace file size can be limited

Debugging: Totalview

- Commercial product of ETNUS Inc.
- UNIX Symbolic Debugger
  for C, C++, f77, f90, PGI HPF, assembler programs
- „Quasi" standard for debugger
- Selected as DOE "ASCI debugger"
- Special, non-traditional features
  - Multi-process and multi-threaded
  - C++ support (templates, inheritance, inline functions)
  - F90 support (user types, pointers, modules)
  - 1D + 2D Array Data visualization
  - parallel debugging
    - MPI (automatic attach, message queues)
    - HPF (HPF source level, distributed array access, distribution display)
  - support for OpenMP on IRIX and Tru64 UNIX (version 3.9)
  - support for IRIX 6.5 pthreads (version 3.9)

Totalview: Availability

- Supported platforms
  - IBM RS/6000 and SP2
  - SGI workstations and O2K
  - Compaq Alpha workstations and Clusters
  - Sun Solaris Sparc + x86, Sun SunOS
- Also available from vendor or 3rd party for
  - Cray
  - Fujitsu VPP
  - QSW CS2,
    NEC SX4 + Cenju
  - Hitachi SR22xx
- Plans for HP, Linux, NT

- `http://www.etnus.com/products/totalview/`

CRAY T3E: Performance Tools

- time / HW counter measurements
  - Performance Analysis Tool (PAT)
- flat profiling (sampling)
  - PAT
- call graph profiling
  - PAT
- detailed (basic block) profiling
  - Apprentice
- tracing
  - PAT / [Vampir]

PAT

- Features
  - Profiling: execution time profile for functions (sampling)
  - Call Site Reporting: call graph profiling (number of calls, execution time) of selected functions
  - HW Counter Measurement: e.g. Number of FLOPS
  - [Object-code instrumentation for tracing with Vampir]
- Advantages (especially compared to Apprentice)
  - simple, low overhead => for quick overview!
  - Does not need re-compilation, only re-linking
  - can analyze system and 3rd party libraries
- Disadvantages
  - can only analyze program as a whole
  - no GUI

PAT: Usage

- Prepare user application by linking with PAT library (`-lpat`) and PAT linker command file (`pat.cld`)

```
t3e% f90 *.o -o myprog -lpat pat.cld          # Fortran
t3e% cc *.o -o myprog -lpat pat.cld           # ANSI C
t3e% CC *.o -o myprog -lpat pat.cld           # C++
```

- If necessary, select T3E HW performance counter through environment variable $PAT_SEL

```
t3e% export PAT_SEL=FPOPS      # floating-point (default)
t3e% export PAT_SEL=INTOPS     # integer instructions
t3e% export PAT_SEL=LOADS      # load instructions
t3e% export PAT_SEL=STORES     # store instructions
```

- If necessary, change sampling rate (default 10000)

```
t3e% export PAT_SAMPLING_RATE=1000
```

[Value is in microseconds]

PAT: Performance Overview

- Execute application as usual (creates file: `myprog.pif`)

  t3e% `mpprun -n ## myprog -`*`myoptions myargs`*

  Start PAT

  t3e% `pat -L myprog myprog.pif`

- Execution time overview

```
=> time
 Elapsed Time             1.129 sec   16 PEs
 User    Time (ave)       2.090 sec   98%
 System  Time (ave)       0.027 sec    1%
```

- HW performance counter report

```
=> perfcntr
 Performance counters for FpOps (Values in MILLIONS)
 PE  cycles operations  ops/sec  dmisses  misses/sec
  0  104.16     19.33     83.52     5.17      22.32
  1  194.00     20.19     46.84     7.01      16.27
  2  193.39     20.19     46.99     7.01      16.32
     ...
```

PAT: Profiling

- Function profiling report (sampling report):

```
=> profile
                          Percent    90% Conf. Interval
 VELO                        52%          1.4
 _shmem_long_wait             7%          0.7
 CURR                         6%          0.7
 barrier                      5%          0.6
 MPI_RECV                     5%          0.6
 TEMP                         3%          0.5
 ...
```

- Instrument for "Call Site Reporting"

```
=> instcall VELO
=> quit
```

generates "new a.out"

- Execute again:

t3e% mpprun -n ## a.out -*myoptions myargs*

PAT: Profiling

- Execute PAT again for "Call Site" report:

```
t3e% pat -L a.out a.out.pif
 Interactive mode. Valid commands:
 csi hist instcall perfcntr profile quit time ...

 => csi
 Name   PE   called from   #calls   total time avg./call
 VELO:
        PE:0
                 CX3D         4      165.1102    41.2775
        PE:1
                 CX3D         4      166.7334    41.6834
        PE:2
                 CX3D         4      166.6664    41.6666
        PE:3
                 CX3D         4      165.3808    41.3452
        ...
```

Apprentice

- Tool for detailed profiling on basic block level
- Usage
  - Instrumentation by Cray compiler

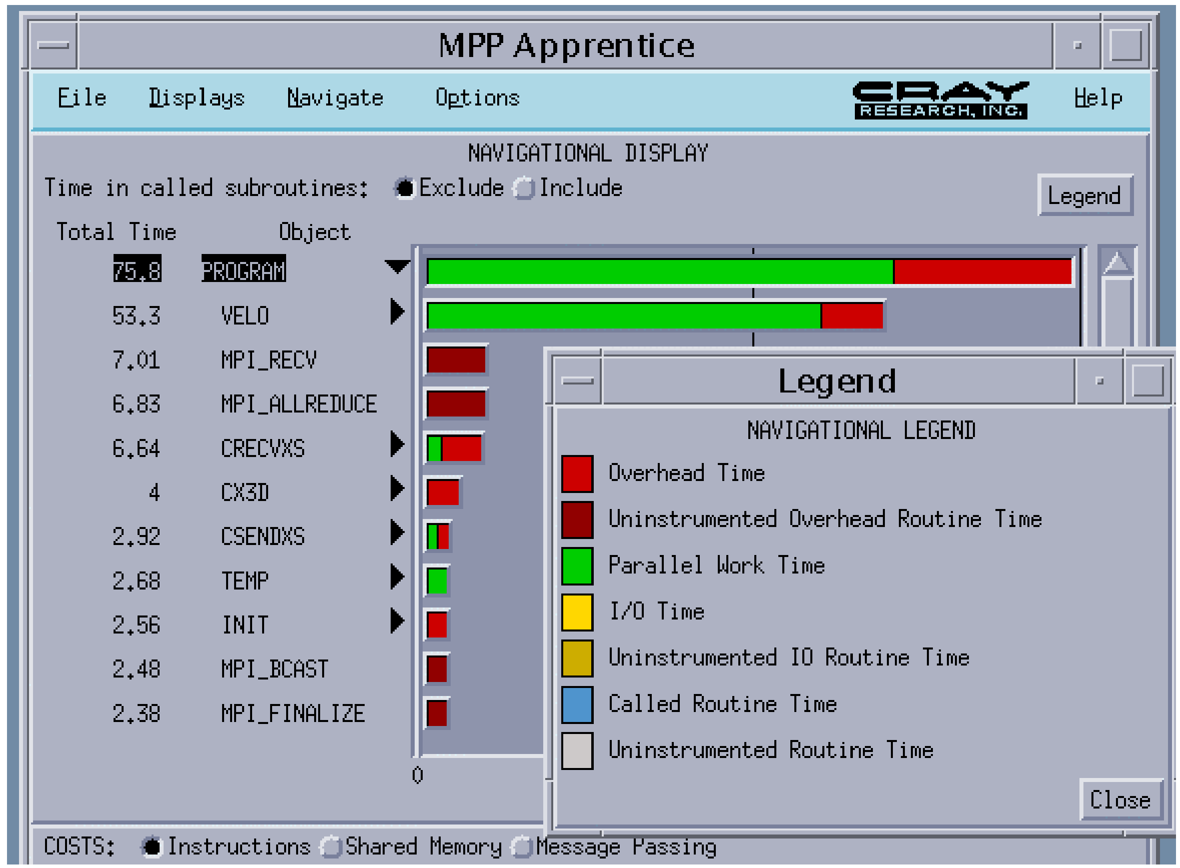
    ```
    t3e% f90 -eA myprog.f -lapp
    t3e% cc -happrentice myprog.c -lapp
    ```
  - Executing program generates app.rif
  - Analyze performance

    ```
    t3e% apprentice app.rif
    ```
- Features
  - Provides summary data (sum over all PE and total execution time)
  - Provides
    - execution time (measured)
    - number of floating-point, integer, load, store instructions (calculated)
  - Automatically corrects measurement overhead

Apprentice: Navigation Window

- Shows time profile for
  - program
  - functions
  - basic blocks

  sorted by usage



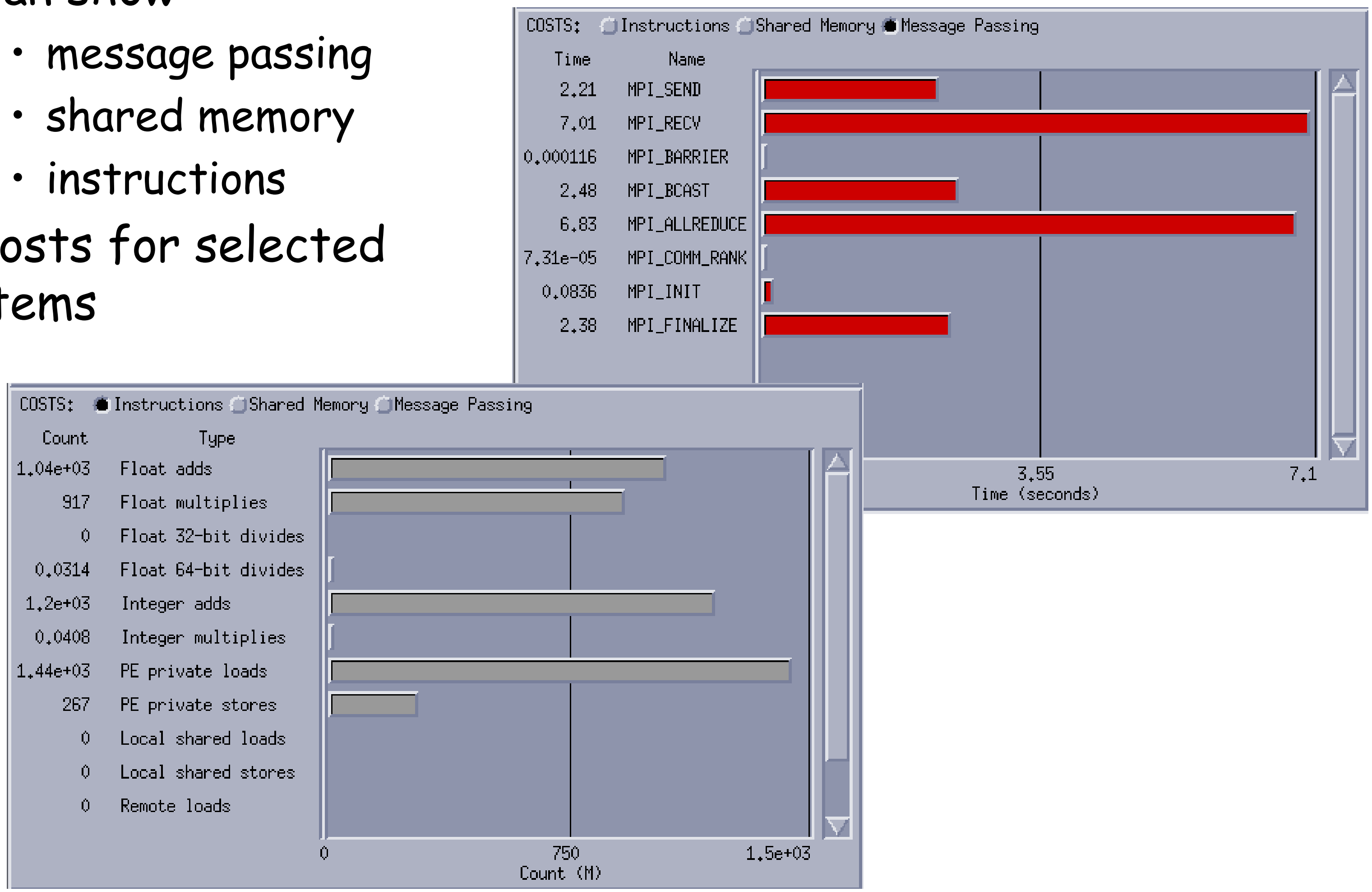
- Items can be "expanded" by clicking on black triangle

- Can show time including or excluding the time used by subregions

Apprentice: Costs Window

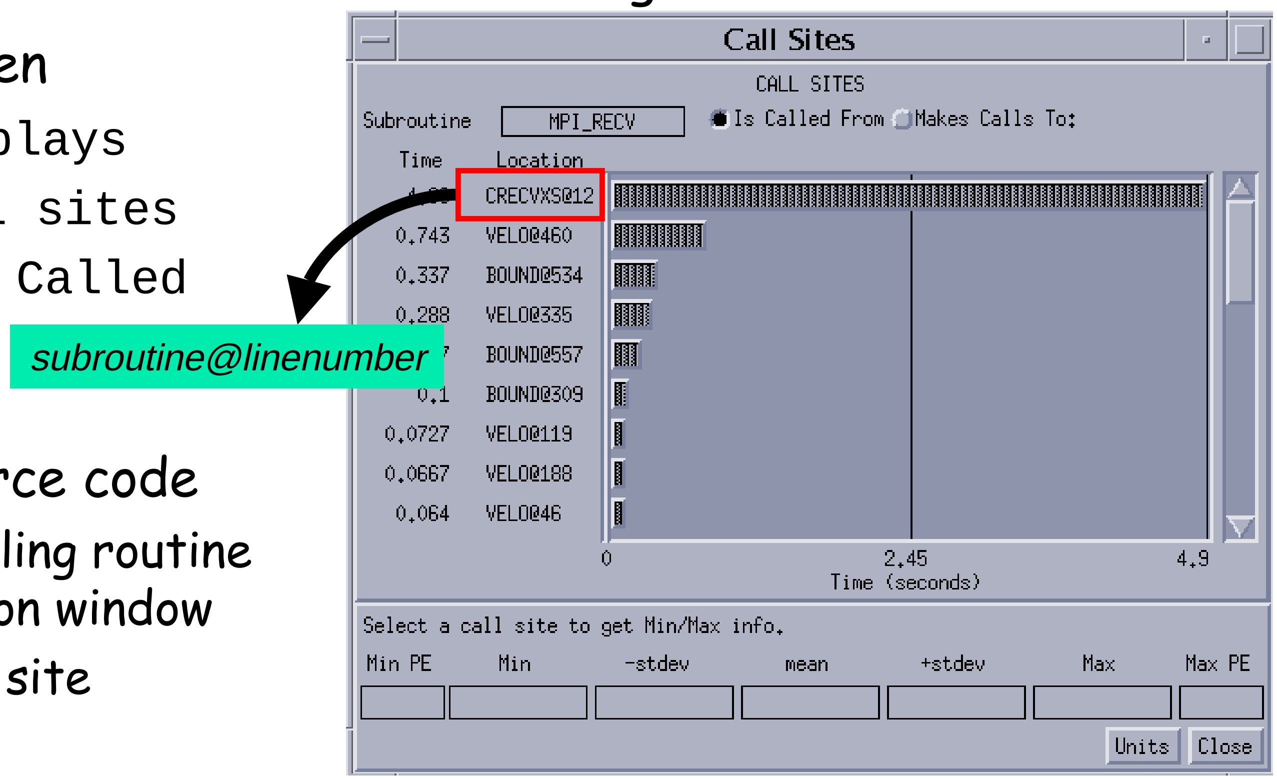
- Can show
  - message passing
  - shared memory
  - instructions

  costs for selected items



Apprentice: Finding Communication Bottleneck

- Compare values for 1st line (program) in navigation window:
  - Overhead (red) is communication time
  - parallel work (green) is calculation part
- Limiting MPI call => 1st MPI call in navigation window
- Select it, then
  - Menu `Displays`
  - Item `Call sites`
  - Option `Is Called From`

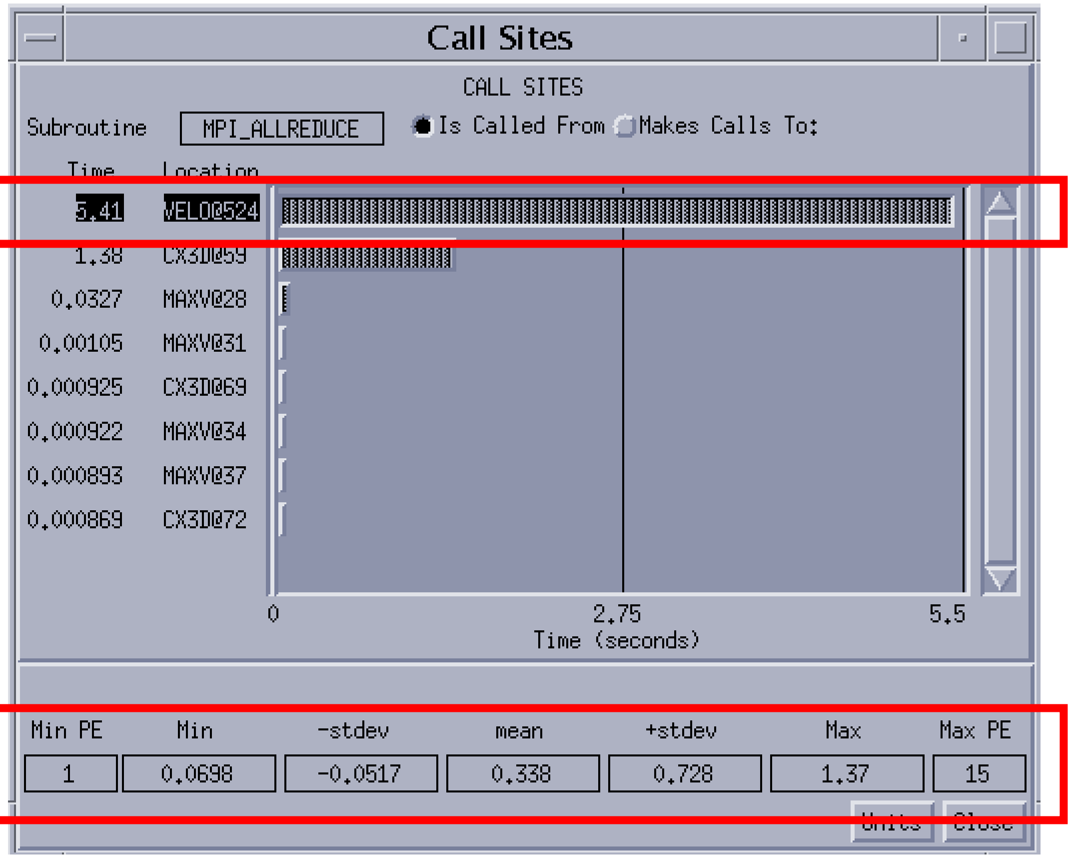


- To show source code
  - expand calling routine in navigation window
  - select call site

Apprentice: Finding Load Imbalance

- Select barrier or MPI collective communication routine in navigation window, then
  - Menu `Displays`
  - Item `Call sites`
  - Option `Is Called From`
- Select call site to see
  - minimum
  - mean
  - maximum

  execution time



T3E: Tracing

- There is no SGI/Cray tracing tool => use Vampir
- Necessary trace instrumentation can be done in two ways
  - Object code instrumentation with PAT
    - collaboration between SGI/Cray and Forschungszentrum Jülich
    - supports MPI-, PVM-, and SHMEM programs
    - additional manual source code instrumentation for selective tracing
  - Commercial Vampirtrace tracing library
    - supports MPI programs only
    - additional manual source code instrumentation for recording of user subroutines and selective tracing
- See

  `http://www.fz-juelich.de/zam/RD/coop/cray/crayperf.html`

  for up-to-date description and additional tips and hints

PAT: Instrumentation for Tracing

- Prepare user application by linking with PAT library (`-lpat`), message passing wrapper library (`-lwrapper`) and PAT linker command file (`pat.cld`)

  ```
  t3e% cc *.o -o myprog -lpat -lwrapper pat.cld
  ```

- Instrument for tracing

  ```
  => insttrace CX3D VELO barrier CURR MPI_Recv TEMP...
  => quit
  ```

- For real programs unusable
  better: create list of functions to instrument
  - one function per line
  - Note!!! names have to be specified as linker symbol names (i.e. Fortran: all capital letters; C++: "mangled names")
  - ready-to-use lists of message passing routines at website
- Then use -B option for PAT to instrument executable

  ```
  t3e% pat -L -B MYLIST myprog
  ```

PAT: Trace Generation

- If necessary, parameters for trace recording can be specified through environment variables

```
t3e% export PAT_NUM_TRACE_ENTRIES=20000  # default: 8192
t3e% export PAT_TRACE_LIMIT=20000        # unlimited
t3e% export PAT_TRACE_COLLECTIVE=1       # 0
```

- Execute program again (to generate pif file)

```
t3e% mpprun -n ## a.out -myoptions myargs
```

- Convert PAT output into trace format of Vampir [pif2bpv available at website]

```
t3e% pif2bpv a.out.pif mytrace.bpv
```

- Analyze trace file with Vampir

```
t3e% vampir mytrace.bpv
```


PAT: Trace File Size Reduction

- Manually insert functions (defined in `pat.h` and `pat.fh`)

- for selective tracing

C/C++	Fortran	
`TRACE_OFF();`	`PIF$TRACEOFF()`	# Turn tracing off
`TRACE_ON();`	`PIF$TRACEON()`	# Turn tracing on

- for trace size limitation

`TRACE_LIMIT(li);`	`PIF$TRACELIMIT(li)`	# Set limit to `li` # trace records # -1 => unlimited

Pat stops after tracing after recording *`li`* records

CRAY T3E: URLs

- Cray Research Online Software Publications Library
  http://www.cray.com/swpubs/
  - CRAY T3E C and C++ Optimization Guide, 004-2178-002
  - CRAY T3E Fortran Optimization Guide, 004-2518-002
  - Introducing the MPP Apprentice Tool, IN-2511 3.0
- Cray T3E vendor Information
  http://www.cray.com/t3e/
  - White Papers (http://www.cray.com/t3e/white_papers.html)
- Forschungszentrum Jülich Cray Performance Tools Page
  http://www.fz-juelich.de/zam/RD/coop/cray/crayperf.html
- Various T3E documents and talks about optimization
  http://www.fz-juelich.de/zam/docs/craydoc/t3e/

IBM SP2: Performance Tools

- flat profiling (sampling)
  - [prof]
  - gprof
- call graph profiling
  - gprof / Xprofiler
- detailed (source line) profiling
  - Xprofiler
- tracing
  - VT

Xprofiler

- Gprof: time sampled call graph profiling
- Xprofiler: graphical analysis interface for gprof outputs
- Usage
  - Compile and link with "`-g -pg`" flags and optimization
  - Run the code; generates `gmon.out.`*N* files (N = 0 .. P-1)
  - Analyze with gprof or xprofiler

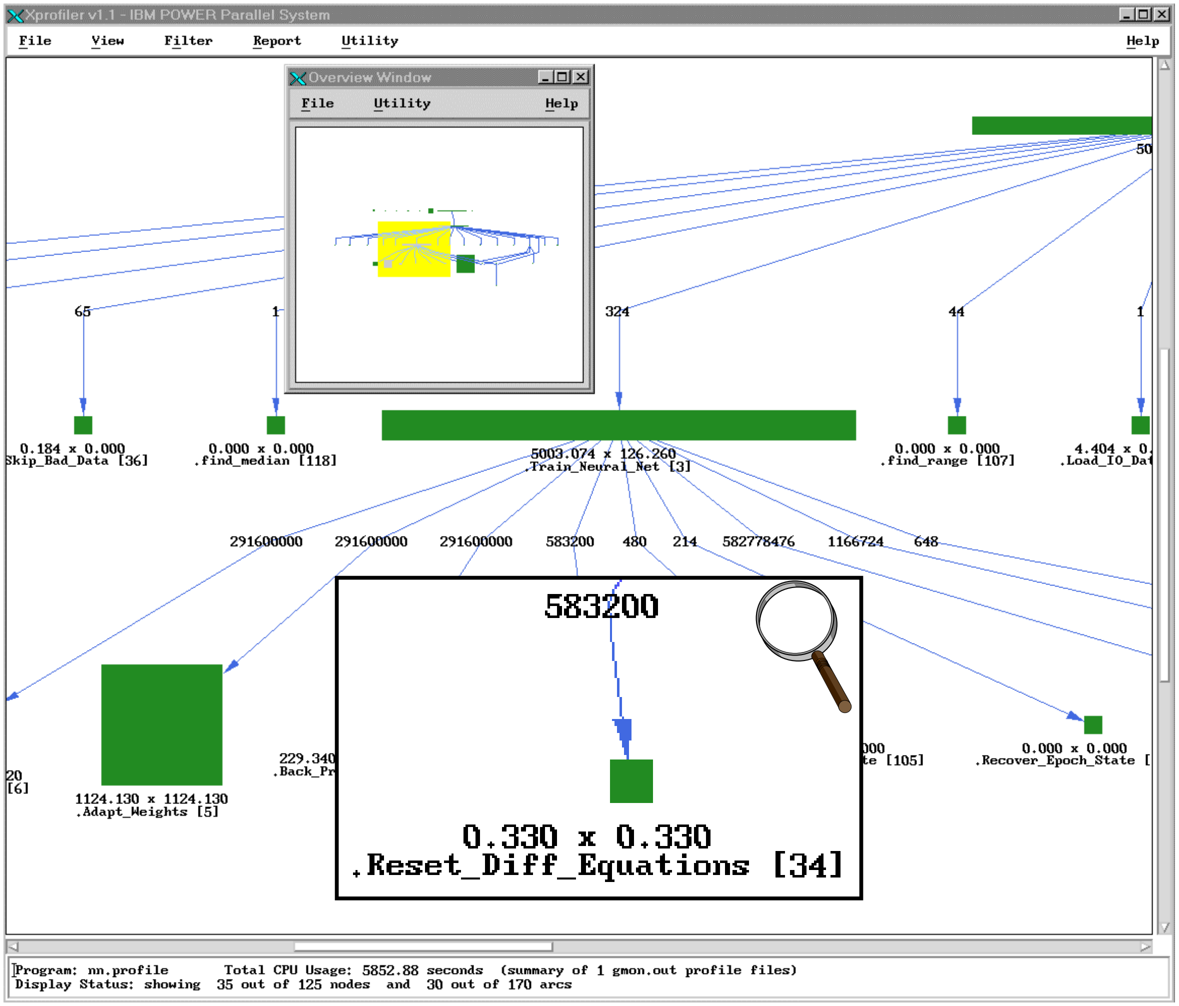
```
sp2% gprof gmon.out.* > gprof.report
sp2% xprofiler myprog gmon.out.*
```

- Features
  - graphical call graph performance display
    - execution time bottleneck location
    - call sequence identification
  - gprof reports
  - source line profiling

Xprofiler: Main Display

- width of a bar
  $\propto$ time including called routines
- height of a bar
  $\propto$ time excluding called routines
- call arrows labeled with number of calls

- Overview window for easy navigation (View -> Overview)



UNIVERSITY OF WISCONSIN MADISON

Forschungszentrum Jülich

Xprofiler: Gprof Reports

- Menu `Report` provides usual gprof reports plus some extra ones
  - Flat Profile
  - Call Graph Profile
  - Function Index
  - Function Call Summary
  - Library Statistics

Flat Profile

File Code Display Utility Help

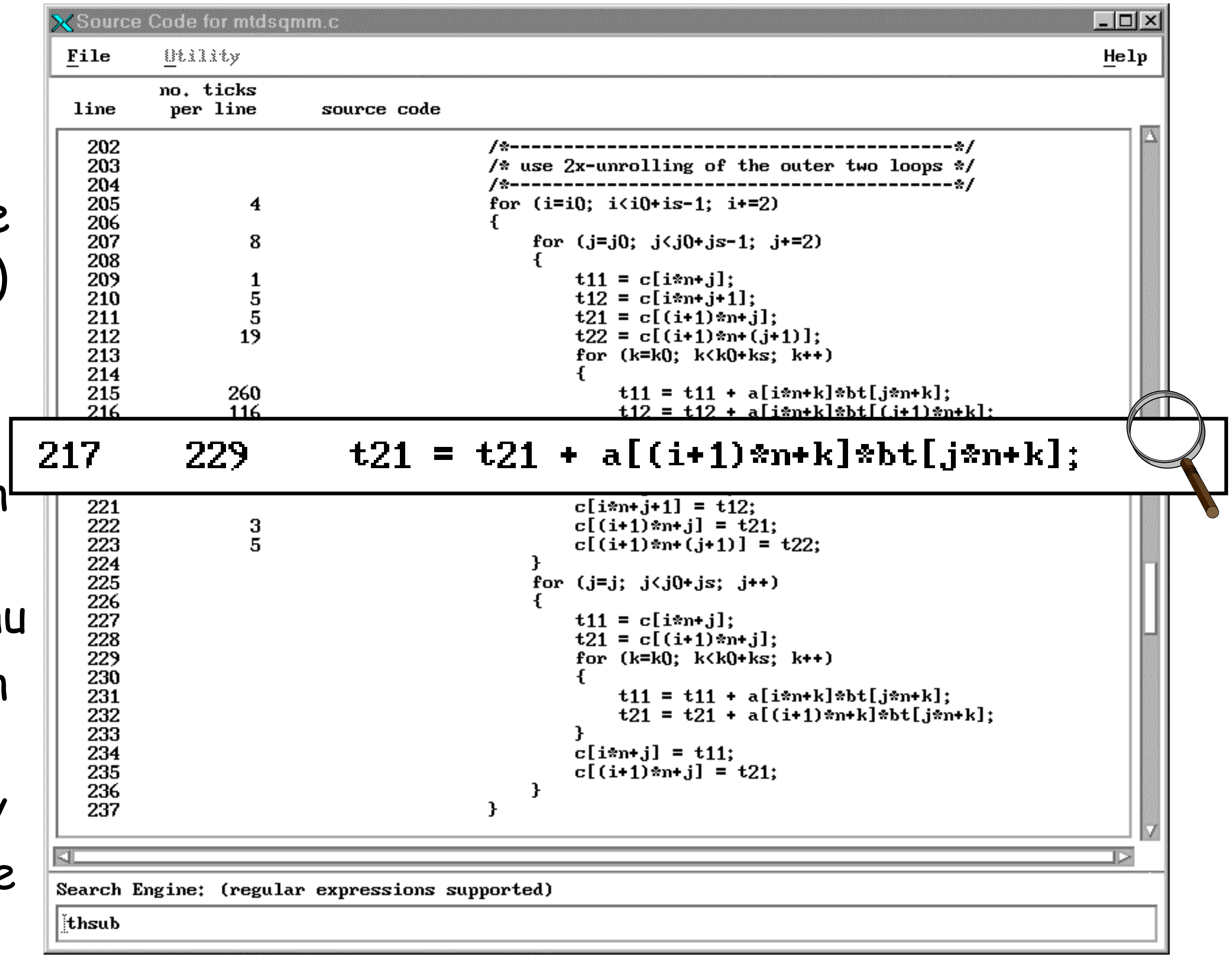
%time	cumulative seconds	self seconds	calls	self ms/call	total ms/call	name	
62.9	15.64	15.64	1	15640.00	15650.00	.main [1]	
0.2	24.85	0.04				.durand [7]	durand.f
0.0	24.86	0.01	28	0.36	0.36	.fwrite_unlocked [9]	../../../../../
0.0	24.87	0.01				.dgetmo [12]	dgetmo.f
0.0	24.87	0.00	55	0.00	0.00	.leftmost [13]	../../../../../
0.0	24.87	0.00	43	0.00	0.00	.splay [14]	../../../../../
0.0	24.87	0.00	35	0.00	0.00	.malloc [15]	../../../../../
0.0	24.87	0.00	35	0.00	0.00	.malloc_y [16]	../../../../../
0.0	24.87	0.00	32	0.00	0.00	.free [17]	../../../../../
0.0	24.87	0.00	32	0.00	0.00	.free_y [18]	../../../../../
0.0	24.87	0.00	28	0.00	0.36	.fwrite [8]	../../../../../
0.0	24.87	0.00	28	0.00	0.00	.memchr [19]	../../../../../
0.0	24.87	0.00	16	0.00	0.00	.rightmost [20]	../../../../../
0.0	24.87	0.00	10	0.00	0.00	.mtdsqmm [21]	mtdsqmm.c
0.0	24.87	0.00	10	0.00	0.00	.splint [22]	../../../../../
0.0	24.87	0.00	10	0.00	0.00	.syncthreads [23]	mtdsqmm.c
0.0	24.87	0.00	9	0.00	1.11	._doprnt [10]	../../../../../
0.0	24.87	0.00	9	0.00	0.00	._xflsbuf [24]	../../../../../
0.0	24.87	0.00	9	0.00	0.00	._xwrite [25]	../../../../../
0.0	24.87	0.00	9	0.00	1.11	.printf [11]	../../../../../
0.0	24.87	0.00	9	0.00	0.00	.time_base_to_time [26]	../../../../../

Search Engine: (regular expressions supported)

Xprofiler: Source Code Window

- Source code window displays source code with time profile (in ticks=.01 sec)

- Access
  - select function in main display
    -> context menu
  - select function in flat profile
    -> Code Display
    -> Show Source Code



Xprofiler: Tips and Hints

- Simplest when gmon.out.*, executable, and source code are in one directory
- By default, call tree in main display is "clustered"
  - Menu `Filter` -> Item `Uncluster Functions`
  - Menu `Filter` -> Item `Hide All Library Calls`
- Libraries must match across systems!
  - on measurement SP2 nodes
  - on workstation used for display!
- Must sample realistic problem (sampling rate is 1/100 sec)
- PVM programs require special hostfile (specify different wd's otherwise gmon.out files overwrite each other)

Xprofiler: Sample PVM Hostfile for Profiling

```
#host configuration for v08 nodes
#
#executable path for all hosts
*
ep=$PVM_ROOT/bin/$PVM_ARCH:$PVM_ROOT/lib/$PVM_ARCH:
   $HOME/bin:$PVM_ROOT/lib
v08l01 wd=/cfs/profile/01
v08l02 wd=/cfs/profile/02
v08l03 wd=/cfs/profile/03
v08l04 wd=/cfs/profile/04
v08l05 wd=/cfs/profile/05
v08l06 wd=/cfs/profile/06
...
```

Alternative : add a `chdir()` statement to the procedure code.

VT

- MPI message passing visualization tool
- No re-compiling or re-linking necessary!
- Trace visualization through animation

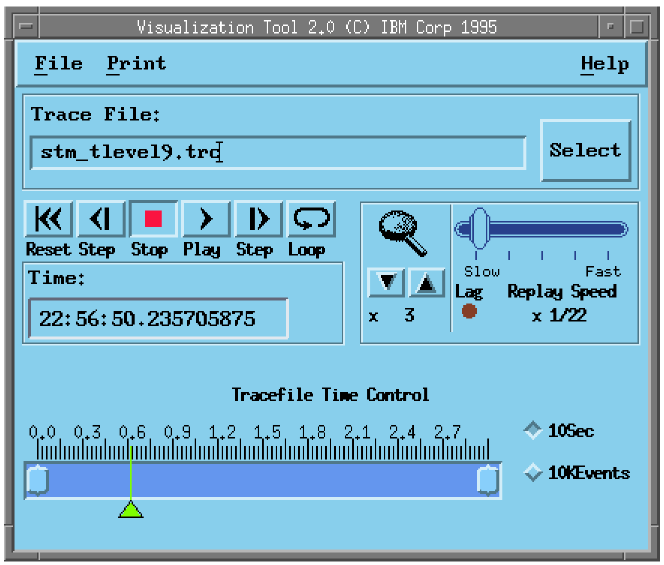
- Does not use AIX tracing library (but own one)

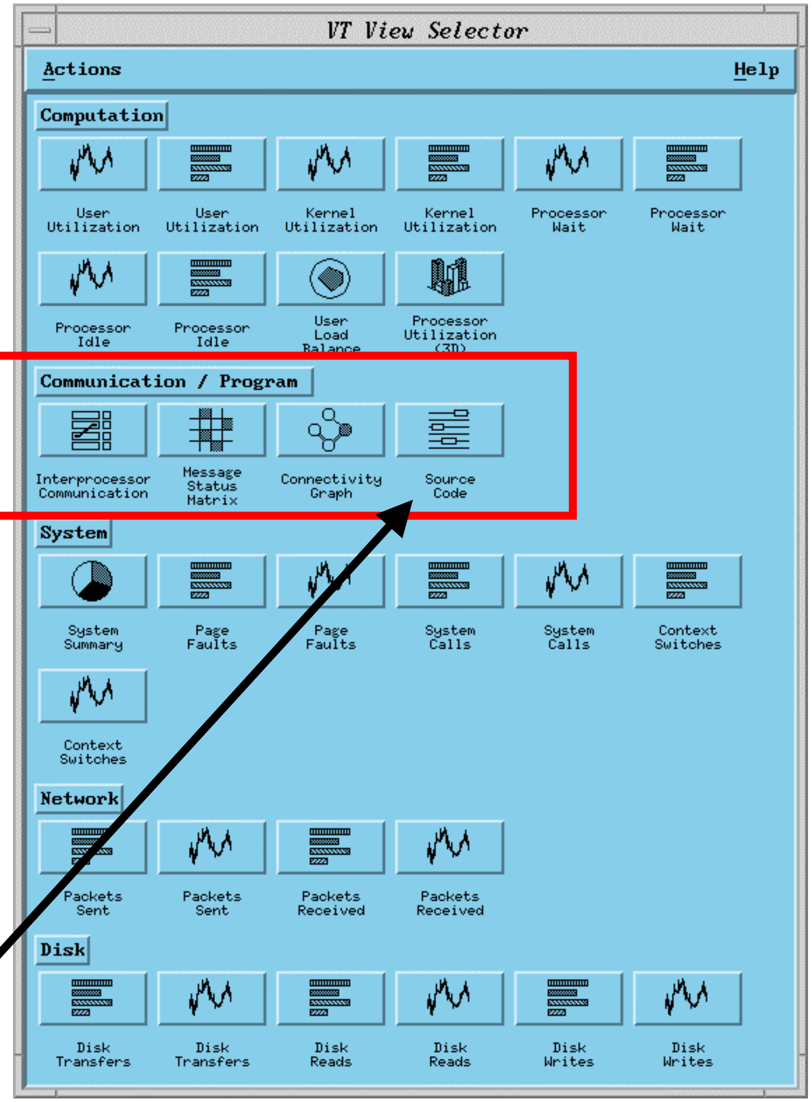
- Trace generation by setting trace level with option `-tlevel`
  sp2% `poe myprog -procs ## -tlevel` *N -myoptions myargs*
  or environment variable `MP_TRACELEVEL`
- Events

Events	Trace level
application markers	1,2,3,9
kernel statistics	2,9
message passing	3,9

VT Displays

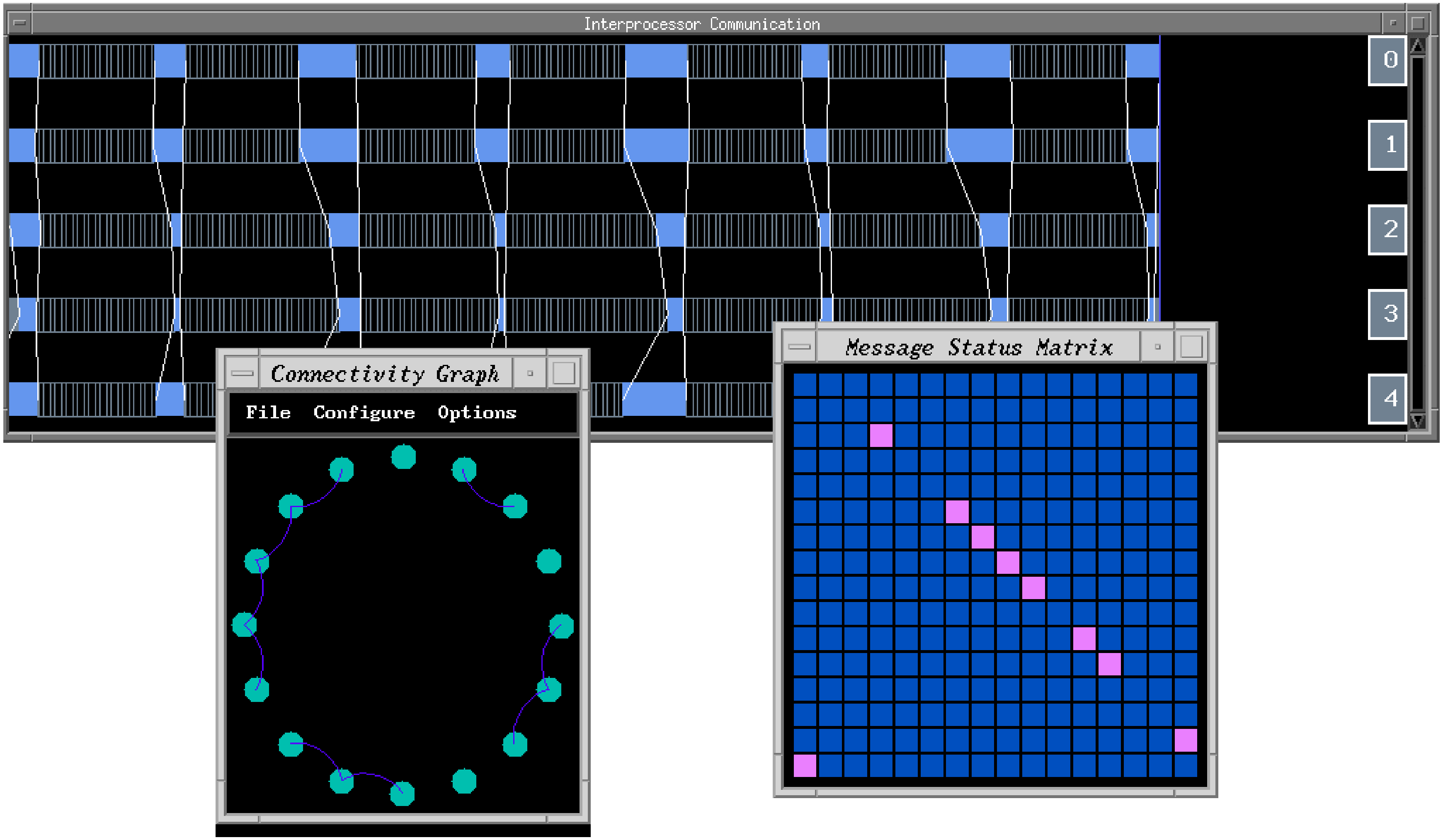
- VT provides a large variety of displays for system and parallel program performance
- Trace Control Window allows control of trace and display animation





- Source display requires -g

VT Communication Displays



VT: Trace Recording Control

- Selective tracing

C/C++	Fortran
`VT_trc_start_c(level);`	`VT_TRC_START(level, ierr)`
`VT_trc_stop_c();`	`VT_TRC_STOP(ierr)`

- Application marker

`mpc_marker(...)`	`MP_MARKER(light, col, str)`

- Trace size limitation
  - Command line options
    - `tbuffsize` *size* # default 1M
    - `tpermsize` *size* # 10M
  - Environment variables

```
sp2% export MP_TBUFFSIZE=size
sp2% export MP_TPERMSIZE=size
```

IBM SP2: Future Tools

- Dynamic Probe Class Library (DPCL)
  - dynamic instrumentation of running serial or parallel programs
  - foundation for a new family of tools
  - `http://www.ptools.org/projects/dpcl`
- Performance Hardware Monitor API
- Unified Trace Environment (UTE)
  - uses AIX trace facility and standard MPI profiling interface
  - supports MPI event groups (point-to-point, collective, ...)
  - uses Jumpshot for trace visualisation
  - `http://www.research.ibm.com/people/w/wu/UTE.html`
- SvPablo
  - graphical source code instrumentor for C and Fortran
  - graphical performance analysis and presentation tool
  - captures HW + SW statistics per functions / loops / statements

IBM SP2: URLs

- Parallel Environment - Product Information
  http://www.rs6000.ibm.com/software/sp_products/pe.html
- Parallel Environment - Online Documentation
  http://www.rs6000.ibm.com/resource/aix_resource/sp_books/pe/
  - SC28-1980: PE Operation and Use (describes xprofiler + vt)
- IBM Redbooks
  http://www.redbooks.ibm.com
  - RS/6000 Scientific and Technical Computing: POWER Introduction and Tuning Guide, SG24-5155
  - RS/6000 SP: Practical MPI Programming, SG24-5380
- White Papers and Technical Reports
  http://www.rs6000.ibm.com/resource/technology/index.html#sp
- POWERPARALLEL User Group
  http://spud-web.tc.cornell.edu/HyperNews/get/SPUserGroup.html
- Advanced Computing Technology Center (ACTC)
  http://www.research.ibm.com/actc/

SGI O2K: Performance Tools

- time / HW counter measurements
  - timex, perfex, SpeedShop
- flat profiling (sampling)
  - SpeedShop, Cvperf
- call graph profiling
  - SpeedShop, Cvperf
- detailed (basic block) profiling
  - SpeedShop, Cvperf
- data / memory profiling
  - dprof records memory access information
  - dlook displays placement of memory pages
- tracing
  - SpeedShop / [Vampir]

Timex

- Command line tool for measuring
  - elapsed, user, and system time
  - processor accounting data (see `man timex`)

- Usage

```
o2k% timex options myprog -myoptions myargs
```

- Example

```
o2k% timex myprog
==> setup ...
==> calculation ...

real      1.63
user      0.85
sys       0.58
```


Perfex

- Command line tool for accessing MIPS hardware counters (R10000 + R12000 only)
- Usage

  o2k% `perfex` *`options`* `myprog` *`-myoptions myargs`*
- Features
  - exact count of one or two events (option `-e` *num*)
  - approximate count of all countable events by multiplexing (`-a`)
  - can include analytic output (`-y`)
  - use signals to control start/stop (`-s`)
  - per-thread + total report for multprocessing programs (`-mp`)
- No re-compilation or re-linking necessary!
- Selective profiling with calls to perfex library
- Using perfex with MPI programs

  o2k% `mpirun -np # perfex -mp -operf.out myprog my`*`args`*

Perfex: MIPS HW Counter

- R10000 HW Counters
  - 0 = Cycles
  - 1 = Issued instructions
  - 2 = Issued loads
  - 3 = Issued stores
  - 4 = Issued store conditionals
  - 5 = Failed store conditionals
  - 6 = Decoded branches
  - 7 = Quadwords written back from secondary cache
  - 8 = Correctable secondary cache data array ECC errors
  - 9 = Primary (L1) instruction cache misses
  - 10 = Secondary (L2) instruction cache misses
  - 11 = Instruction misprediction from secondary cache way prediction table
  - 12 = External interventions
  - 13 = External invalidations
  - 14 = Virtual coherency conditions
  - 15 = Graduated instructions
  - 16 = Cycles
  - 17 = Graduated instructions
  - 18 = Graduated loads
  - 19 = Graduated stores
  - 20 = Graduated store conditionals
  - 21 = Graduated floating point instructions
  - 22 = Quadwords written back from primary data cache
  - 23 = TLB misses
  - 24 = Mispredicted branches

Perfex: MIPS HW Counter

- R10000 HW Counters (cont.)
  - 25 = Primary (L1) data cache misses
  - 26 = Secondary (L2) data cache misses
  - 27 = Data misprediction from secondary cache way prediction table
  - 28 = External intervention hits in secondary cache (L2)
  - 29 = External invalidation hits in secondary cache
  - 30 = Store/prefetch exclusive to clean block in secondary cache
  - 31 = Store/prefetch exclusive to shared block in secondary cache
- R12000 HW Counter Differences to R10000
  - 1 = Decoded instructions
  - 2 = Decoded loads
  - 3 = Decoded stores
  - 4 = Miss handling table occupancy
  - 6 = Resolved conditional branches
  - 14 = Always 0
  - 16 = Executed prefetch instructions
  - 17 = Prefetch primary data cache misses

Perfex Example: Getting MFlops

```
o2k% perfex -y -e 21 myprog
 ==> setup ...
 ==> calculation ...
 Summary for execution of myprog
                  Based on 195 MHz IP27
                      MIPS R10000 CPU
                      Counter   Typical Minimum Maximum
 Event Counter Name    Value    Time(s) Time(s) Time(s)
 ======================================================
  0 Cycles.......... 5158743137 26.455  26.455  26.455
-e  21 Floating point.. 3651000162 18.723   9.361 973.600

 Statistics
 ======================================================
 Floating point instructions/cycle.........   0.707731
 MFLOPS (average per process)............... 138.007459
```

SpeedShop

- Program profiling with three different methods
  - sampling based on different time bases
  - ideal time
  - exception trace for fpe's
- No re-compilation or re-linking necessary!
- Supports
  - unstripped executables, shared libraries
  - C, C++, f77, f90, Ada, Power Fortran, Power C
  - sproc/fork parallelism, pthreads, MPI, PVM, shmem, OpenMP
  - lots of different experiments (see man speedshop, ssrun, prof)
- Usage
  - run experiments on the executable: `ssrun -`*`exp`* `[-workshop]`
  - generates file *`executable.experiment.pid`*
  - examine performance data: `prof/cvperf` *`ssrun.outfile`*
- Selective profiling with calls to ssapi library

SpeedShop: Sampling Experiments

- Sampling based on
  - actual elapsed time (-totaltime, -usertime, -pcsamp, -cy_hwc)
    - finds the code where the program spends the most time
    - use to get an overview of the program and to find major trouble spots
  - instruction counts (-gi_hwc, -gfp_hwc)
    - finds the code that actually performs the most instructions
    - Use to find the code that could benefit most from a more efficient algorithm
  - data access (-dc_hwc, -sc_hwc, -tlb_hwc)
    - finds the code that has to wait for its data to be brought in from another level of the memory hierarchy
    - Use these to find memory access problems
  - code access (-ic_hwc, -isc_hwc)
    - finds the code that has to be fetched from memory when it is called
    - Use these to pinpoint functions that could be reorganized for better locality, or to see when automatic inlining has gone too far

SpeedShop: Other Experiments

- Ideal
  - provides exact measurements of executed basic blocks
  - reports cycle count (ideal time) => ignores cache misses, overlap...
  - execution slowdown: factor 3 to 6
- io
  - traces calls to UNIX i/o system calls e.g. `read`, `write`, ...
- mpi
  - traces calls to MPI point-to-point, MPI_Barrier, and MPI_Bcast
  - generates file viewable with cvperf
  - ssfilter can produce Vampir traces from "-mpi" output (beta)
- fpe
  - floating-point exceptions trapped in HW, but ignored by default
  - collects data on all floating-point exceptions
  - exception free code allows for higher level of optimization

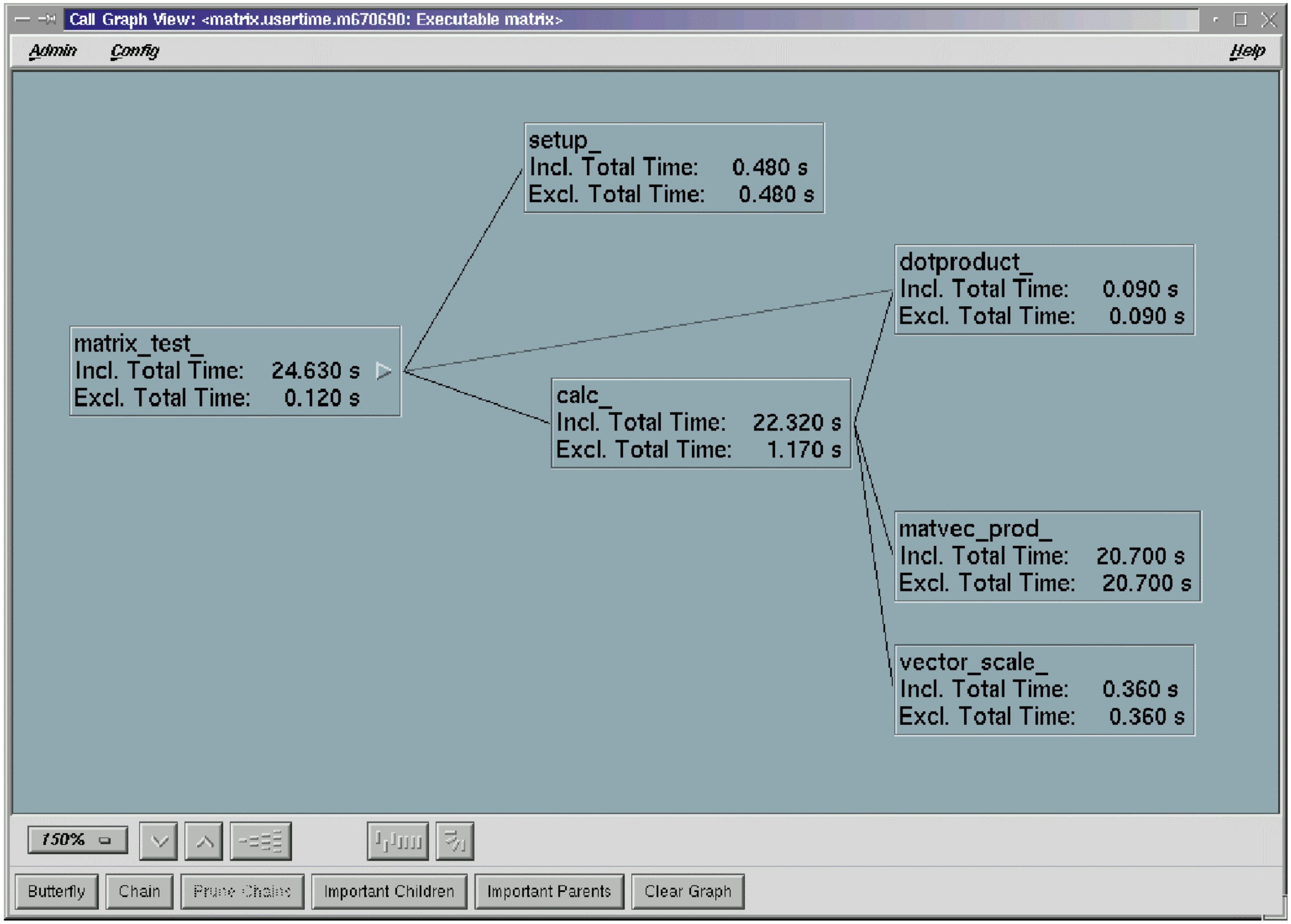
SpeedShop: Performance Analysis

- Prof
  - command line performance analyzer
  - important options
    - heavy — reports most heavily used lines in each function
    - quit n or n% — truncates after the first n lines / n%
    - butterfly — call graph profiling (only for some experiments)
  - compiler + linker feedback file generation
- Cvperf
  - Visual Workshop Performance Analyzer
  - GUI front-end
  - performance experiment and option specification
  - performance analysis specification and performance views

SpeedShop Example: usertime Sampling

```
o2k% ssrun -usertime myprog
o2k% prof myprog.usertime.m95674
 ...
 ------------------------------------------------------
 function list, in descending order by exclusive time
 ------------------------------------------------------
 [index] excl.s excl.%   cum%  incl.s  inc.% procedure
     [5] 10.410  71.8%  71.8%  10.410  71.8% MATVEC
     [6]  2.400  16.6%  88.4%   2.400  16.6% SETUP
     [7]  0.900   6.2%  94.6%   0.900   6.2% SCALE
     [8]  0.780   5.4% 100.0%   0.780   5.4% DOTPROD
     [1]  0.000   0.0% 100.0%  14.490 100.0% __start
     [2]  0.000   0.0% 100.0%  14.490 100.0% main
     [3]  0.000   0.0% 100.0%  14.490 100.0% MAT_VEC_PR
     [4]  0.000   0.0% 100.0%  12.060  83.2% CALC
 ...
```

Cvperf: Call Graph View



SGI O2K: URLs

- SGI Origin2000 Pages
  `http://www.sgi.com/origin/2000/`
- SGI Online Publication Library
  `http://techpubs.sgi.com/library`
  - MIPSpro C, C++, Fortran Programmer's Guides
  - MIPSpro Compiling and Performance Tuning Guide
  - Developer Magic: ProDev Workshop MP User's Guide
  - Developer Magic: Performance Analyzer User's Guide
  - SpeedShop User's Guide
  - O2K and Onyx2 Performance Tuning and Optimization Guide
- NCSA: Frequently Used Tools and Methods for Performance Analysis and Tuning on SGI systems
  `http://www.ncsa.uiuc.edu/SCD/Perf/Tuning/Tips/`
- Maui High Perf. Computing Center Performance Tuning Pages
  `http://www.mhpcc.edu/doc/perf.html`

3rd Party: Performance Tools

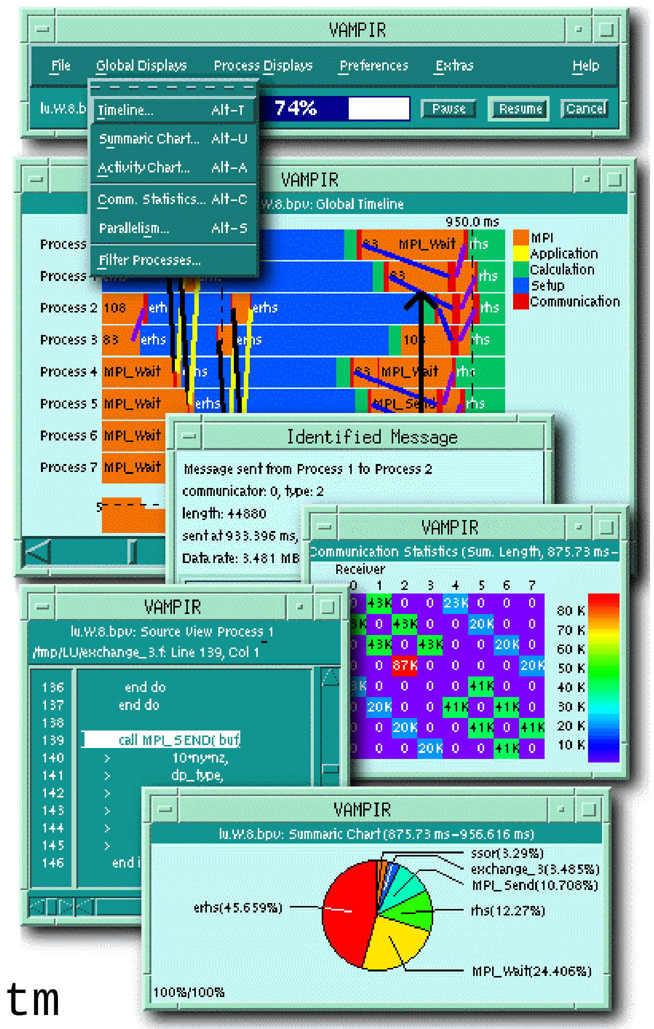
- Tracing of MPI Programs
  - Vampir (Pallas)
  - Vampirtrace (Pallas)

- Performance Prediction
  - Dimemas (Pallas)

- Performance Analysis of OpenMP Programs
  - GuideView (KAI)

Vampir

- Visualization and Analysis of MPI Programs
- Originally developed by Forschungszentrum Jülich
- Now main development by Technical University Dresden
- Commercially distributed by PALLAS, Germany
- `http://www.pallas.de/pages/vampir.htm`

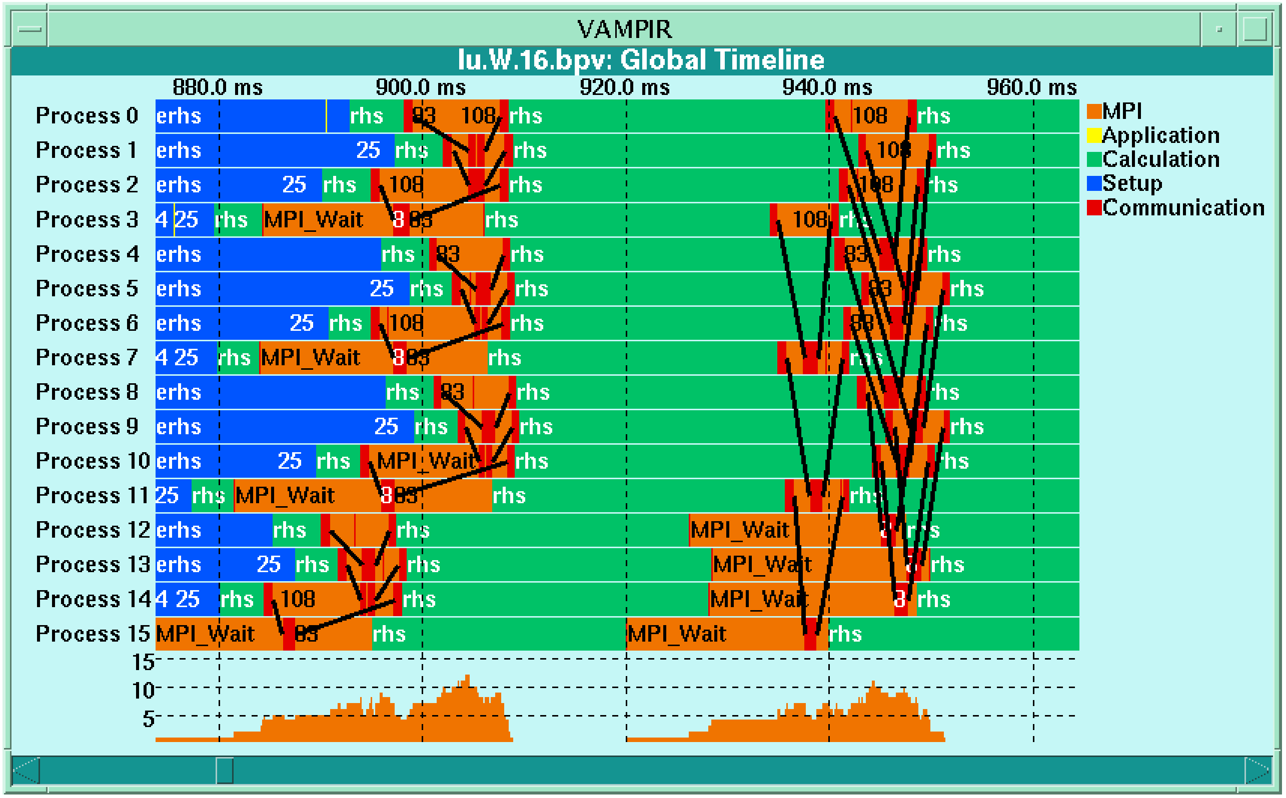


Vampir: General Description

- Offline trace analysis for message passing trace files
- Convenient user-interface / Easy customization
- Scalability in time and processor-space
- Excellent zooming and filtering
- Display and analysis of MPI and application events:
  - user subroutines
  - point-to-point communication
  - collective communication (Version 2.5)
  - MPI-2 I/O operations (Version 2.5)
- Large variety of displays for ANY part of the trace

Vampir: Time Line Diagram

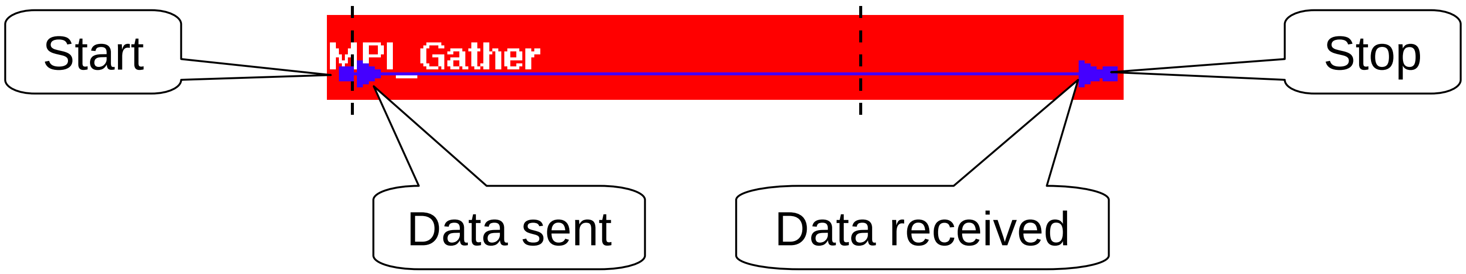
- Functions organized into groups
- coloring by group
- Message lines can be colored by tag or size



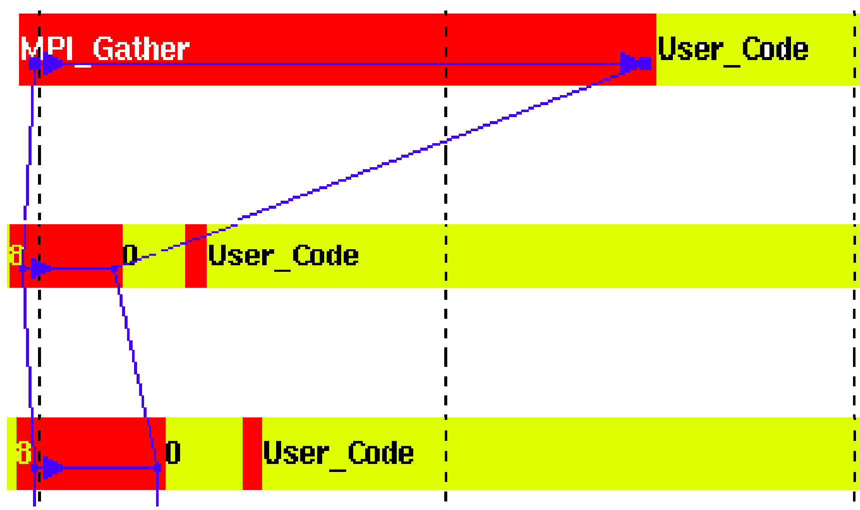
- Information about states, messages, collective and I/O operations available through clicking on the representation
- Source-code references can be displayed if recorded in trace

Vampir: Support for Collective Communication

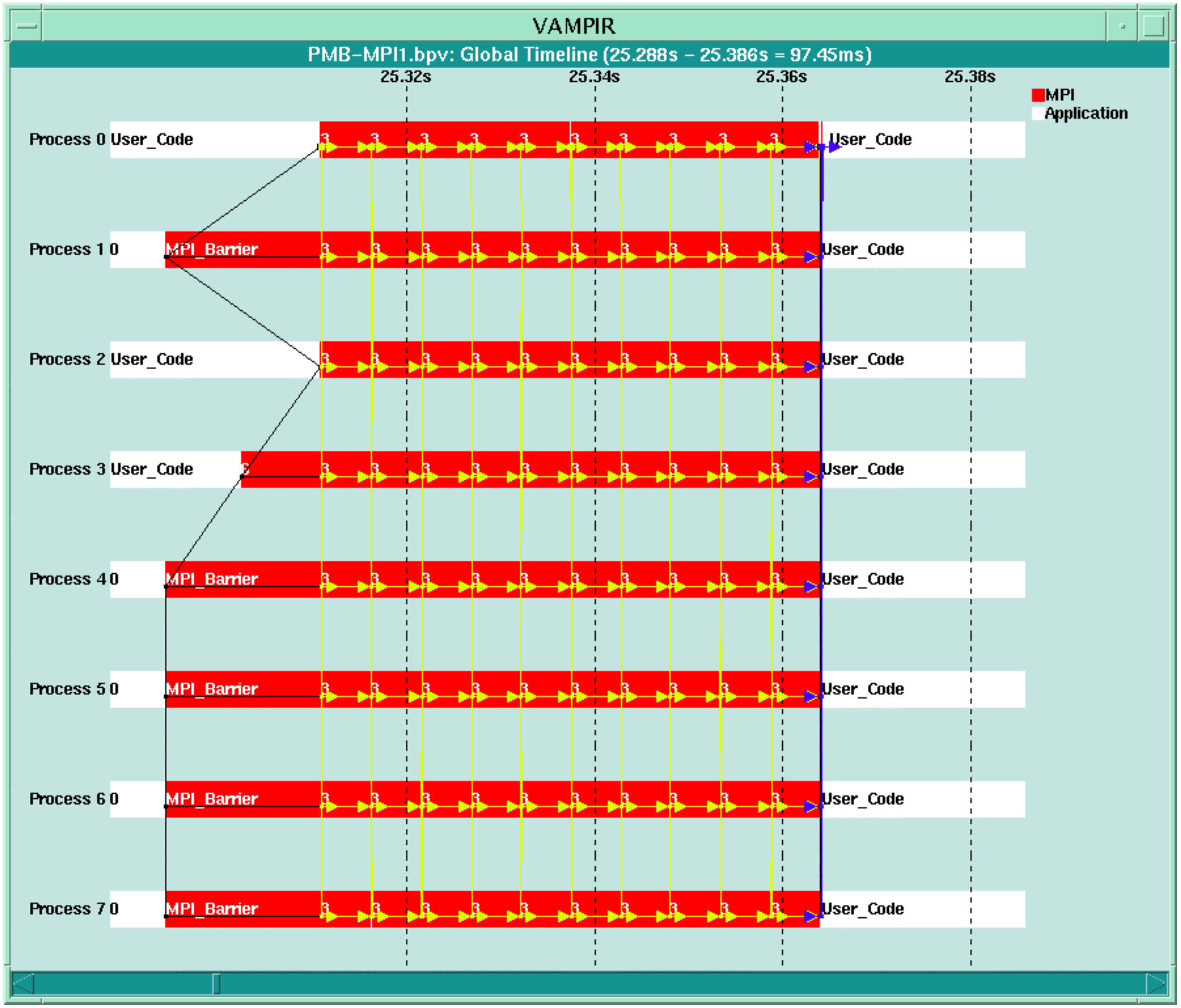
- For each process: locally mark operation



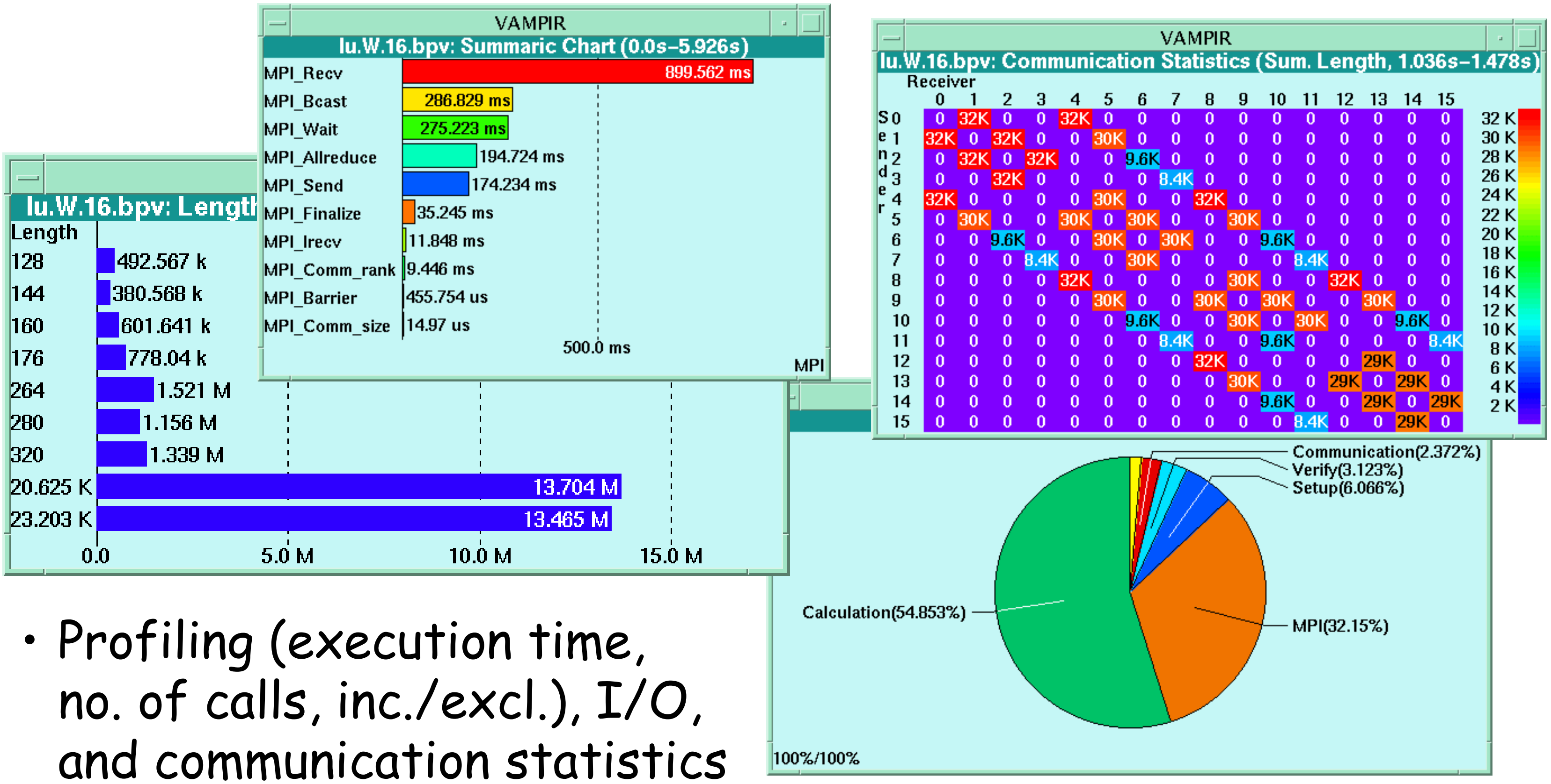
- Connect start/stop points by lines



Vampir: Collective Communication

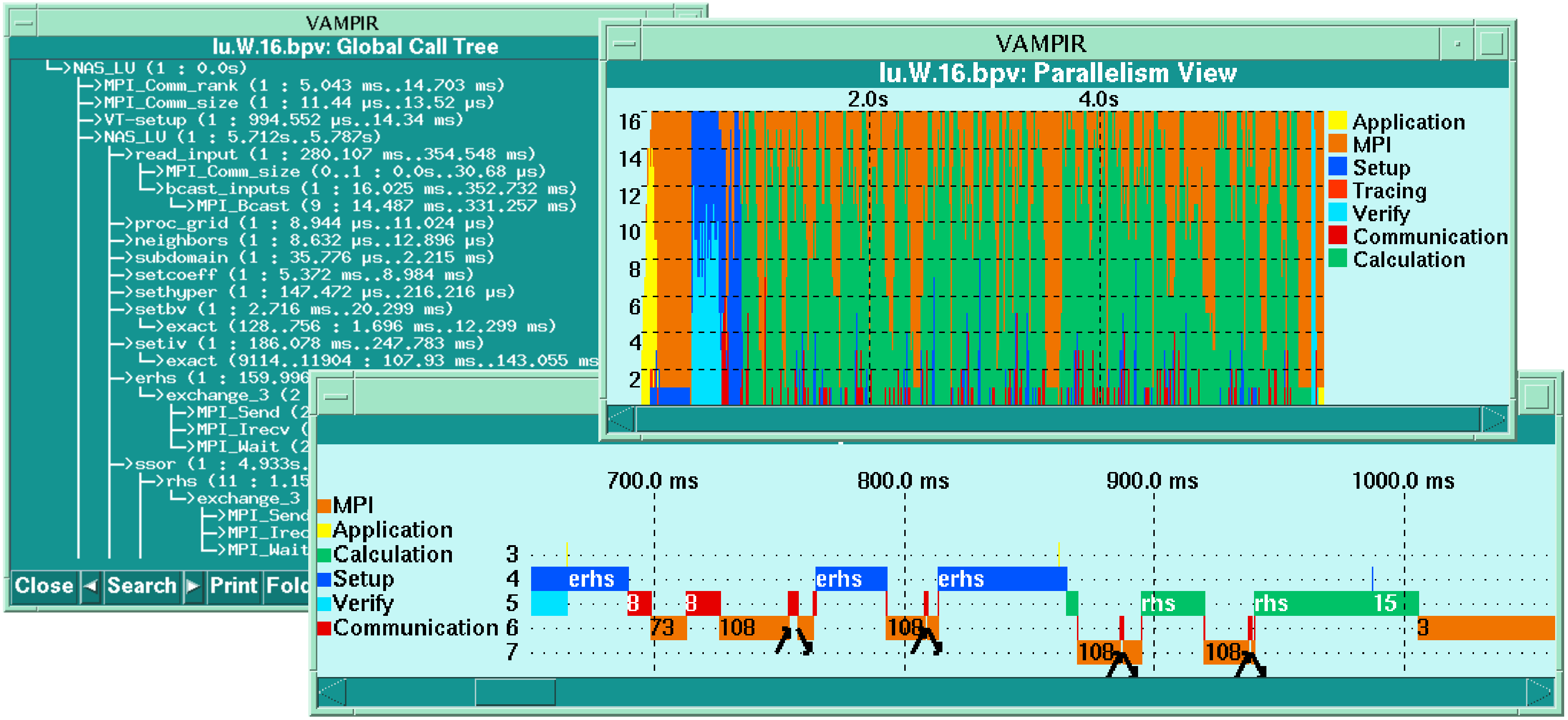


Vampir: Statistical Displays



- Profiling (execution time, no. of calls, inc./excl.), I/O, and communication statistics (byte and message count, message length and bandwidth)
- Available for any part of the trace (selectable through time line diagram)

Vampir: Other Features



- All diagrams highly customizable (through context menus)
- Most diagrams also available in local (per process) form
- Source code, call graph, parallelism diagrams
- Powerful filtering and trace comparison features

Vampir: Availability

- Supported platforms
  - Compaq Alpha, Tru64 Unix
  - Cray T3E
  - Hitachi SR2201, HI-UX/MPP
  - HP PA, HP-UX 10
  - HP Exemplar, SPP-UX 5.2
  - IBM RS/6000 and SP-2, AIX 4
  - Linux/Intel 2.0
  - NEC EWS, EWS-UX 4
  - NEC SX-4, S-UX 8
  - SGI workstations, O2K and PowerChallenge, IRIX 6
  - Sun Solaris/SPARC 2.5
  - Sun Solaris/Intel 2.5

Vampirtrace

- Commercial product of Pallas, Germany

pallas

- Library for Tracing of MPI and Application Events
  - records point-to-point communication
  - records user subroutines (on request)
- New version 2.0
  - records collective communication
  - records MPI-2 I/O operations
  - records source-code information (some platforms)
  - support for shmem (Cray T3E)
- uses the MPI profiling interface
- `http://www.pallas.de/pages/vampirt.htm`

Vampirtrace: Usage

- Record MPI-related information
  - Re-link a compiled MPI application (no re-compilation necessary!)

```
% f90 *.o -o myprog -L$(VTHOME)/lib -lVT -lpmpi -lmpi
% cc  *.o -o myprog -L$(VTHOME)/lib -lVT -lpmpi -lmpi
% CC  *.o -o myprog -L$(VTHOME)/lib -lVT -lpmpi -lmpi
```

  - Execute MPI binary as usual

- Record user subroutines
  - insert calls to the Vampirtrace API (portable, but inconvenient)
  - use automatic instrumentation (NEC SX, Fujitsu VPP, Hitachi SR)
  - use instrumentation tool (Cray PAT, dyninst, ...)

- Reduce trace file sizes
  - filter events in a configuration file
  - enable tracing for part of the application only

Vampirtrace Instrumentation API (C/C++)

- Calls for recording user subroutines

```
#include "VT.h"

VT_symdef(123, "foo", "USER");  // once after MPI_Init!
...

void foo {
    VT_begin(123);              // 1st executable line
    ...
    VT_end(123);                // at EVERY exit point!
}
```

- Event numbers used must be unique
- Selective tracing through
  - `VT_traceoff();` # Turn tracing off
  - `VT_traceon();` # Turn tracing on

VT++.h - C++ class wrapper for Vampirtrace

```
#ifndef __VT_PLUSPLUS_
#define __VT_PLUSPLUS_
#include "VT.h"
class VT_Trace {
  public:  VT_Trace(int code) {VT_begin(code_ = code);}
          ~VT_Trace()          {VT_end(code_);}
  private: int code_;
};
#endif /* __VT_PLUSPLUS_ */
```

- Same tricks can be used to wrap other tracing APIs for C++ too
- Usage:

```
VT_symdef(123, "foo", "USER");  // symbol definition as before
void foo(void) {                // user subroutine to monitor
  VT_Trace vt(123);             // declare VT_Trace object in 1st line
  ...                           // => automatic tracing by ctor/dtor
}
```

Vampirtrace Instrumentation API (Fortran)

- Calls for recording user subroutines

```
      include 'VT.inc'
      integer ierr
      call VTSYMDEF(123, "foo", "USER", ierr)
C
      SUBROUTINE foo(...)
      include 'VT.inc'
      integer ierr
      call VTBEGIN(123, ierr)
C     ...
      call VTEND(123, ierr);
      END
```

- Selective tracing through
  - VTTRACEOFF() # Turn tracing off
  - VTTRACEON() # Turn tracing on

Vampirtrace: Availability

- Supported platforms
  - Compaq Alpha, Tru64 Unix
  - CRAY T3D and T3E, Unicos
  - Fujitsu VPP300 and VPP700, UXP/V
  - Hitachi SR2201, HI-UX/MPP
  - HP PA, HP-UX 10
  - IBM RS/6000 and SP-2, AIX 4
  - Intel Paragon, Paragon OS 1.5
  - Linux/Intel 2.x
  - NEC Cenju-3, Paralib/cj
  - NEC SX-4, S-UX 8
  - SGI workstations, O2K, and PowerChallenge, IRIX 6
  - Sun Solaris/SPARC 2.5
  - Sun Solaris/Intel 2.5

DIMEMAS

- Developed by CEPBA-UPC, Spain
- Now commercial product of Pallas, Germany
- Performance prediction tool for message-passing programs
  - supports several message-passing libraries including PVM, MPI and PARMACS
- Uses
  - Prediction of application runtime on a specific target machine
  - Study of load imbalances and potential parallelism
  - Sensitivity analysis for architectural parameters
  - Identification of user modules that are worthwhile to optimize
- Limitations
  - cache effects
  - process scaling
  - non-deterministic programs
- `http://www.pallas.de/pages/dimemas.htm`

Dimemas Model

- Trace file contains
  - CPU time spent in each code block
  - parameters of communication events (point-to-point, collective)
- Dimemas simulates application execution
  - scales time spent in each block according to target CPU speed
  - performs communication according to target machine model
- Dimemas can model
  - multitasking / multithreading
  - arbitrary process-to-processor mappings
  - heterogeneous machines with various interconnections
    - includes database of machine parameters
  - communication: point-to-point according to latency/bandwidth model, network contention, collective communication (constant, linear, logarithmic)

Dimemas Outputs

- Simulator
  - Execution time + Speed-up
  - Per task:
    - Execution, CPU, Blocking time
    - Messages sent + received
    - Data volume communicated
- What-If Analysis
  - Analysis per code block or subroutine
  - Analysis for target machine parameters
- Critical Path Analysis
  - Critical path (longest communication path)
  - Analysis per code block: percentage of computing + communication time
- Synthetic Perturbation Analysis
- Vampir Trace files

Dimemas: Application Analysis

- Analyze load-balance and communication dependencies:
  - set bandwidth=∞, latency=0
- Should messages be aggregated?
  - set bandwidth= ∞
- Does the bandwidth constrain performance?
  - set latency=0
- Does message contention constrain performance?
  - set number of connections=1, 2, ...

Dimemas: Availability

- Supported platforms
  - IBM RS/6000 and SP-2, AIX 4
  - SGI workstations, O2K, and PowerChallenge, IRIX 6
  - Sun Solaris/SPARC 2.4

GuideView

- Commercial product of KAI
- OpenMP Performance Analysis Tool
- Part of KAP/Pro Toolset for OpenMP
- Looks for OpenMP performance problems
  - load imbalance
  - synchronisation (waiting for locks)
  - false sharing
- Works from execution trace(s)
- Usage:
  - compile code with Guide OpenMP compiler
  - link with instrumented library
  - run with real input datasets
  - view traces with GuideView

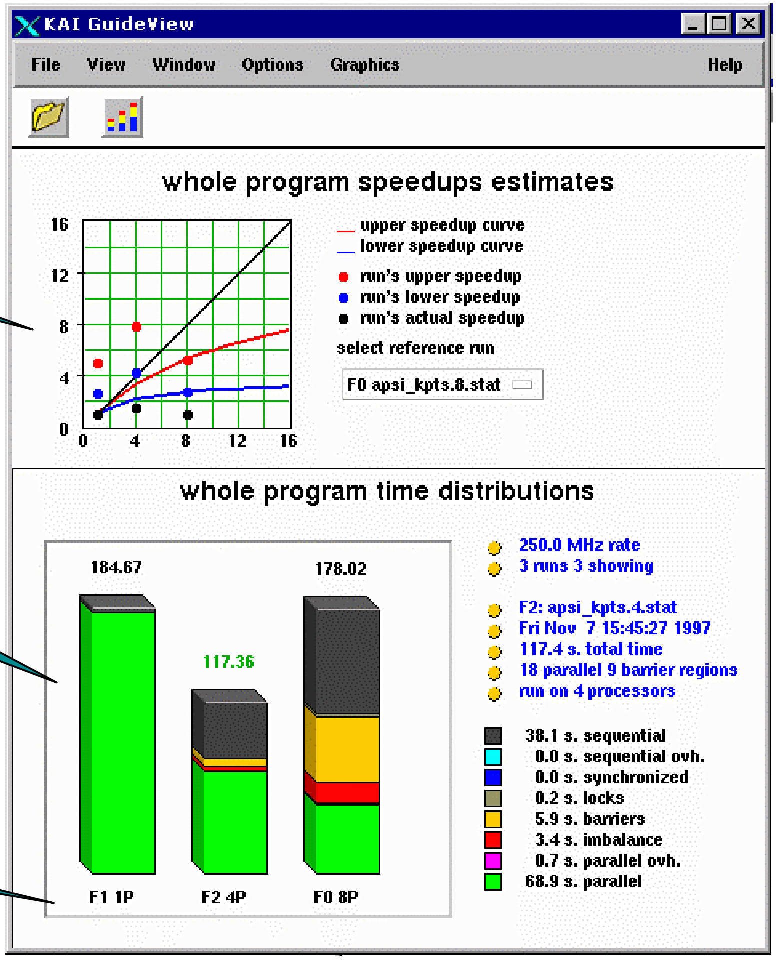
- `http://www.kai.com/parallel/kappro/`

GuideView: Whole Application View

Compare actual vs. ideal performance

Identify bottlenecks (barriers, locks, seq. time)

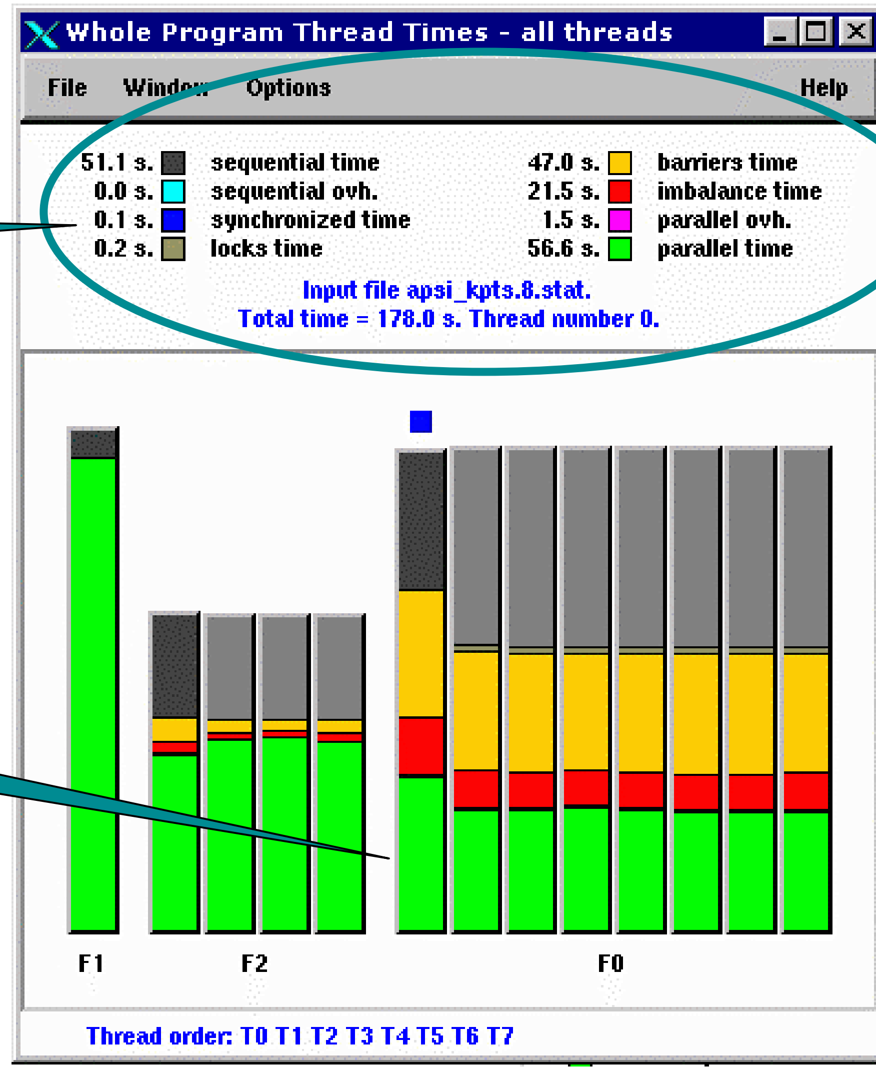
Compare multiple runs



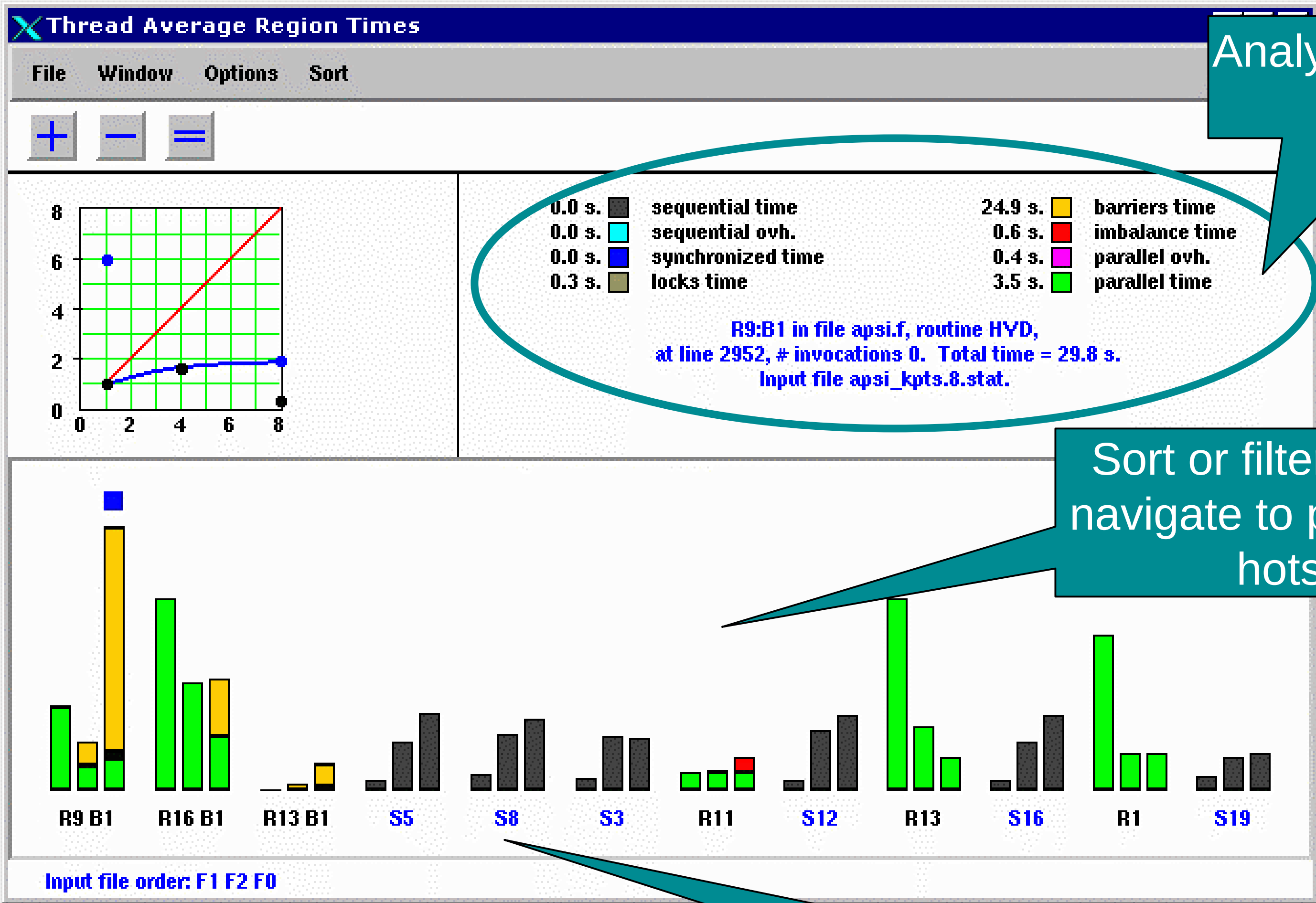
GuideView: Per-Thread View

Analyse each thread's performance

Show scalability problems



GuideView: Per-Section View



Analyse each parallel region

Sort or filter regions to navigate to performance hotspots

Identify serial regions that hurt scalability

KAP/Pro (GuideView): Availability

- Supported platforms
  - Compaq Alpha Systems
    - Compaq Tru64 Unix 4.0 (C/C++, f77, f90)
    - Windows NT 4.0 (f77, f90)
  - SGI MIPS Systems
    - Irix 6.5 (C/C++, f77, f90)
  - Sun SPARC Systems
    - Solaris 2.5, 2.6, and 2.7 (C/C++, f77, f90)
  - Intel (IA32) Systems
    - Windows NT 4.0 (C, f77, f90)
    - Linux 2.0 (C/C++)
    - Solaris 2.5 (f77)
  - Hewlett Packard PA-RISC 2.0 Systems
    - HP-UX 11.0 (C/C++, f77, f90)
  - IBM RS/6000 Systems
    - IBM AIX 4.1 - 4.3 (C/C++, f77, f90)

3rd Party: URLs

- TRAPPER's parallel programming environment includes performance analysis and execution visualization tools
  `http://www.genias.de/products/trapper/`

- PGI's PGPROF HPF Profiler
  Post-mortem, Graphical or command-level profiling of HPF programs on MPP, SMP, and workstation cluster systems
  `http://www.pgroup.com/hpf_prof_desc.html`

- ETNUS Inc. TimeScan Multiprocess Event Analyzer
  `http://www.etnus.com/products/timescan/`

Research: Performance Tools

- Tracing of MPI Programs
  - Nupshot / Jumpshot (MPICH)
  - MPICL / Paragraph
  - AIMS, NTV
- Profiling / Tracing of parallel, multithreaded programs
  - TAU's Portable Profiling and Tracing Package
- Dynamic object code instrumentation
  - dyninst
  - DPCL
- Automatic Performance Analysis
  - Paradyn

Part III

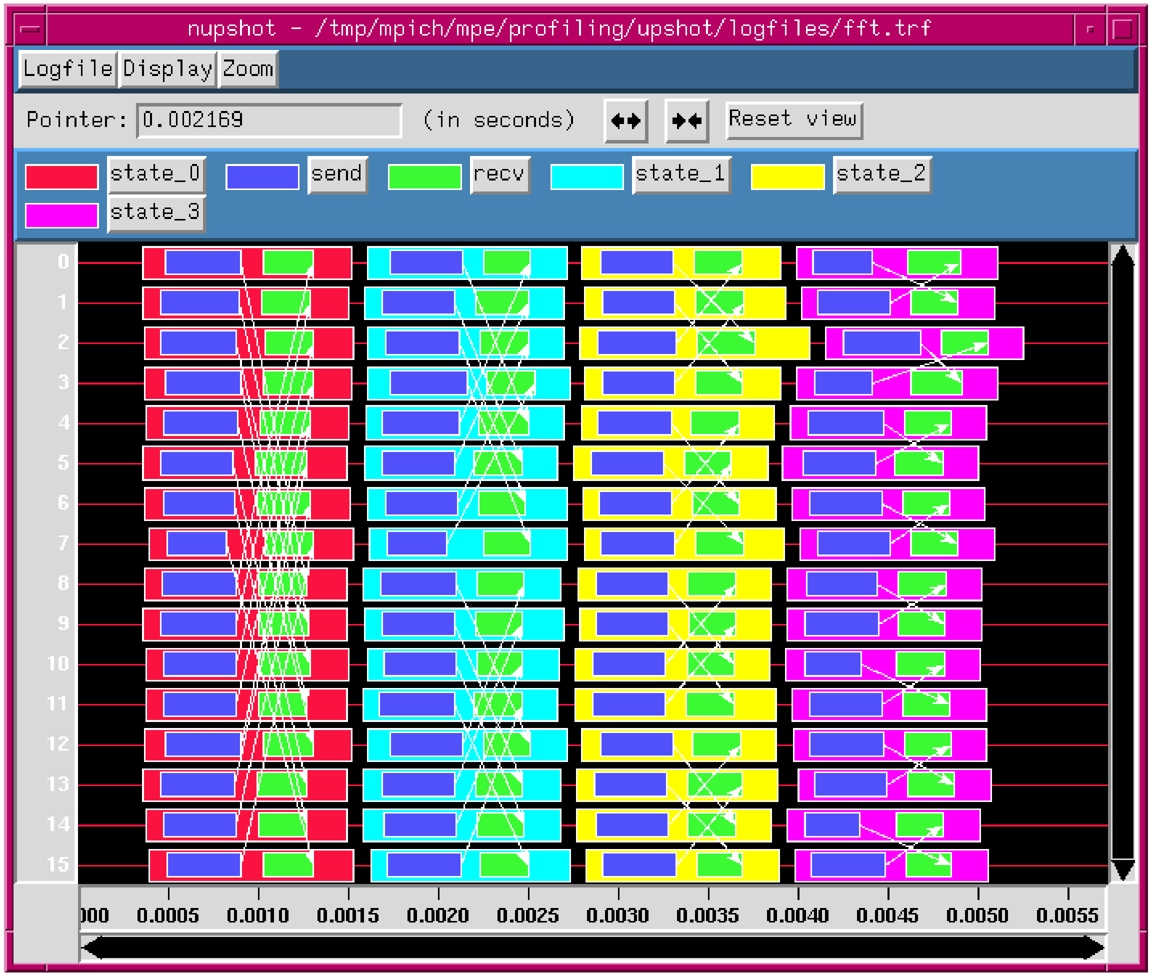
MPICH Tracing

- MPICH distribution provides portable MPI tracing library (called logging by MPICH) through MultiProcessing Environment (MPE)
- MPI programs generate traces when compiled with `-mpilog` option to `mpicc`, `mpiCC`, `mpif77`, or `mpif90` command
  [or link with `-llmpi -lmpe -lpmpi(ch) -lmpi(ch)`]
- implemented the standard MPI profiling interface
  - ⇒ works with other MPI implementations too (SGI, IBM, Cray)
- supports two trace formats
  - ALOG: older, can be viewed with nupshot
  - CLOG: newer, can be viewed with Jumpshot

  controlled by environment variable MPI_LOG_FORMAT
- `http://www-fp.mcs.anl.gov/~lusk/upshot/`

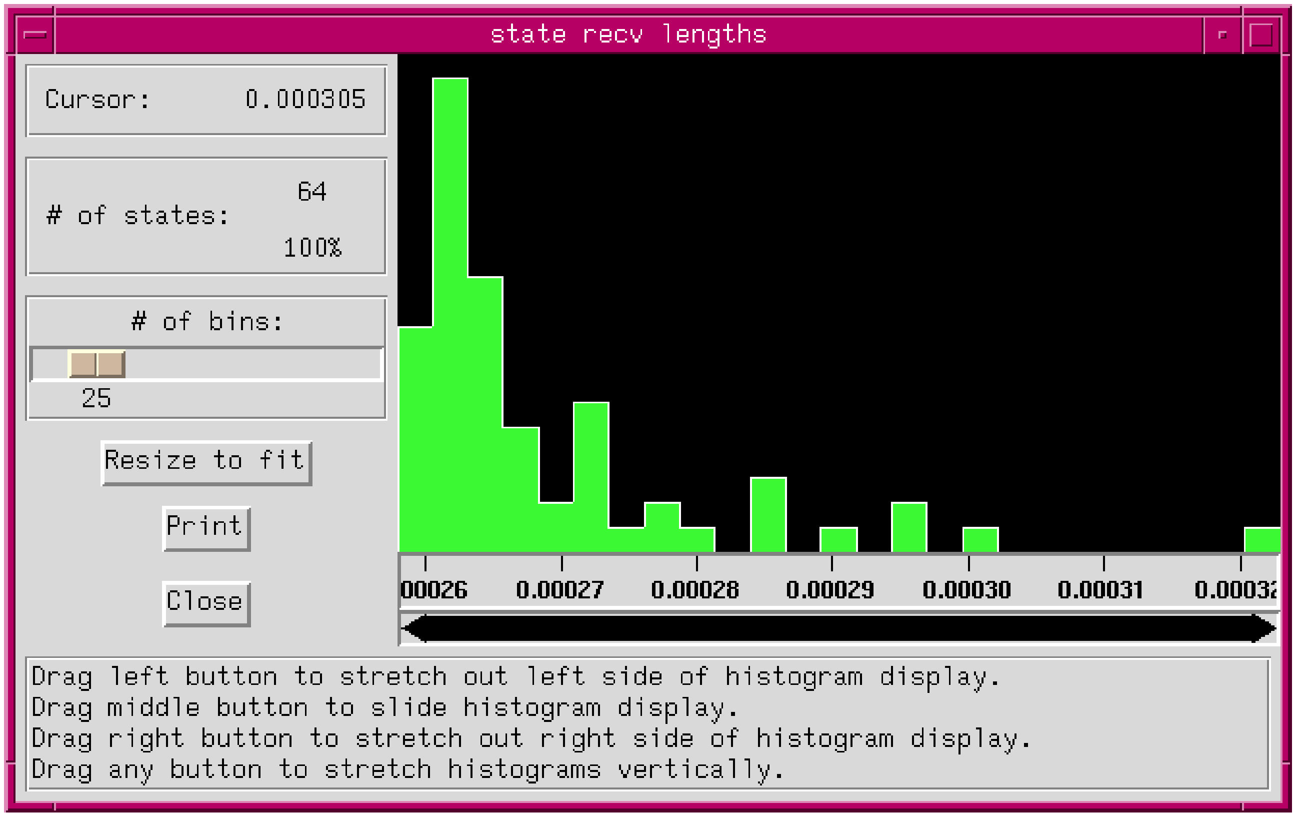
Nupshot: Timeline Display

- Static timeline display with zooming / panning
- Displays ALOG and PICL V1 formats
- Implemented with Tcl/Tk (3.6/7.3 needed)
- More portable, but slower version available as upshot



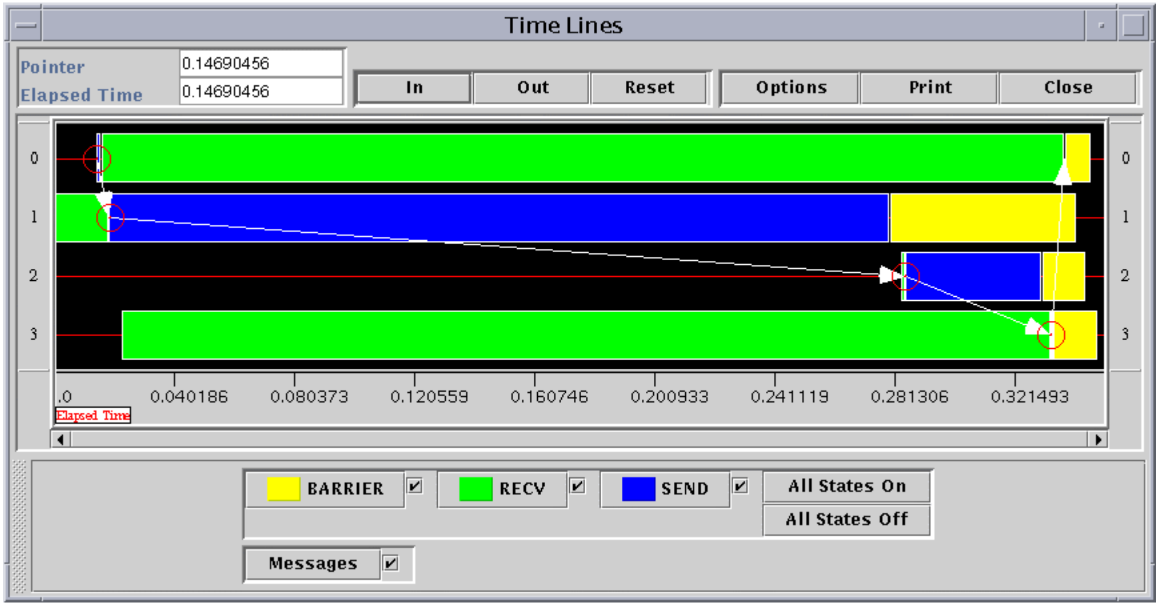
Nupshot: Statistics Display

- Statistic display showing execution time distribution of selected state
- Accessed through "state" button in timeline display



Jumpshot

- Static timeline display with zooming / panning
- Displays CLOG and PICL V1 formats
- Implemented in Java



- http://www-unix.mcs.anl.gov/~zaki/JS/home.html

MPE: Customizing Logfiles (C/C++)

- MPE calls for recording user subroutines

```
#include "mpe.h"
MPE_Describe_state(101, 102, "foo", "blue");
...

void foo {
    MPE_Log_event(101, 0, (char *)0);
    ...
    MPE_Log_event(102, 0, (char *)0);
}
```

- Event numbers used must be unique
- `MPE_Log_event` can log one integer and string argument
- Selective tracing through
  - `MPE_Stop_log();` # Turn tracing off
  - `MPE_Start_log();` # Turn tracing on

MPE: Customizing Logfiles (Fortran)

- MPE calls for recording user subroutines

```
      include 'mpef.h'
      call MPE_DESCRIBE_STATE(101, 102, "foo", "blue")
C
      SUBROUTINE foo(...)
      include 'mpef.h'
      call MPE_LOG_EVENT(101, 0, "")
C     ...
      call MPE_LOG_EVENT(102, 0, "")
      END
```

- Selective tracing through
  - `MPE_STOP_LOG()` # Turn tracing off
  - `MPE_START_LOG()` # Turn tracing on

MPICL / Paragraph

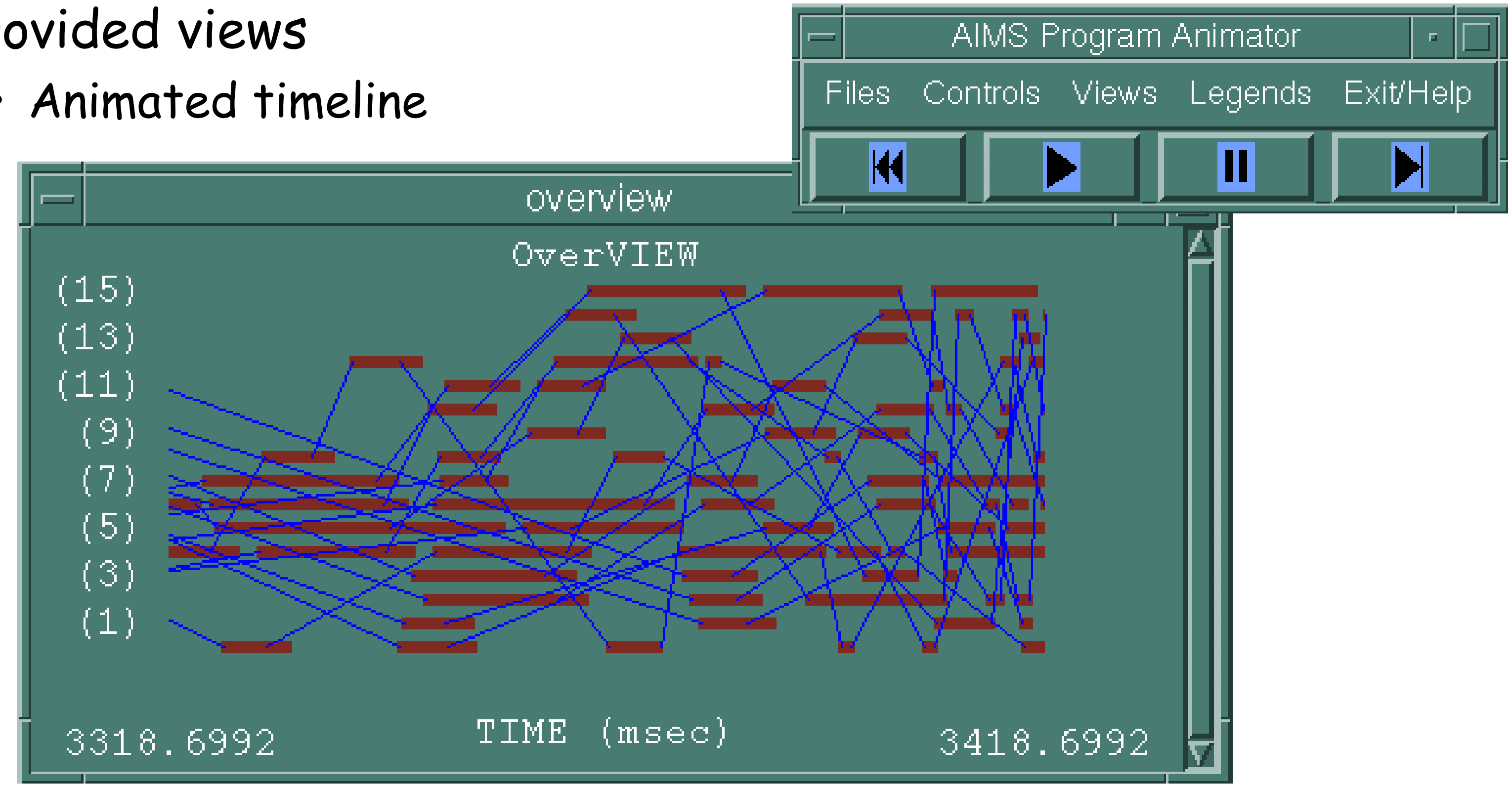
- subroutine library for collecting information
  - on communication and user-defined events
  - for Fortran / C MPI programs
- uses the standard MPI profiling interface
- two collection modes
  - profile data, summarizing the number of occurrences, the associated volume statistics, and the time spent in communication and user-defined events for each processor
  - collect detailed traces of each MPI function in PICL format suitable for viewing with Paragraph (nupshot, jumpshot)
- Tested on HP/Convex Exemplar, IBM SP, Intel Paragon, SGI/Cray O2K, SGI/Cray T3E, and on COW / MPICH
- But can easily be ported to any standards-compliant MPI
- http://www.epm.ornl.gov/picl/mpicl.html
- http://www.csar.uiuc.edu/software/paragraph

AIMS

- Automated Instrumentation and Monitoring System
- tool suite for performance measurement and analysis
  - xinstrument: source-code instrumentor for Fortran77 and C message-passing programs (MPI or PVM)
  - monitor: trace-collection library (for IBM SP-2 and workstation cluster (Convex/HP, Sun, SGIs, and IBM)
  - pc: utility for removing monitoring overhead and its effects on the communication patterns
  - trace file visualization and analysis toolkit: AIMS provides four trace post-processing kernels:
    - visualization/animation (VK)
    - text-based profiling (tally)
    - hierarchical performance tuning (xisk)
    - performance prediction (MK)
  - trace converters for PICL (Paragraph) and SDDF(Pablo)

AIMS: VK

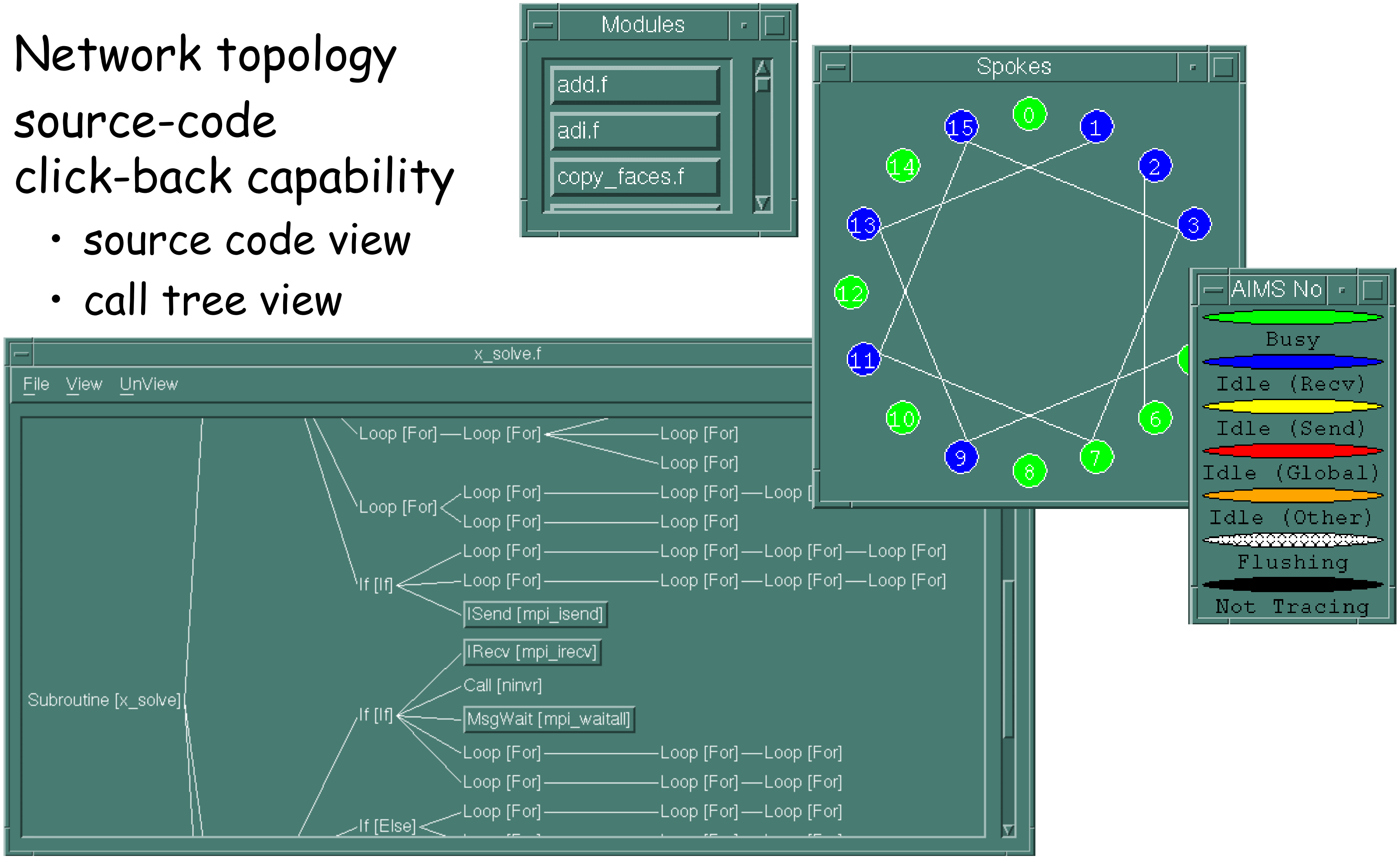
- Provided views
  - Animated timeline



  - The amount, type, duration of various I/O activities
  - Cost for partitioning data structures across the machine
  - The effective rate of execution for each basic block

AIMS: VK

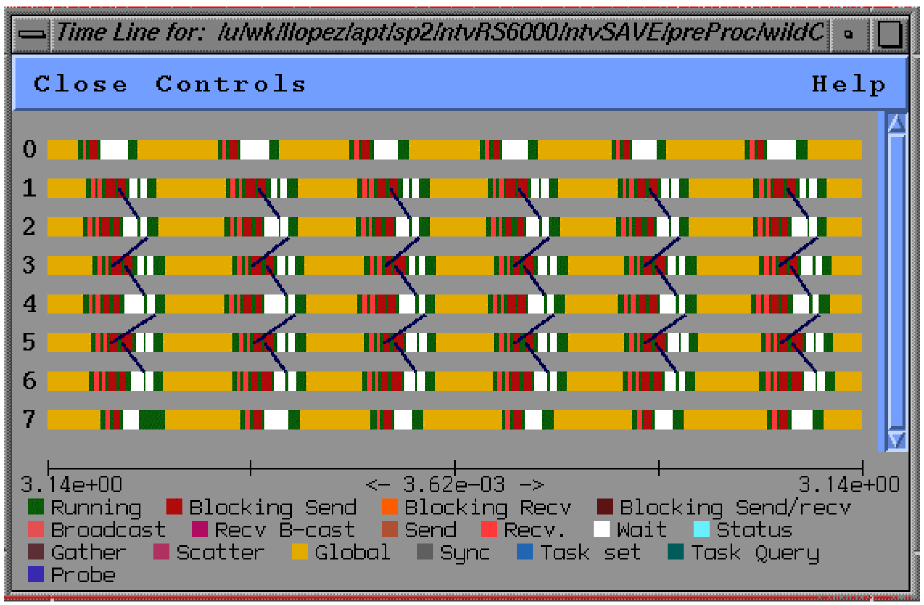
- Network topology
- source-code
  click-back capability
  - source code view
  - call tree view



- `http://www.nas.nasa.gov/Groups/Tools/Projects/AIMS/`

NTV

- NAS Trace Visualizer
- Supports AIMS trace format and IBM AIX trace format
- Static timeline with zooming / panning



- http://www.nas.nasa.gov/Groups/Tools/Projects/NTV/

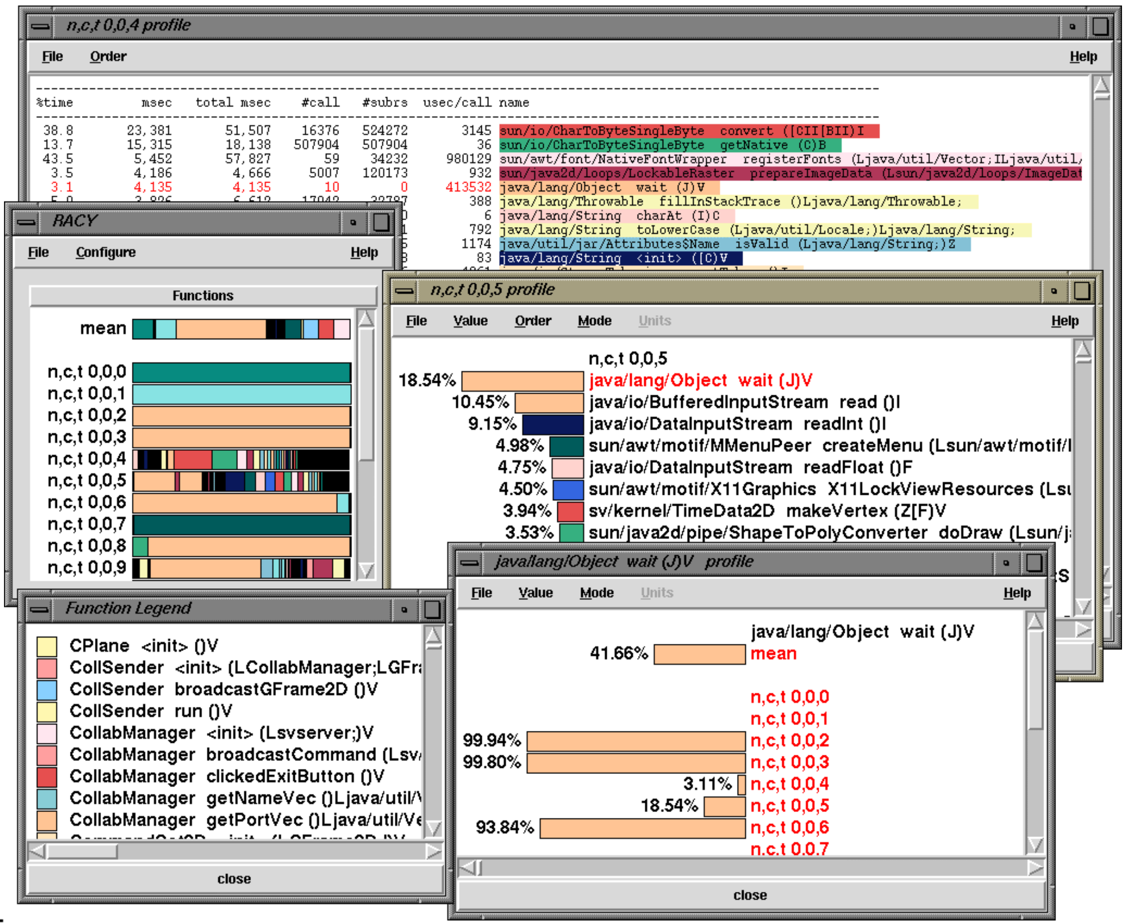
TAU's Portable Profiling and Tracing Package

- Portable toolkit for performance instrumentation, measurement, and analysis of parallel, multithreaded programs
- captures data for functions, methods, basic blocks, statement execution at all execution levels
- instrumentation API that allows the user to select
  - between profiling and tracing
  - application level
  - measurements alternative (e.g., timers, HW counters (via PCL))
  - measurement groups for organizing and controlling instrumentation
- works with a powerful code analysis system, the Program Database Toolkit (PDT), to implement automatic source instrumentation and static program browsers linked to dynamic performance information

Tuning and Analysis Utilities

TAU's Profile Visualization Tool: RACY

- provides graphical displays of all the performance analysis results, in aggregate and per node/context/thread form



TAU's Portable Profiling and Tracing Package

- Trace analysis utilizes the Vampir trace visualization tool
- Supports
  - platforms: SGI Power Challenge and O2K, IBM SP2, Intel Teraflop, Cray T3E, HP 9000, Sun, Windows 95/98/NT, Compaq Alpha and Intel Linux cluster
  - languages: C, C++, Fortran 77/90, HPF, HPC++, Java
  - thread packages: pthreads, Tulip threads, SMARTS threads, Java threads, Win32 threads
  - communications libraries: MPI, Nexus, Tulip, ACLMPL
  - compilers: KAI, PGI, GNU, Fujitsu, Sun, Microsoft, SGI and Cray

- `http://www.acl.lanl.gov/tau/`
- `http://www.cs.uoregon.edu/research/paracomp/pdtoolkit/`

Research: URLs: Profiling

- DCPI, the Digital Continuous Profiling Infrastructure
  `http://www.research.digital.com/SRC/dcpi`
- Rational Quantify
  `http://www.rational.com/products/quantify/`
- ThreadMon
  `http://www.cs.brown.edu/research/thmon/`
- WARTS, Wisconsin Architectural Research ToolSet, includes a number of profiling and tracing tools based on EEL:
  - QPT, Quick program Profiling and Tracing system
  - Cprof is a cache performance profiler that processes program traces generated by QPT (above)
  - PP is a Path Profiler

  `http://www.cs.wisc.edu/~larus/warts.html`

Research: URLs: Tracing

- Review of Performance Analysis Tools for MPI Programs (AIMS, Nupshot, SvPablo, Paradyn, VAMPIR, VT)
  `http://www.cs.utk.edu/~browne/perftools-review/`
- PABLO performance analysis and visualization toolkit
  `http://vibes.cs.uiuc.edu/`
  Includes SDDF trace file format
  `http://vibes.cs.uiuc.edu/Project/SDDF/SDDFOverview.htm`
- SvPablo, graphical source code browser for performance tuning and visualization
  `http://vibes.cs.uiuc.edu/Software/SvPablo/svPablo.htm`
- Scala, HPF+ post-execution performance tool
  `http://www.par.univie.ac.at/~scholz/scala-project/`
- MEDEA, MEasurements Description, Evaluation and Analysis
  `http://mafalda.unipv.it/Docs/medea.html`

Research: URLs: Catalogs / Misc

- NHSE tool catalog
  `http://www.nhse.org/rib/repositories/ptlib/catalog/`
- Parallel Tools Index from Cornell Theory Center
  `http://www.tc.cornell.edu/UserDoc/Software/PTools/`
- NAS Parallel Tools Group Hotlist
  `http://www.nas.nasa.gov/Groups/Tools/Outside/`
- Nan's Parallel Computing Page (Huge Index)
  `http://www.cs.rit.edu/~ncs/parallel.html`
- Ptools:The Parallel Tools Consortium
  `http://www.ptools.org`
- EuroTools Working Group
  `http://www.eurotools.org`

Software Tools
for Computational and Data Intensive Applications

Fall-back: Home-grown Performance Tools

- If performance analysis and tuning tools are
  - not available
  - too complex and complicated

  it is still possible to do some simple measurements

- Time Measurements
  - clock( )
  - times( )
  - ...
- Hardware Performance Counter Measurements
  - PCL
  - PAPI

Timer: clock

- ANSI C / C++ function
- returns amount of CPU time (user+system) in microseconds used since first call to clock()

```
#include <time.h>

clock_t startime, endtime;
double elapsed;   /* seconds */

startime = clock();
   /* -- long running code -- */
endtime = clock();

elapsed = (endtime - startime)
          / (double) CLOCKS_PER_SEC;
```

Timer: clock

- If measured region is short, run it in a loop
  [applies to all measurements]

```
#include <time.h>

clock_t startime, endtime;
double elapsed;   /* seconds */
int i;

startime = clock();
for (i=0; i<1000; ++i)
   /* -- short running code -- */
endtime = clock();
elapsed = (endtime - startime)
          / (double) CLOCKS_PER_SEC
          / i;
```

- But beware of compiler optimizations!!!

Timer: times

- Std. UNIX function: returns wall clock, system and user time

```
#include <sys/times.h>
#include <limits.h>

struct tms s, e;
clock_t startime, endtime;
double wtime, utime, stime;   /* seconds */

startime = times(&s);
   /* -- long running code -- */
endtime = times(&e);

utime = (e.tms_utime - s.tms_utime) / (double) CLK_TCK;
stime = (e.tms_stime - s.tms_stime) / (double) CLK_TCK;
wtime = (endtime - startime) / (double) CLK_TCK;
```

Timer: gettimeofday

- OSF X/Open UNIX function
- returns wall clock time in microsecond resolution
- base value is 00:00 UCT, January 1, 1970
- portability quirk: optional / missing 2nd argument

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

struct timeval tv;
double walltime;   /* seconds */

gettimeofday(&tv, NULL);
walltime = tv.tv_sec + tv.tv_usec * 1.0e-6;
```

Timer: getrusage

- OSF X/Open UNIX function
- fills in structure with lots of information:
  user time, system time, memory usage, context switches, ...

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

struct rusage ru;
double usrtime;  /* seconds */
int memused;

getrusage(RUSAGE_SELF, &ru);
usrtime = ru.ru_utime.tv_sec +
          ru.ru_utime.tv_usec * 1.0e-6;
memused = ru.ru_maxrss;
```

Timer: others

- MPI programmers can use portable MPI wall-clock timer

```
#include <mpi.h>
double walltime;   /* seconds */

walltime = MPI_Wtime();
```

- Fortran90 users can use intrinsic subroutines
  - cpu_time()
  - system_clock()
- Ptools Portable Timing Routines (PTR) Project
  - library of high resolution timers supported across current MPP and workstation platforms
  - see `http://www.ptools.org/projects/ptr/`

HW Counter: PCL

- Performance Counter Library (PCL)
  - portable API for accessing hardware performance counters
  - provides C, C++, Fortran, Java interfaces
  - supported platforms
    - SGI/Cray T3E with DEC Alpha 21164 CPU
    - Compaq/DEC with DEC Alpha 21164 and 21264 CPU
    - SUN with UltraSPARC I and II CPU
    - SGI O2K with MIPS R10000 CPU
    - IBM with PowerPC 604e CPU
    - Intel/Linux with Pentium, Pentium Pro, Pentium II, Pentium III CPU
  - see `http://www.fz-juelich.de/zam/PCL`

HW Counter: PCL

```
#include <stdio.h>
#include “pcl.h”

PCL_CNT_TYPE i_result[2];
PCL_FP_CNT_TYPE fp_result[2];
int counter_list[2] = { PCL_FP_INSTR, PCL_CYCLES };
unsigned int flags = PCL_MODE_USER;

if ( PCLstart(counter_list, 2, flags) != PCL_SUCCESS )
    error();
long_running_function();
if ( PCLstop(i_result, fp_result, 2) != PCL_SUCCESS)
    error();
printf("%15.0f flops in %15.0f cycles\n",
        (double) i_result[0],
        (double) i_result[1]);
```


HW Counter: others

- Ptools Performance Data Standard and API (PAPI) Project
  - specify a standard application programmer interface (API) for accessing hardware performance counters
  - includes a standard set of definitions for a common set of performance metrics as well as specifications of routines to access these metrics
  - provide a means of accessing platform-specific metrics available on a given processor
  - see `http://icl.cs.utk.edu/projects/papi/`

- HW Counter Reference Information
  - see `http://www.cs.utk.edu/~mucci/pdsa/reference.html`

The Future: Automatic Performance Analysis?

- Paradyn
  University of Wisconsin-Madison
  `http://www.cs.wisc.edu/paradyn/`
- Kappa-PI
  Universitat Autònoma de Barcelona
  `http://www.caos.uab.es/kpi.html`
- Finesse
  Victoria University of Manchester
- KOJAK
  Forschungszentrum Jülich
- Esprit Working Group APART
  Automatic Performance Analysis: Resources and Tools
  `http://www.fz-juelich.de/apart/`

Acknowledgements

- The author wants to thank the following persons for providing very valuable material and advice
  - Reiner Vogelsang, SGI/Cray Research
  - Jim Galarowicz, SGI/Cray Research
  - Alexandros Poulos, SGI
  - Luiz A. DeRose, IBM Research, ACTC
  - Hans-Christian Hoppe, Pallas GmbH
  - Werner Krotz-Vogel, Pallas GmbH
  - Uwe Fladrich, Technische Universität Dresden
  - Sameer Shende, University of Oregon
  - Rudolf Berrendorf, Forschungszentrum Jülich

[This slide intentionally left blank.]

Performance Analysis and Tuning of Parallel Programs: Resources and Tools

PART1 - Introduction and Overview

Michael Gerndt (Forschungszentrum Jülich)

PART2 - Resources and Tools

Bernd Mohr (Forschungszentrum Jülich)

PART3 - Automatic Performance Analysis with Paradyn

Barton Miller (University of Wisconsin-Madison)

Brian Wylie (University of Wisconsin-Madison)

Outline

- Brief motivation

- Sample analysis/tuning session with Paradyn
  - simple application start/attach (with no preparation required)
  - usual performance summaries/visualizations
  - automated exigency/bottleneck search

- Paradyn technologies and architecture
  - ***Dynamic Instrumentation***
  - the ***Performance Consultant***

- On-going research and development
  - current status and availability

Some History and Motivation

Experience with IPS-2 tools project:

- Trace-based tool running on workstations, SMP (Sequent Symmetry), Cray Y-MP.
- Commercial Success: in Sun SPARCWorks, Informix OnView, NSF Supercomputer Centers.
- Many real scientific and database/transaction users.

A 1992 Design Meeting at Intel:

- Goal was to identify hardware support for profiling and debugging for the Touchstone Sigma (Paragon) machine.
- Estimated the cost of tracing, using IPS-2 experience, and extrapolated to the new machine:
  2 MB/sec/node $\rightarrow$ 2 GB/sec of trace data for 1000-node machine.

An entirely new approach was required!

The Challenges

Scalability:
- Large, complex programs
- 100s or 1000s of nodes
- Long runs (hours or days)

Automation:
- Simplify programmer's task in the tuning process
- Manage increasing complexity of application/system

Heterogeneity:
- COWs, SMPs, MPPs
- UNIX, WindowsNT, Linux
- SPARC, x86, MIPS, PowerPC, Alpha
- Source languages: C, C++, Fortran
- Parallel libraries: PVM, MPI

Extensibility:
- Incorporate new sources of performance data and metrics
- Include new visualizations

Searching for Bottlenecks

1. Start with coarse-grain view of whole program performance.
2. When a problem seems to exist, collect more information to refine this problem.
3. Repeat step #2 until a precise enough cause is determined.
4. Collect information to try to refine (*localize*) the problem to particular hosts, processes, modules, functions, files, etc.
5. Repeat step #4 until a precise enough location is determined.

This type of iteration can take many runs of a program (and slow re-builds) to reach a useful conclusion.

Paradyn allows the programmer to do this on-the-fly in a single execution

Paradyn performance analysis/tuning scenario

Parallel/distributed application running on multiple nodes...

- How's it doing?
  - OK: Congratulations! (at least for now)
  - Dunno: Perhaps not so good?

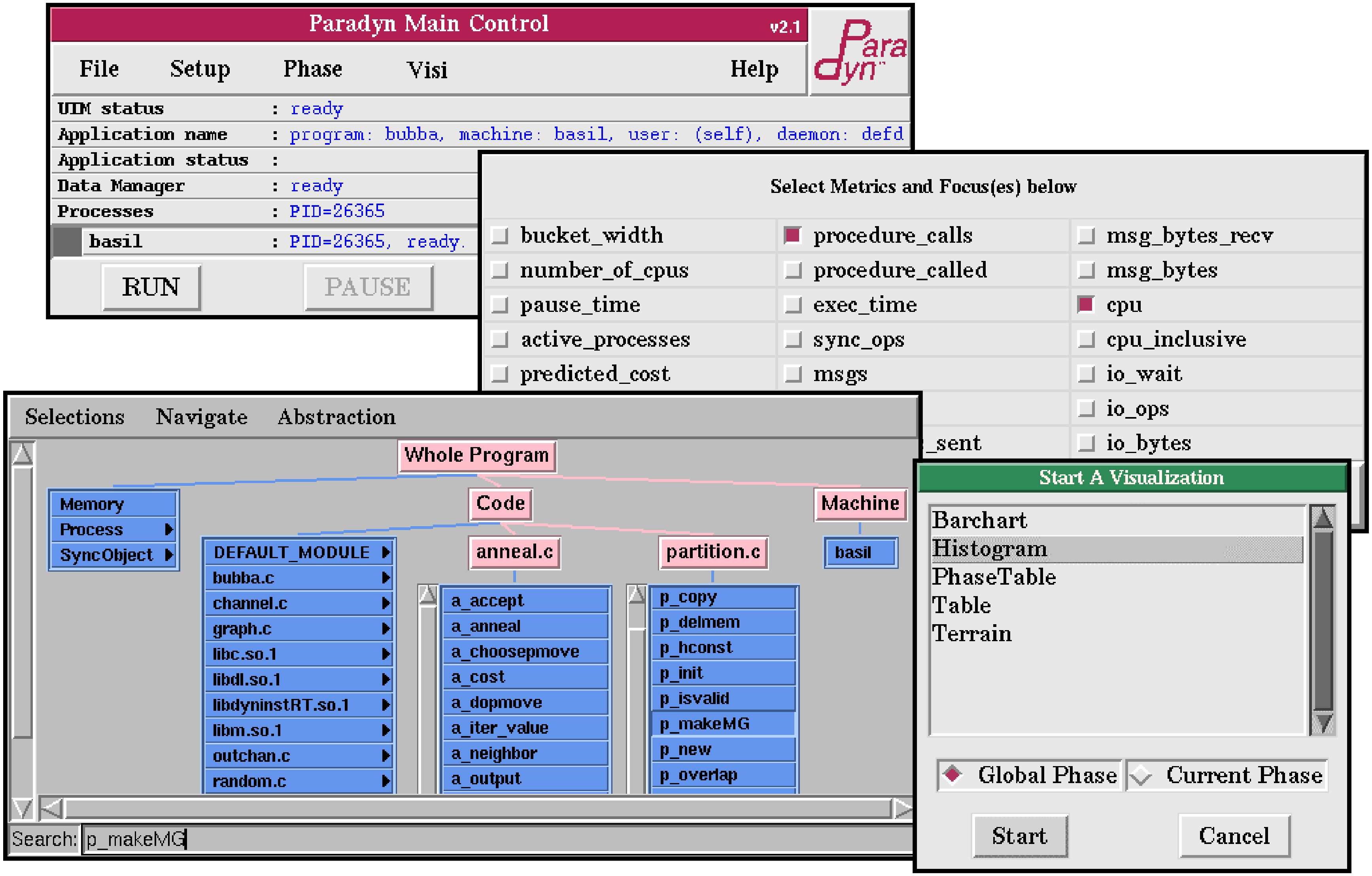
Let's investigate:

- Start Paradyn and attach to running application
  - Executable (and dynamic libraries) parsed to determine structural components and resources used

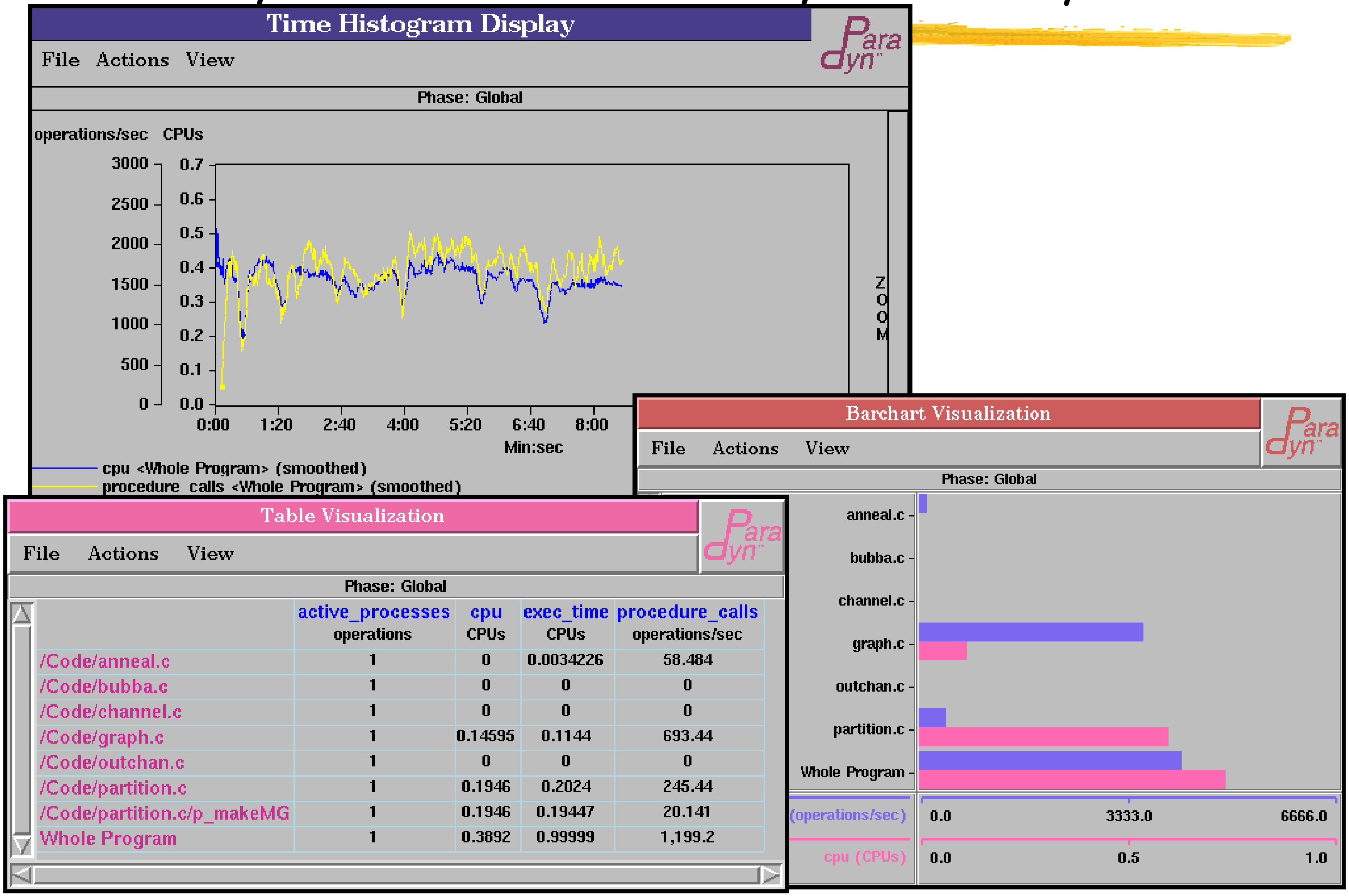
Have some idea where the problem may lie?

- Select components, performance metrics and presentations
  - Required instrumentation generated and patched into application
  - Accumulated metric data periodically sampled
- Examine presented information for insight into potential cause
- Implement a possible solution (rebuild and repeat...)

Paradyn <metric,focus> & visualization selection



Paradyn assorted time-history & summary visis



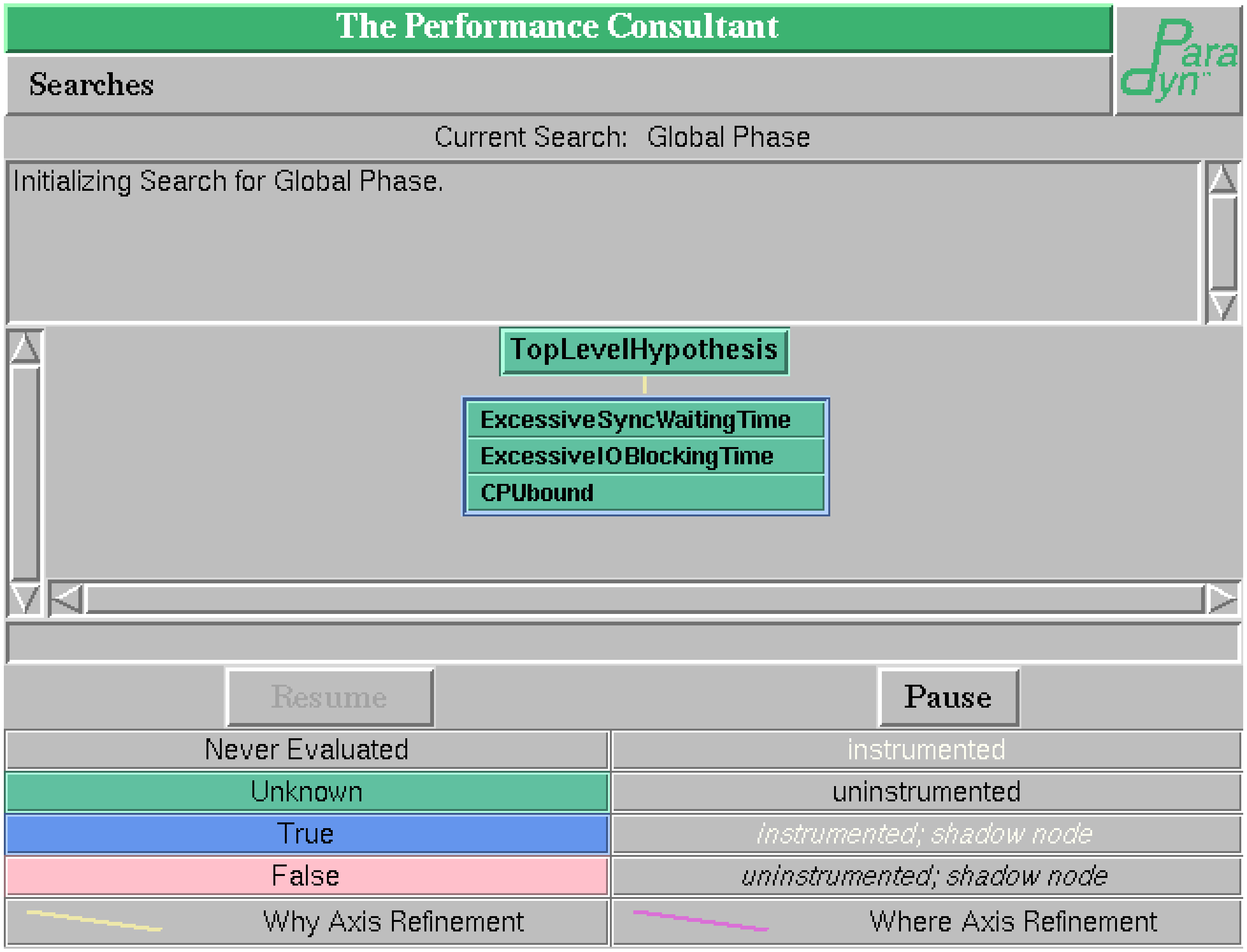
	active_processes operations	cpu CPUs	exec_time CPUs	procedure_calls operations/sec
/Code/anneal.c	1	0	0.0034226	58.484
/Code/bubba.c	1	0	0	0
/Code/channel.c	1	0	0	0
/Code/graph.c	1	0.14595	0.1144	693.44
/Code/outchan.c	1	0	0	0
/Code/partition.c	1	0.1946	0.2024	245.44
/Code/partition.c/p_makeMG	1	0.1946	0.19447	20.141
Whole Program	1	0.3892	0.99999	1,199.2

Paradyn performance analysis/tuning scenario (cont'd)

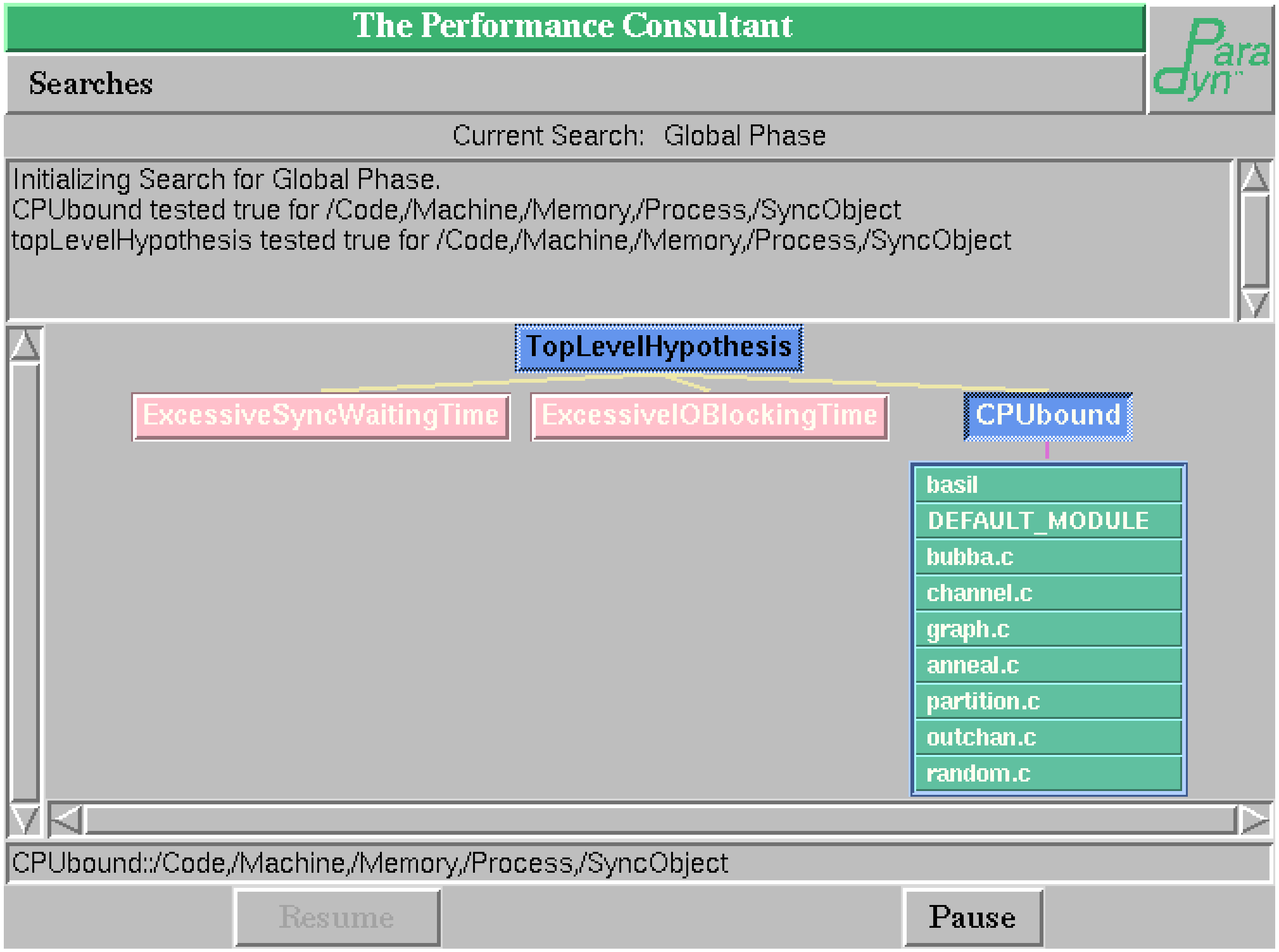
No idea where to start (or not finding the problem quickly)?

- Initiate Paradyn's *Performance Consultant* automated search
  - A pre-defined (tunable) set of hypotheses are considered in turn (to determine what type of problems may exist)
  - Instrumentation enabled as required and execution characteristics tracked for each current hypothesis
  - Step-wise hierarchical refinement to resolve bottleneck(s) (to focus where the problems are located)
  - Manage instrumentation costs/perturbations (trading accuracy with speed to judgement)
- Follow-up with additional execution statistics or time histories targeted at understanding the likely bottleneck(s)
  - Consider execution phases with distinct characteristics separately (to isolate when the problems manifest)
- Implement a possible solution and repeat...

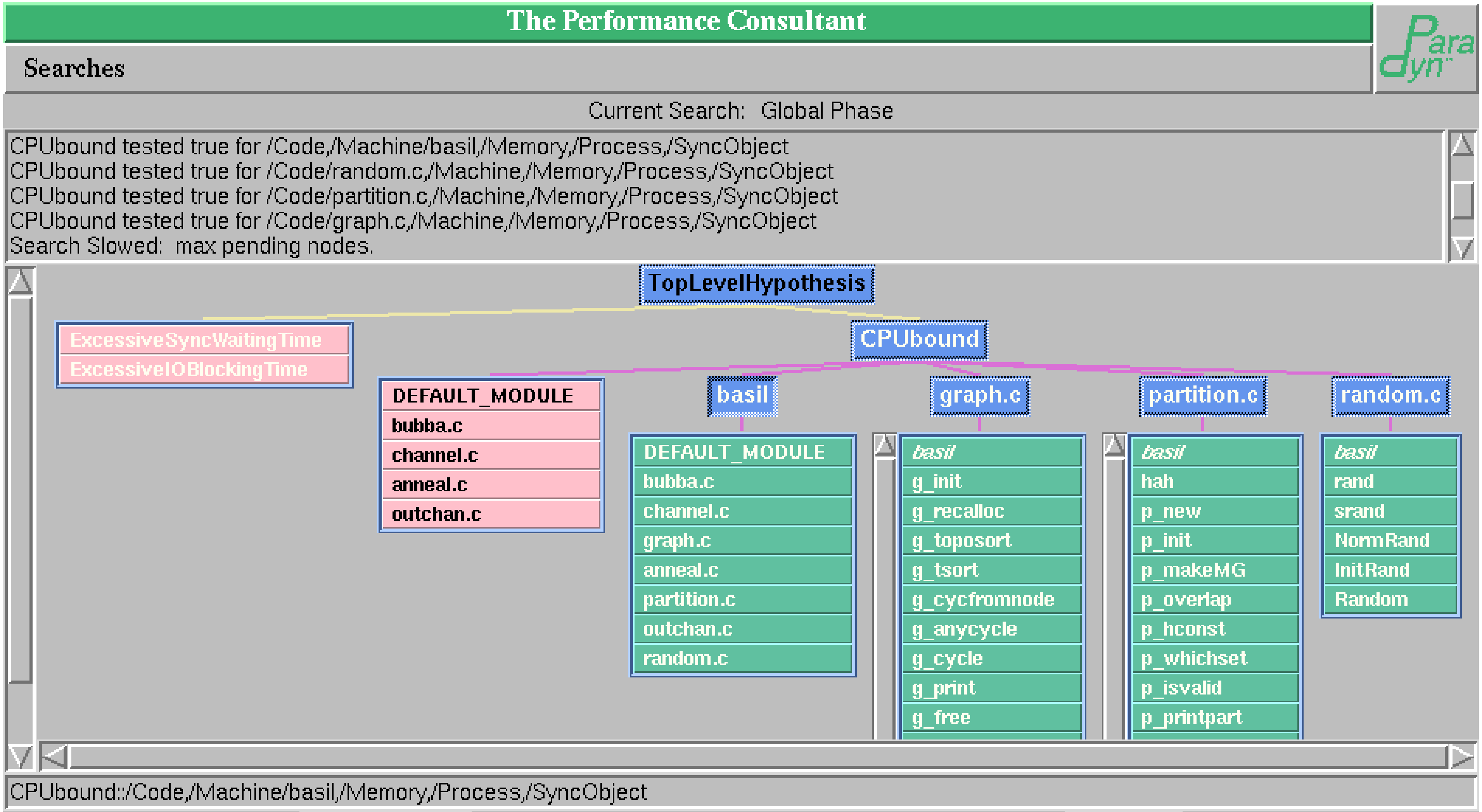
Performance Consultant search begins...



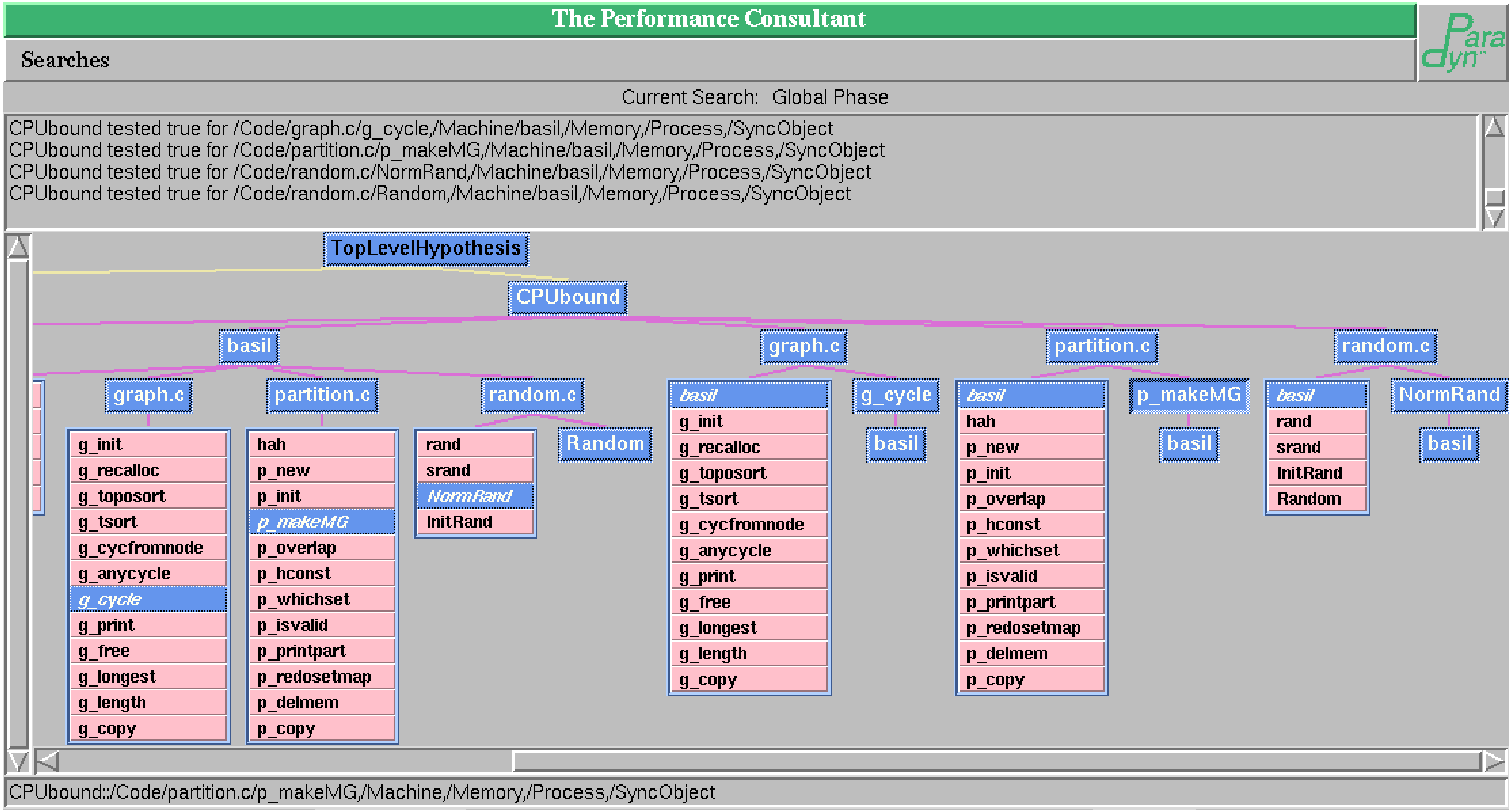
Performance Consultant 1st refinement ...



Performance Consultant 2nd refinements ...



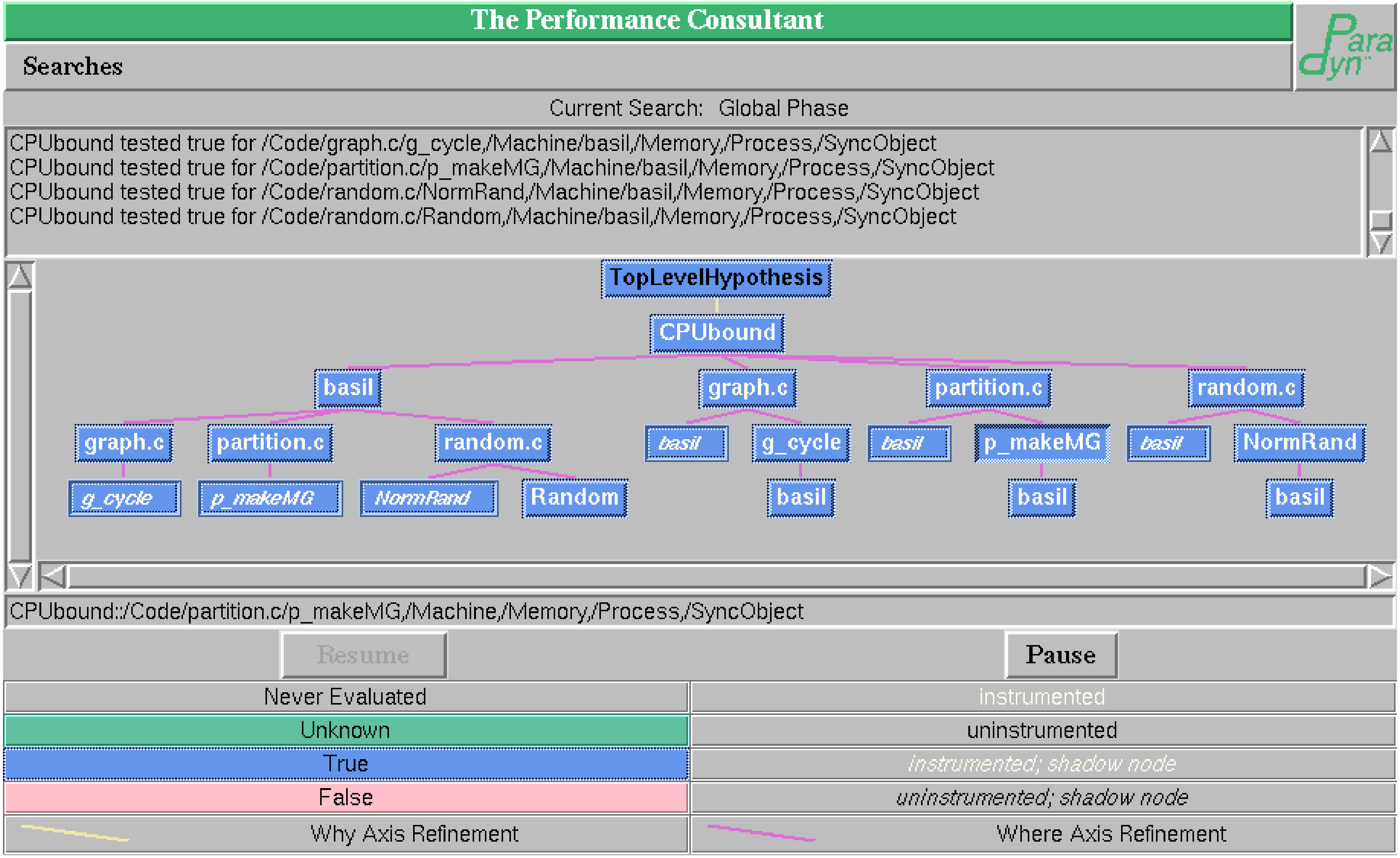
Performance Consultant search complete



UNIVERSITY OF WISCONSIN MADISON

Forschungszentrum Jülich

Performance Consultant complete (compact view)



Paradyn Technologies

Dynamic Instrumentation

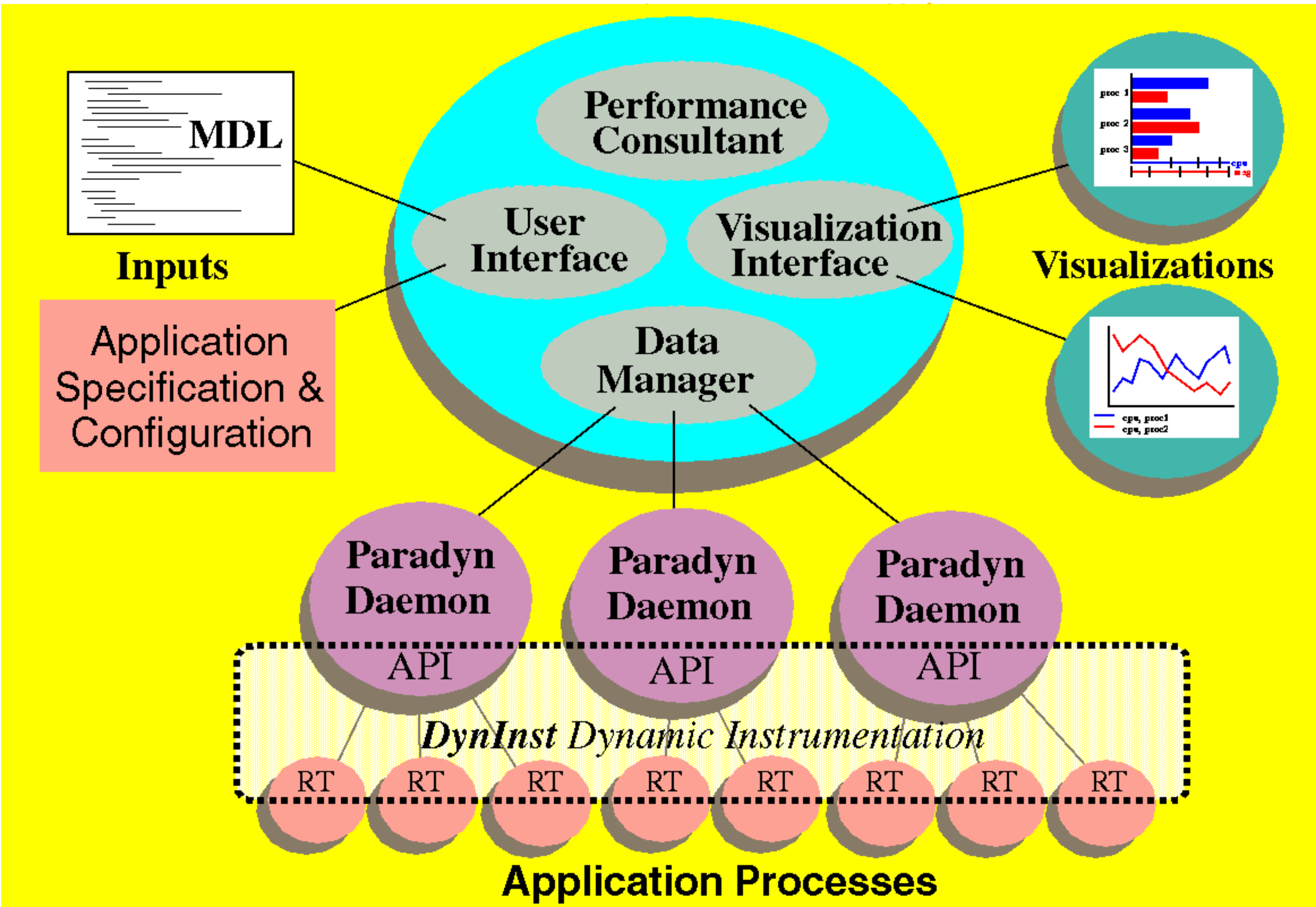
- On-the-fly generation, insertion, removal and modification of instrumentation in the application program while it is running.

Performance Consultant

- Automated (and regulated) exigency search and control of the Dynamic Instrumentation to expediently identify bottlenecks.

- Expressive event/metric instrumentation specification
- Efficient scalable data collection/storage management
- Extensible execution/performance data presentation/visualization

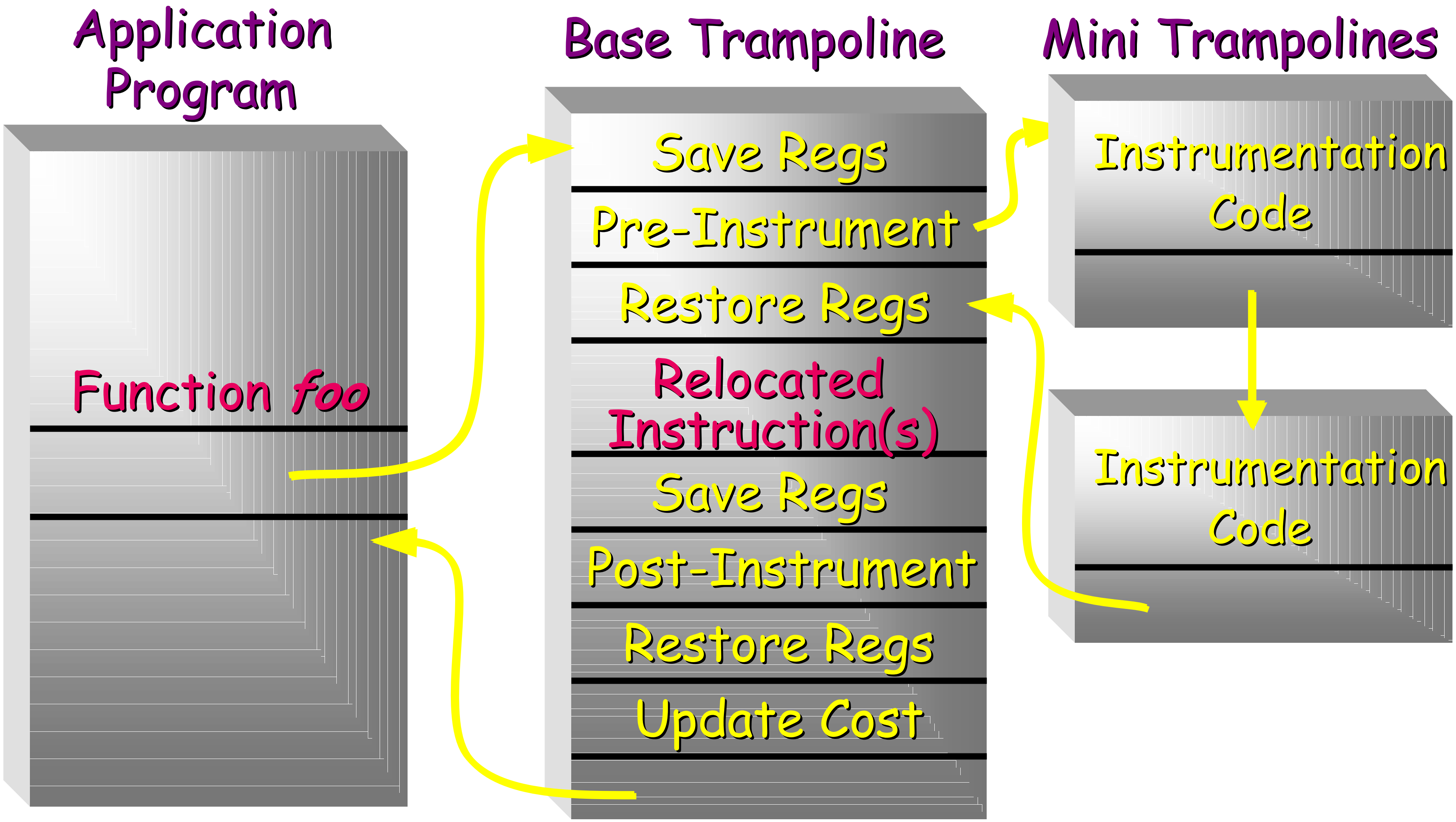
Paradyn Architecture



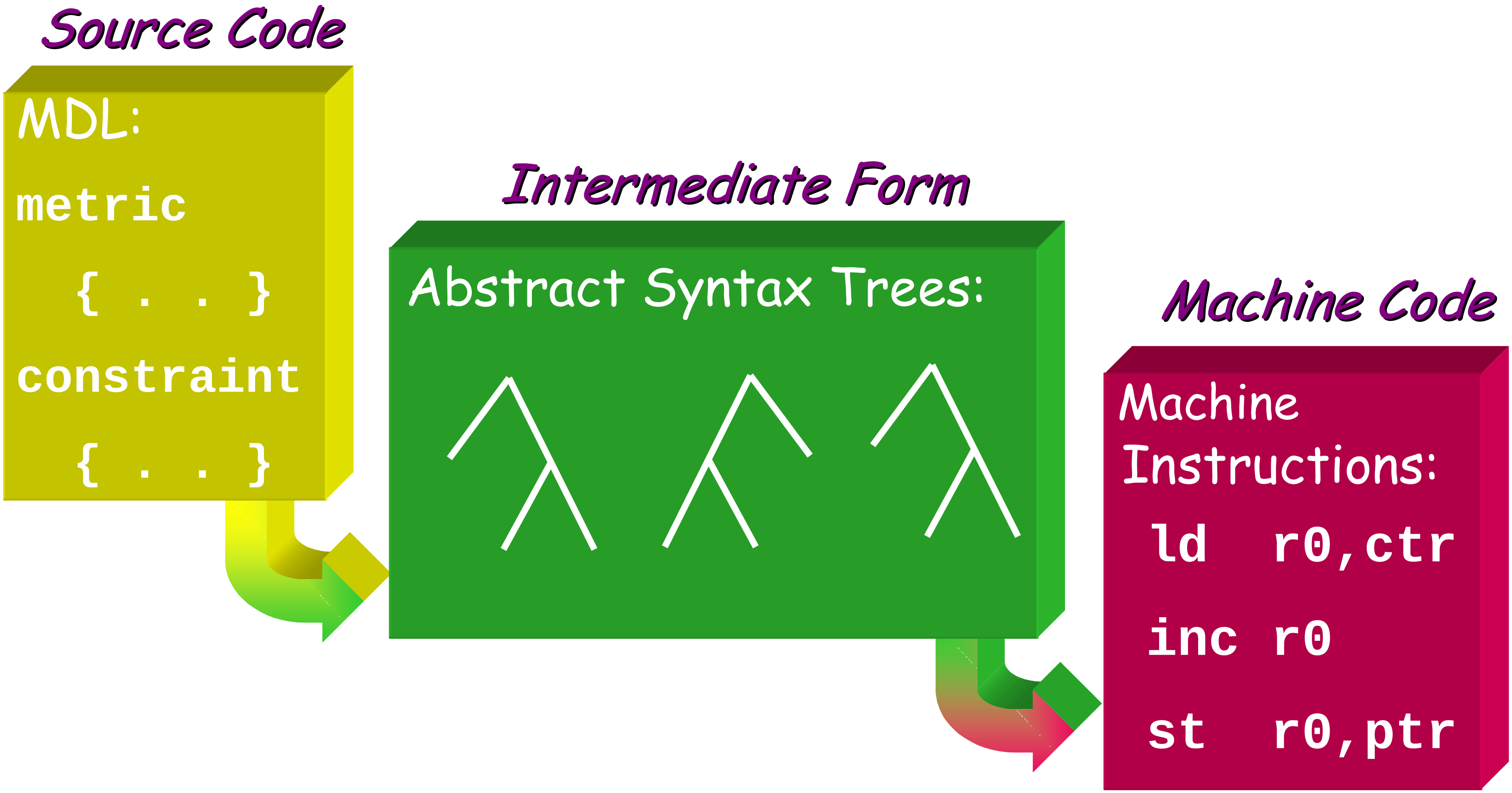
Dynamic Instrumentation

- For each subject program executable object/process:
  - Parse for 'interesting' symbols: functions, variables, etc.
  - Determine potential instrumentation points: *func_entry*, *func_exits*, *callsites*, ...
- At each chosen instrumentation point:
  - Relocate 'footprint' instruction(s) to instrumentation framework ("base trampoline") where execution state is reconstructed
  - De-optimize/re-write/relocate function, as necessary
  - Replace footprint instruction(s) with branch to base trampoline
- For each 'snippet' of executable instrumentation:
  - Synthesize it from abstract metric specification based on primitives and predicates
  - Embed instrumentation snippet in its own mini-trampoline
  - Daisy-chain snippet mini-trampolines from the base trampoline

Instrumentation Patching

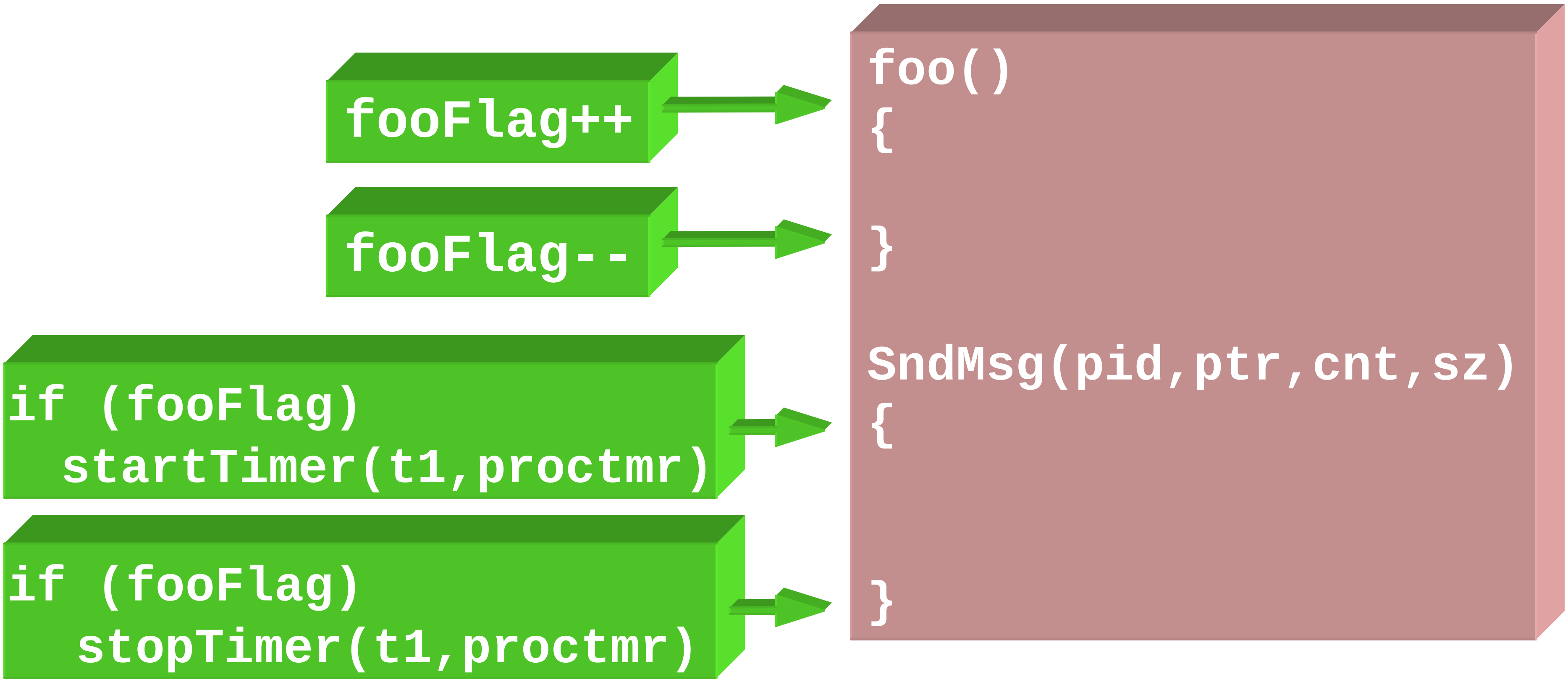


Compiling for Dynamic Instrumentation



Basic Instrumentation Operations

- Points: places to insert instrumentation
- Snippets: code that gets inserted



Dynamic Instrumentation Benefits

- Does not require recompiling or relinking
  - Saves time: compile and link times are significant in real systems.
  - Can profile without the source code (e.g., proprietary libraries).
  - Can profile without linking (relinking is not always possible).
- Instrument optimized code and threaded applications
  - De-optimize code as required on-the-fly
- Can monitor still-running programs (such as database servers)
  - Production systems, embedded systems.
  - Systems with complex start-up procedures.
- Only instrument what's needed, when it's needed
  - No hidden cost of latent instrumentation.
  - No *a priori* restrictions on the granularity of instrumentation.

Enables "one pass" performance sessions.

Dynamic Instrumentation Benefits (cont'd)

- Anything in the application's address space can become a performance measure
  - Application metrics: transactions/second, commits/second.
  - OS metrics: page faults, context switches, disk I/O operations.
  - Hardware metrics: cycle & instruction counters, miss rates, network statistics.
  - User-level protocol metrics: consistency messages, cache activity.
- Metrics defined with the ***Metric Description Language*** (MDL)
  - Neither performance tool nor application need be modified.
  - Define metrics once for each environment.
- Can dynamically monitor and control instrumentation overhead
  - Allows programmer to *monitor* intrusiveness.
  - Allows programmer to *control* intrusiveness.
  - Allows Performance Consultant to work efficiently.

Dynamic Instrumentation Challenges

- Finding instrumentation points (function entry, exits, call sites)
  - Procedure exits are often the toughest.
- Finding space for jump to trampoline
  - Long jumps (2-5 words or 5 bytes).
  - Short code sequences.
  - Small functions.
  - One byte instructions.
- Compiler optimizations (instrumenting optimized code)
  - No explicit stack frame (leaf functions).
  - Tight instrumentation points.
  - Data in code space (e.g., jump tables).
  - De-optimize code on the fly (e.g., tail calls).
- Threaded code

Scalable Data Collection & Storage

- Metrics are time-varying functions that quantify execution behavior (e.g., CPU utilization, messages/second, blocking time, file reads/second, ...)
- Instrumentation code in each application process calculates its own metrics (with counters and timers).

- "Every so often" each associated Paradyn daemon samples the performance data from a shared region.
- Accuracy of performance metrics is not affected by sampling rate ... only how often updated values are provided.

- Fixed-size discrete structure used to store time-varying data.
  - Each bucket holds the metric value for a time interval
  - When histogram is full, interval size doubled and data folded

Decision Support: "Performance Consultant"

Answer three questions:

- ***Why*** is the program running slowly?
- ***Where*** in the program is this occurring?
- ***When*** does this problem occur?

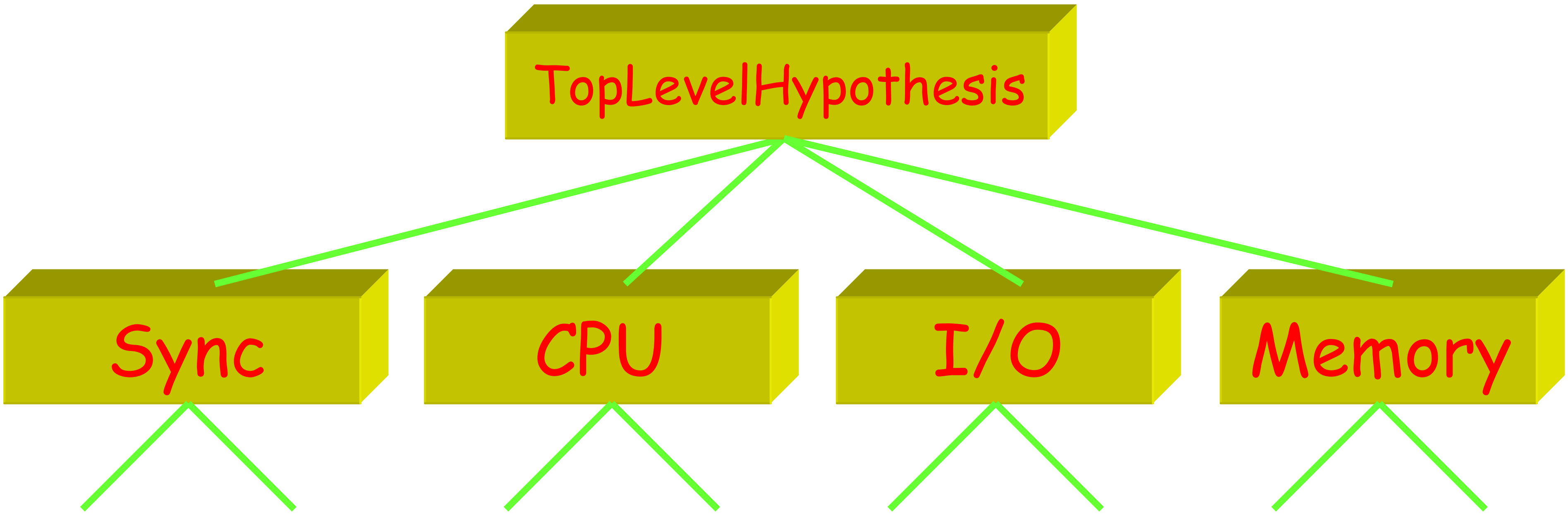
We create a regular structure for the causes of bottlenecks.
This makes it possible to automate the search for bottlenecks.

The "Why" Axis: A Hierarchy of Bottlenecks

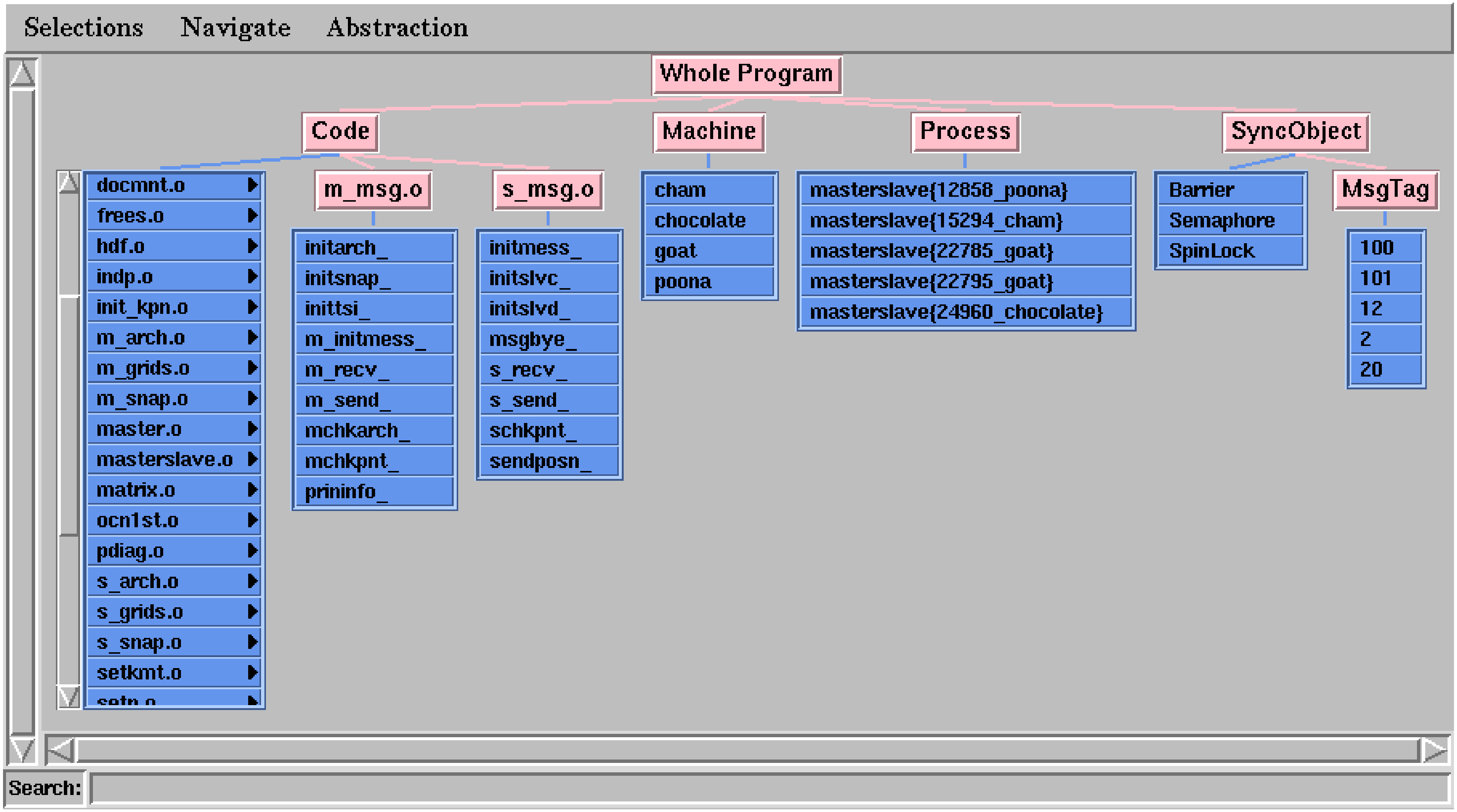
- Potential bottlenecks are represented as hypotheses.
- Evaluating hypotheses triggers dynamic instrumentation.
- Bottlenecks are based on user-set thresholds:

  Total sync blocking time < 25% of exec time

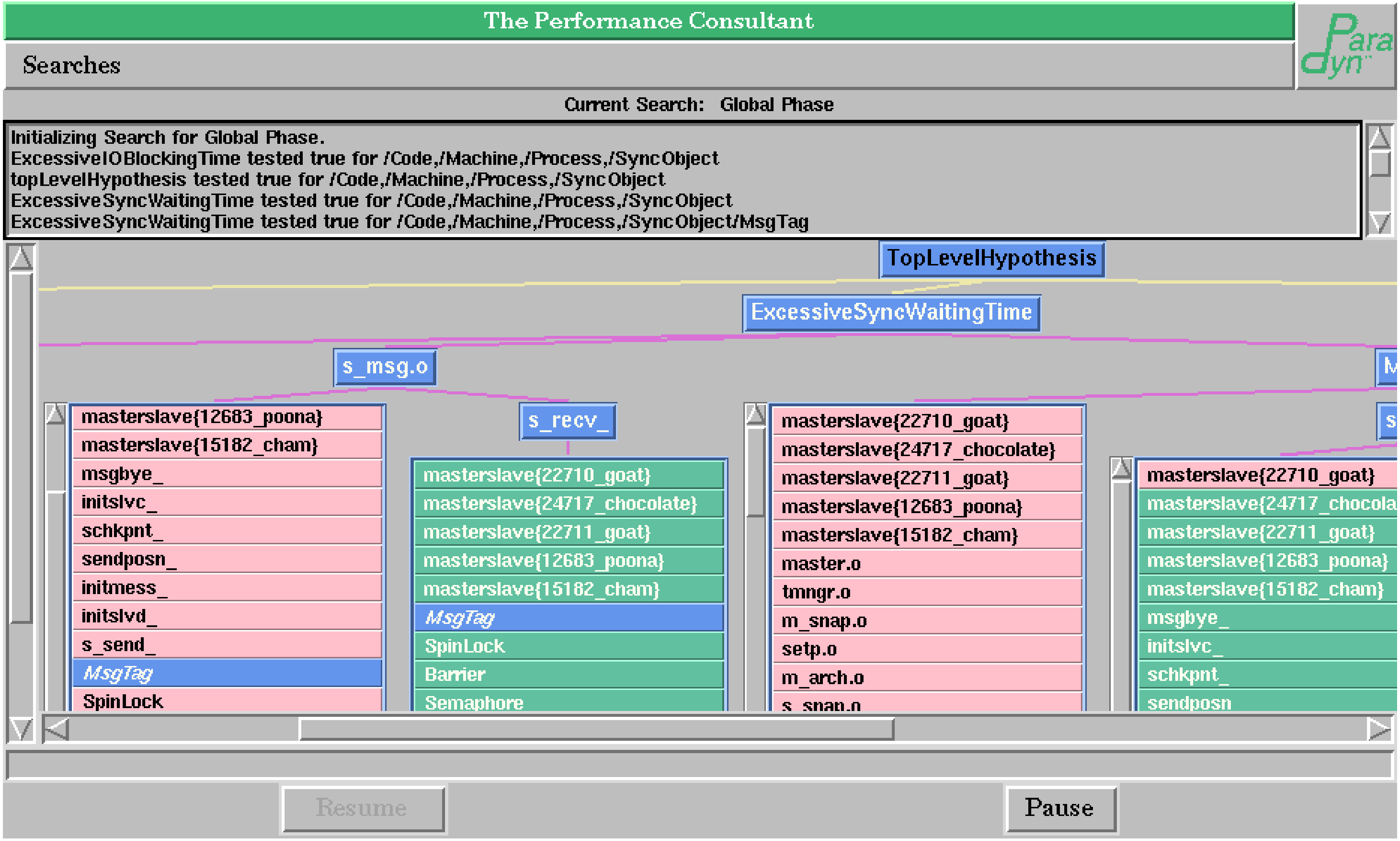
The "Why" Axis: A Hierarchy of Bottlenecks



Sample resource "Where Axis"



Performance Consultant (Ocean PVM)



Controlling Instrumentation Cost

"What is the overhead of instrumentation?"

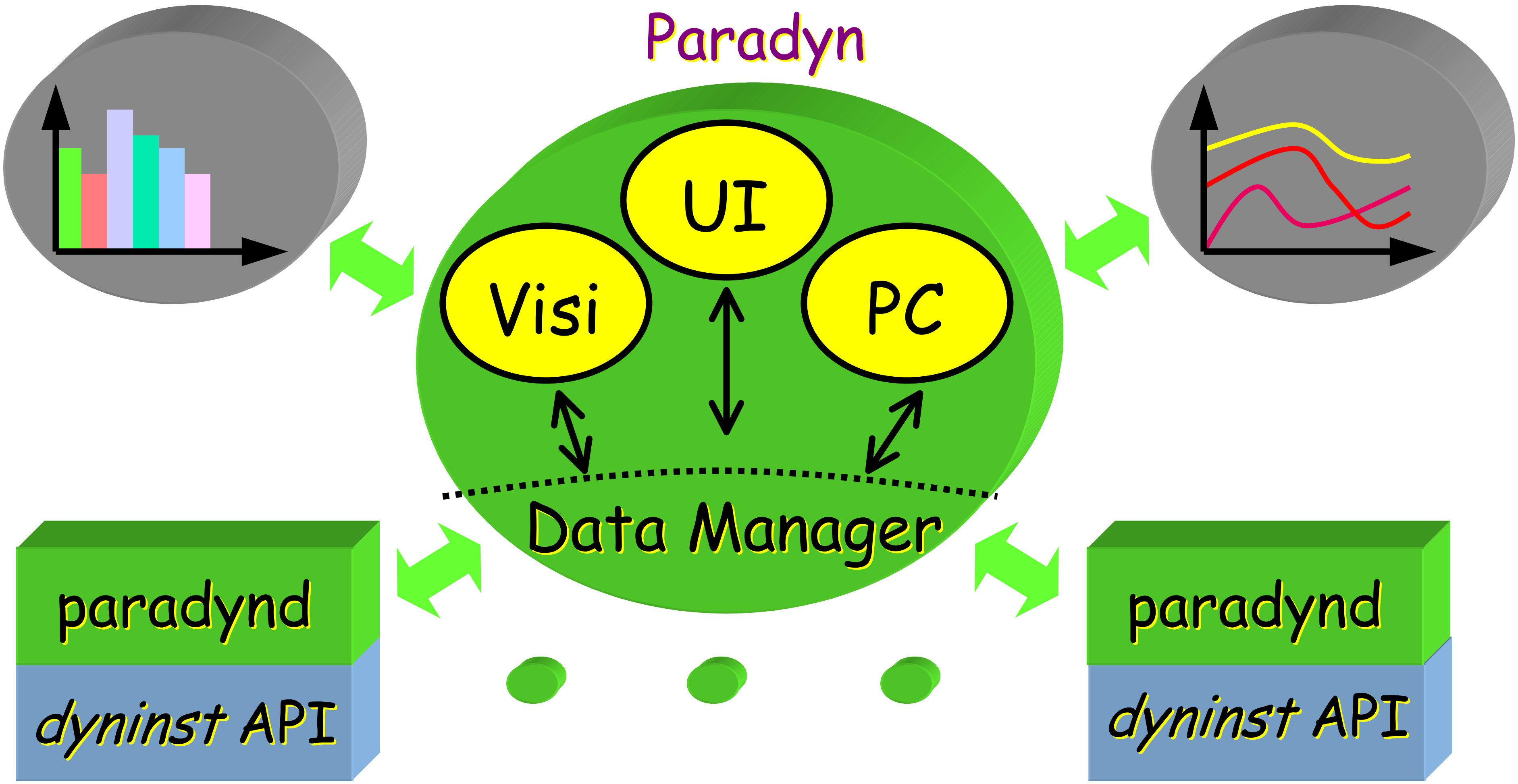
translates to:

"How many hypotheses can be evaluated at once?"

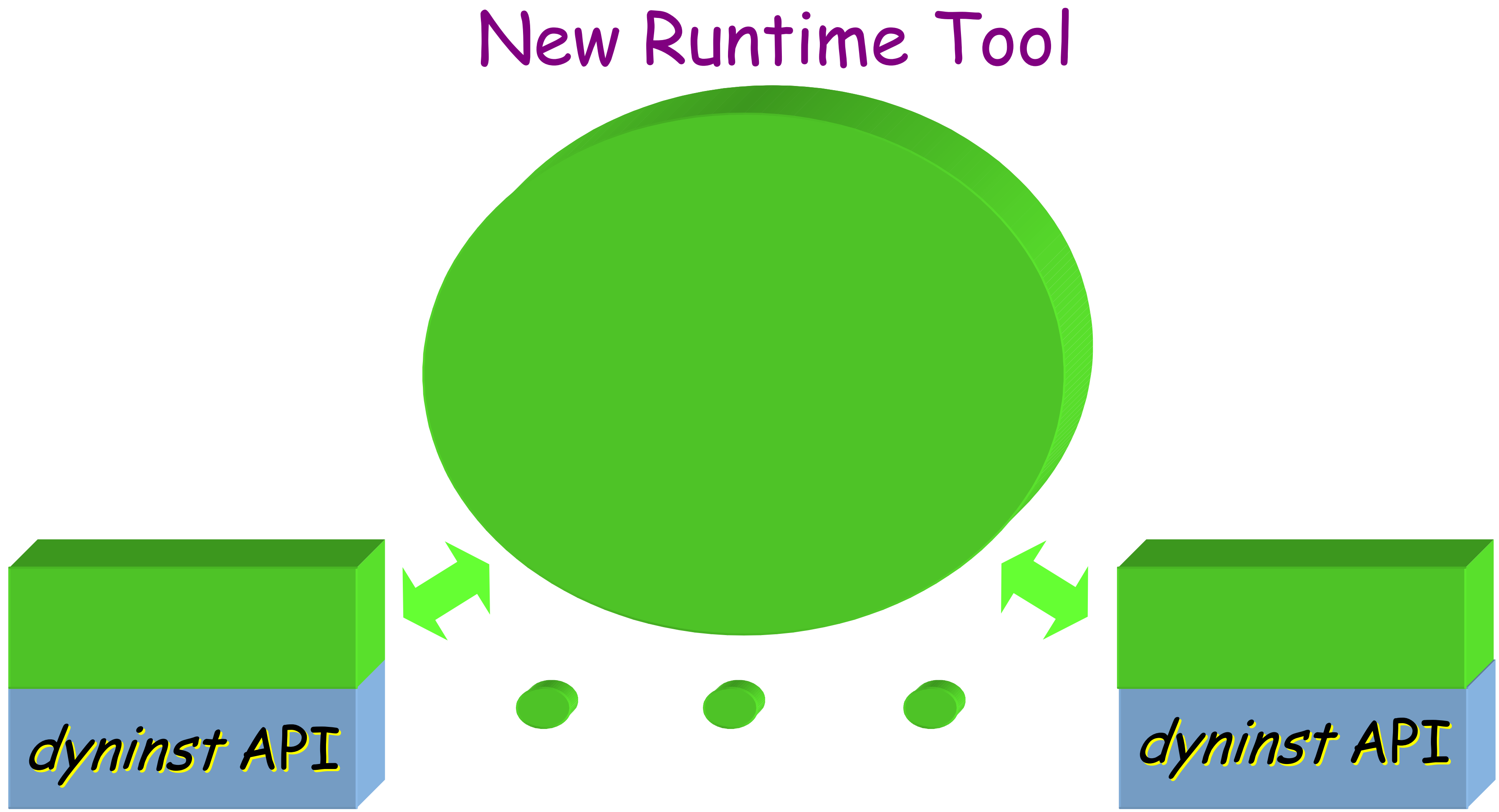
Predicted Cost:
- Known primitive cost
- Estimate frequency
- User-defined threshold

Observed Cost:
- Calculates actual cost
- Meta-instrumentation
- Reports to Performance Consultant

dyninst API: A Common Substrate



dyninst API: A Common Substrate



dyninst API

- Dynamic Instrumentation library and API
  - Basic substrate for building new tools.
  - Functions for control and interrogation of subject process execution
  - Runtime code generation and patching
  - Collaboration with University of Maryland.
- Basis for IBM's ***Dynamic Probe Class Library*** (DPCL) architecture for secure multi-node, multi-tool support
- Open effort to standardize functionality required for tools:
  - correctness debugging, memory stewardship, computational steering, R/A/S, load balancing, checkpointing, coverage testing, etc.
  - Involves computer vendors, tools researchers and users

Current Research Areas

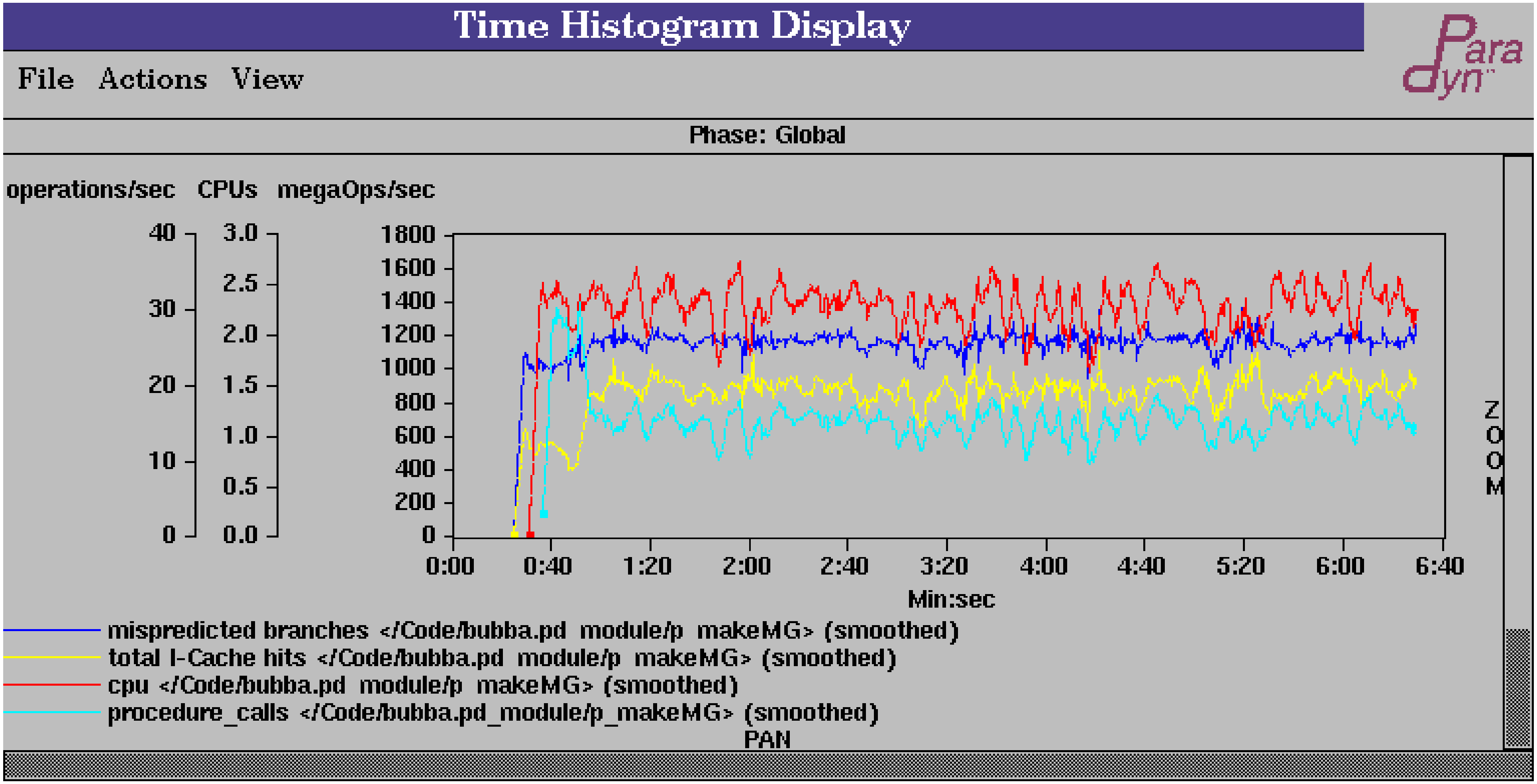
- Improved Performance Consultant (Trey)
  - Code/module/function hierarchy too wide for efficient searches.
  - Module instrumentation not cheaper than function instrumentation.
  - "Exclusive" metrics more expensive than inclusive metrics.

  New search based on static call graph, using inclusive metrics.
  - Search adapted to actual program execution
  - Dynamic call-site instrumentation to resolve calls-thru-registers
  - Instrumentation "ketchup" to retroactively activate new instrumentation for functions currently on the stack

Current Research Areas

- Evolving Operating Systems (Ari,Vic)
  - Fine-grained instrumentation.
  - On-the-fly kernel profiling, debugging, testing.
  - Code that adapts to workload.
  - Dynamically customizable kernels.

UltraSPARC Hardware Performance Counters



Current Research Areas

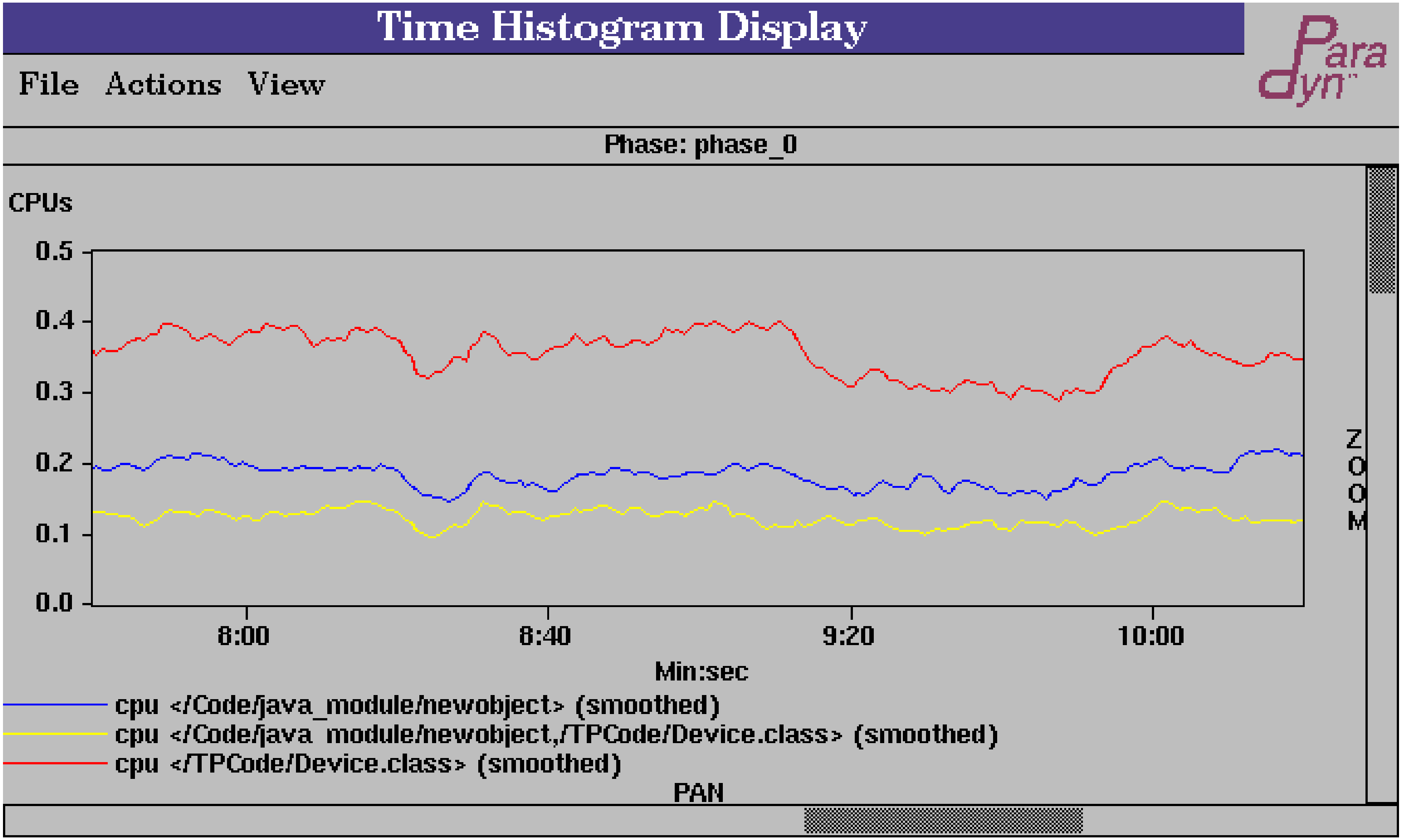
- Profiling Interpreted Code (Tia)
  - Performance data in terms of virtual machine:

    CPU time for interpreter function *f*.
  - Performance data in terms of application:

    CPU for Java method *m*.
  - Interaction effects:

    CPU time for function *f* when interpreting method *m*.
  - Multiple execution forms: interpreted and native machine code, and translation costs.

Java Application and VM Profiling



Current Research Areas

- Experiment Management (Karen)
  - Performance data from multiple runs (huge multidimensional space).
  - Tuning, benchmarking, regression testing, etc.
  - Provides infrastructure for manipulation and management of execution data
  - Automatically compare data from multiple runs.
  - Use historical information to speed performance diagnosis.
  - A "laboratory notebook" for performance studies.

Current Research Areas

- Condor Process Hijacking (Vic)
  - Step 1: Submitting "vanilla" jobs to Condor resource management system.
  - Step 2: Grabbing a running process and submitting it to Condor:
    - Replace running process' system call library.
    - Checkpoint new version of process.
    - Generate new "shadow" process.

- Dynamic Tracing (Chris)
  - Select "vanilla" MPI/PVM-based application (process)
  - Dynamically load desired tracing library: VampirTrace, Pablo, ...
  - Replace process' calls to MPI/PVM communication library with equivalents in tracing library
  - Optionally instrument selected functions with trace annotations
  - Initialize trace library and continue execution

How to Get a Copy of Paradyn

- Documentation: Installation Guide, Tutorial, Users Guide, Developers Guide, Visi/MDL/libthread Programmers Guides.
- Includes *dyninst* API, tests and Programmers Guide
- Free for research use.
- Runs on
  - Solaris (SPARC & x86)
  - Linux (x86)
  - Irix (MIPS)
  - WindowsNT (x86)
  - AIX/SP2 (PowerPC)
  - Tru64 Unix (Alpha)

http://www.cs.wisc.edu/paradyn

paradyn@cs.wisc.edu

Paradyn/dyninst developers

Current:

- Drew Bernat
- Trey Cain
- Chris Chambreau
- Karen Karavanic
- Nick Rasmussen
- Phil Roth
- Brandon Schendel
- Ari Tamches
- Brian Wylie
- Zhichen Xu
- Vic Zandy
- Wei Zhou

- Bryan Buck
- Jeff Hollingsworth
- Mustafa Tikir

Former:

- Mark Callaghan
- Jon Cargille
- Matt Cheyney
- John Davis
- Hyeonsang Eom
- Marcelo Gonçalves
- Krishna Kunchithapadam
- Bruce Irvin
- Oscar Naìm
- Dan Nash
- Tia Newhall
- Chris Serra
- Sunlung Suen
- Frank Tung
- Chun Zhang
- Ling Zheng

