Paradyn Parallel Performance Tools

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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.

More Motivation and History

A 1992 Design Meeting at Intel:

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

We went home to Madison to re-think this.

The Challenges

Scalability:

- Large Programs
- 100's or 1000's of nodes
- Long runs (hours or days)

Automate Tuning Process:

- Simplify the task of programmer
- Deal with increasing complexity.

Support Heterogeneity:

- COWs, SMPs, MPPs.
- UNIX, NT, Linux

Extensible:

- Incorporate new sources of performance data.
- Include new visualizations.

Searching for Bottlenecks

1. Start with coarse-grain view of whole program performance
2. When you see a problem, collect more information to refine this problem.
3. Repeat step #2 until you have a precise enough cause.
4. Collect information to try to refine to particular hosts, processes, modules, functions, files, etc.
5. Repeat step #4 until you have a precise enough location.

This type of iteration can take a user many runs of a program to reach a useful conclusion.

Approach the Problem Differently: Do Everything Dynamically

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

The Major Technologies

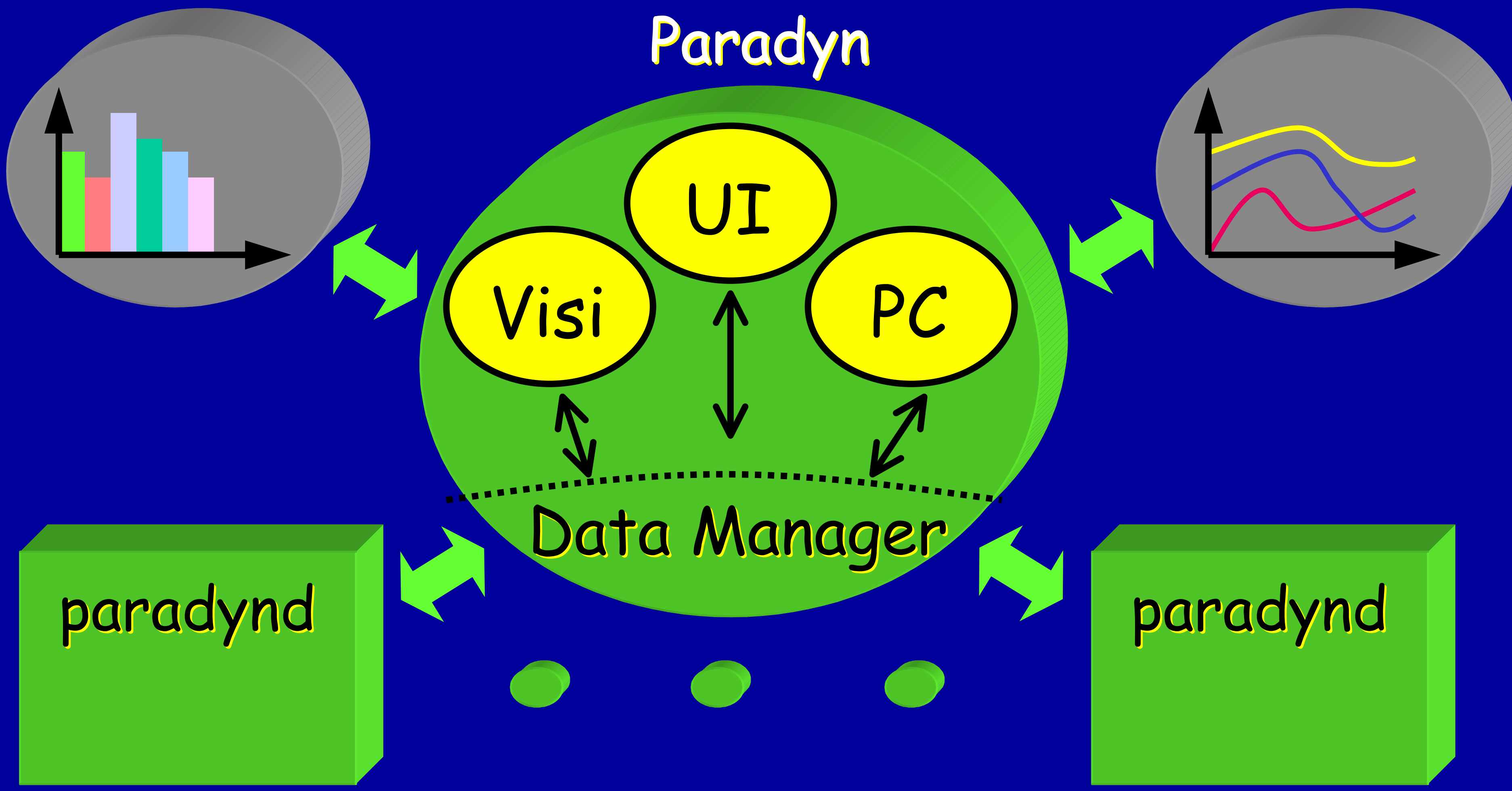
Dynamic Instrumentation

- On-the-fly: Insert, remove, and change instrumentation in the application program while it is running.

Automating the Search for Bottlenecks

- The Performance Consultant: identify bottlenecks and automate control the the Dynamic Instrumentation.

Paradyn Architecture



Dynamic Instrumentation

- ❑ 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.

Dynamic Instrumentation (con'd)

- Only instrument what you need, when you need
  - No hidden cost of latent instrumentation.
  - Enables "one pass" performance sessions.

- Can monitor running programs (such as database servers)
  - Production systems.
  - Embedded systems.
  - Systems with complex start-up procedures.

Dynamic Instrumentation (con'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's.
  - Hardware metrics: cycle & instruction counters, miss rates, network statistics.
  - User-level protocol metrics: Blizzard messages, cache activity.

Dynamic Instrumentation (con'd)

- New metrics defined through our 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 Perf Consultant to work efficiently.

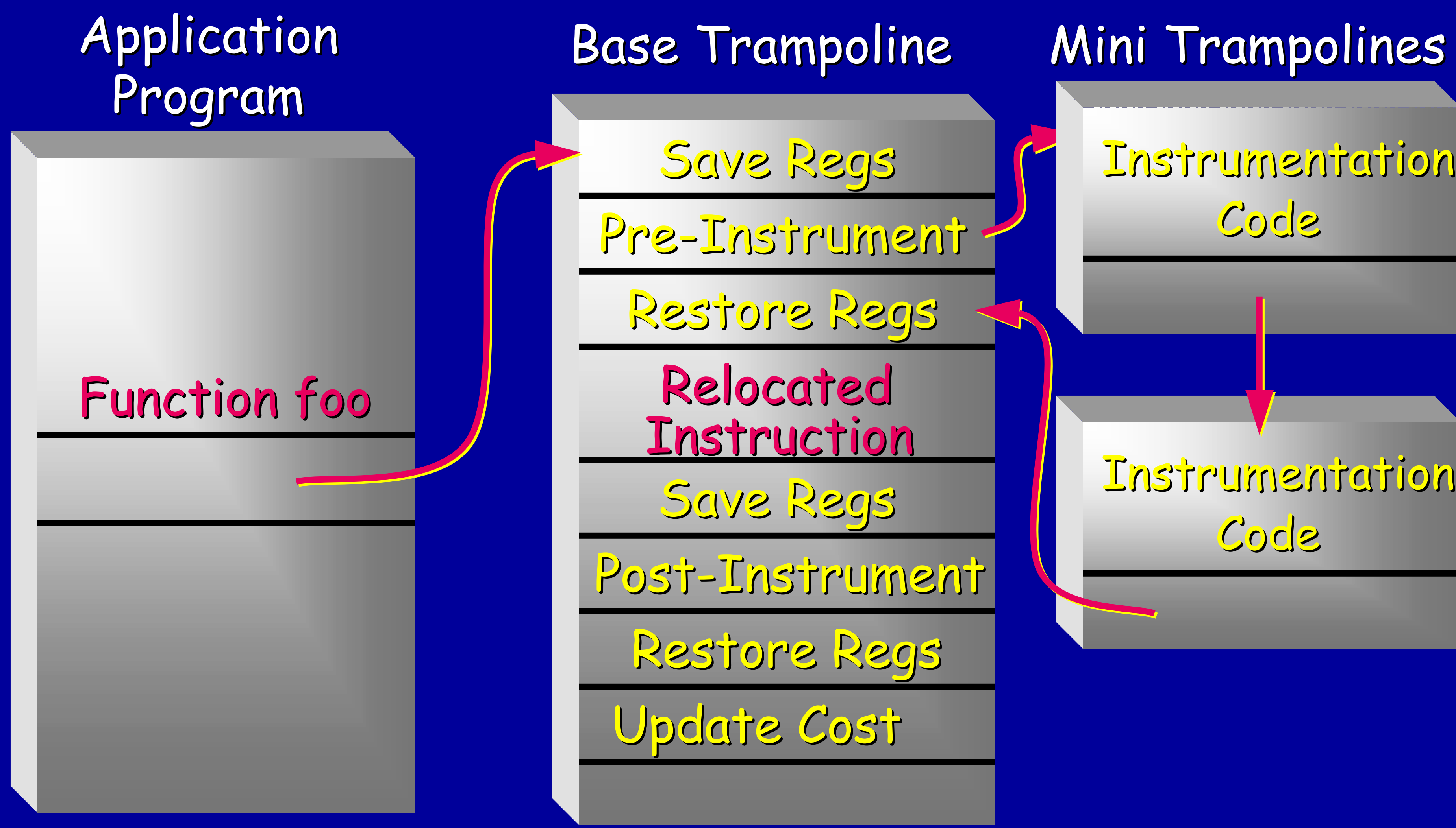
Dynamic Instrumentation Challenges

- Finding instrumentation points (function entry, exit, call site).
  - Procedure exit is 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.

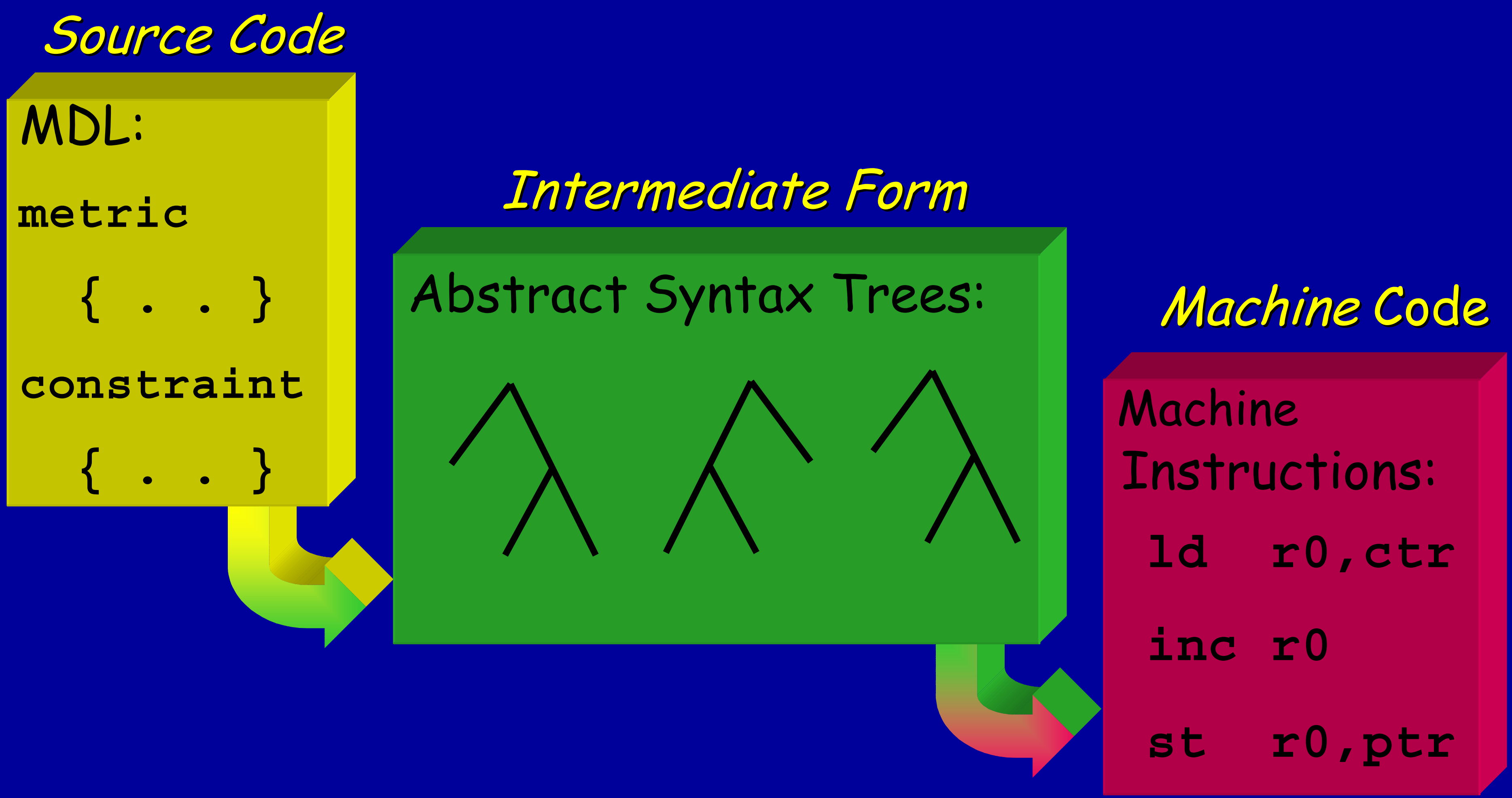
Dynamic Instrumentation Challenges (con'd)

- Compiler optimizations (we instrument 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
  - Multiple threads executing the same instrumentation code; very tricky!

Patching in Instrumentation

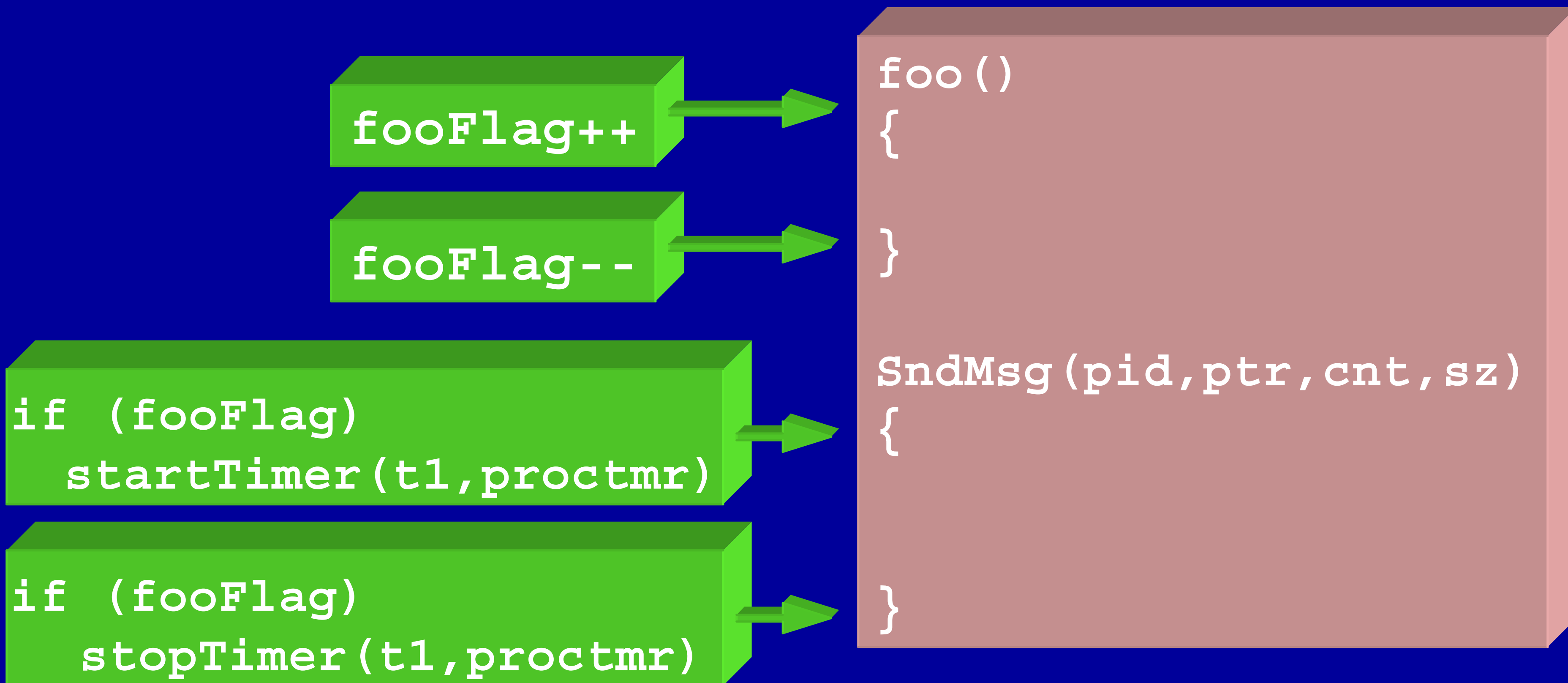


Compiling for Dynamic Instrumentation



Basic Instrumentation Operations

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



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.

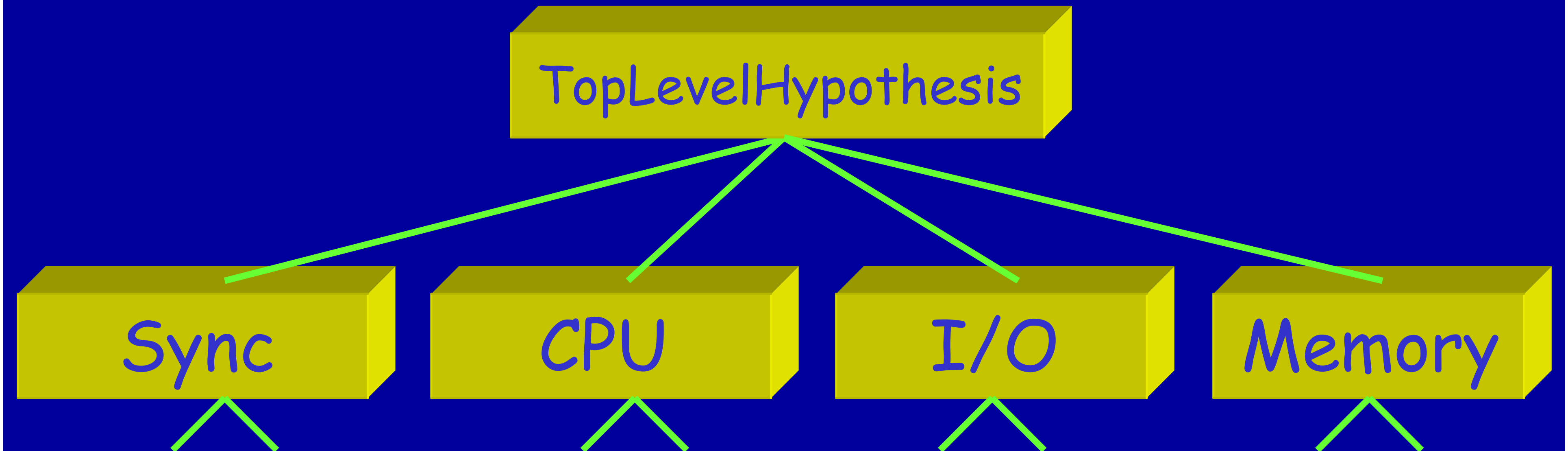
This makes it possible to automate the search for bottlenecks.

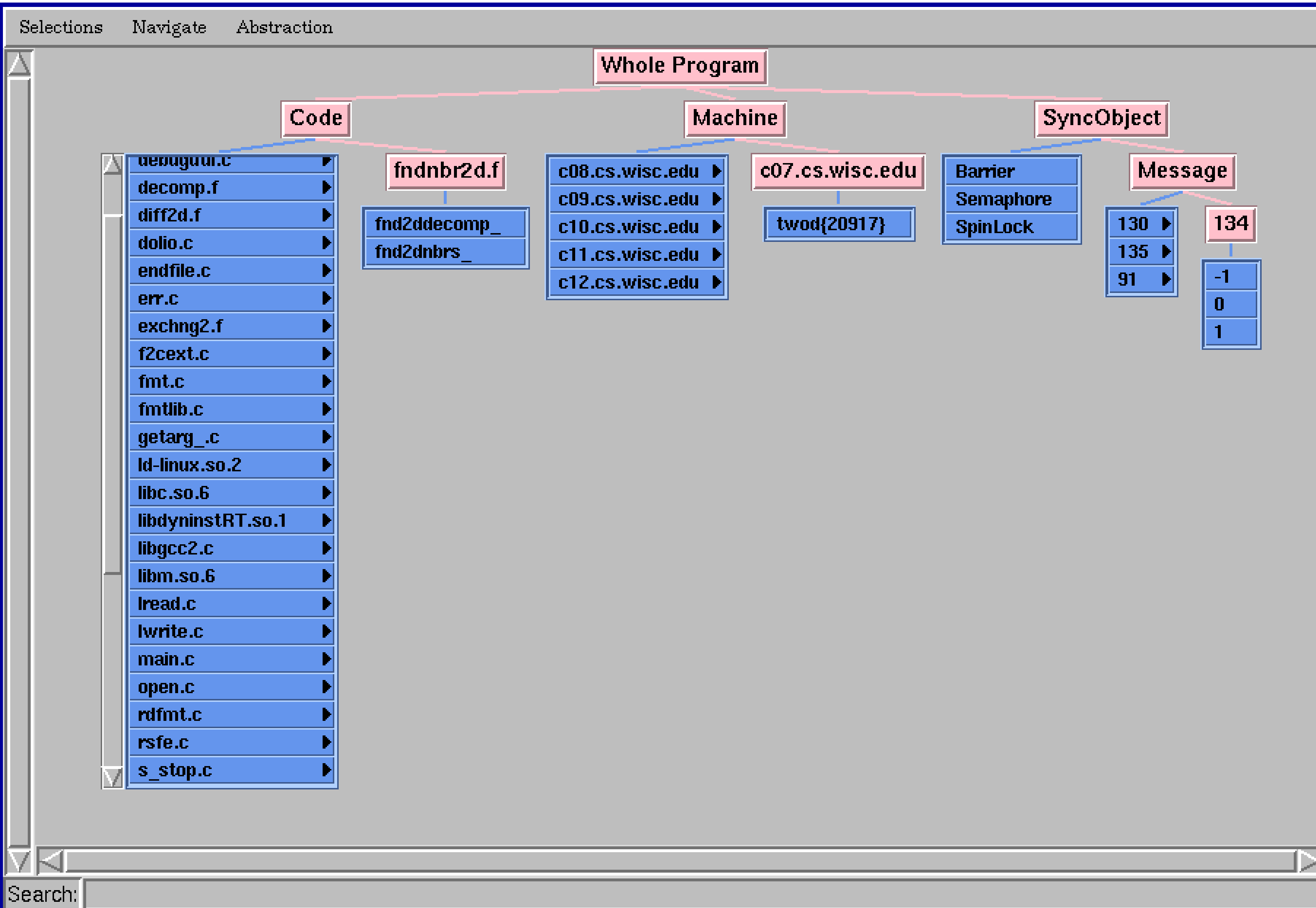
The "Why" Axis: A Hierarchy of Bottlenecks

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

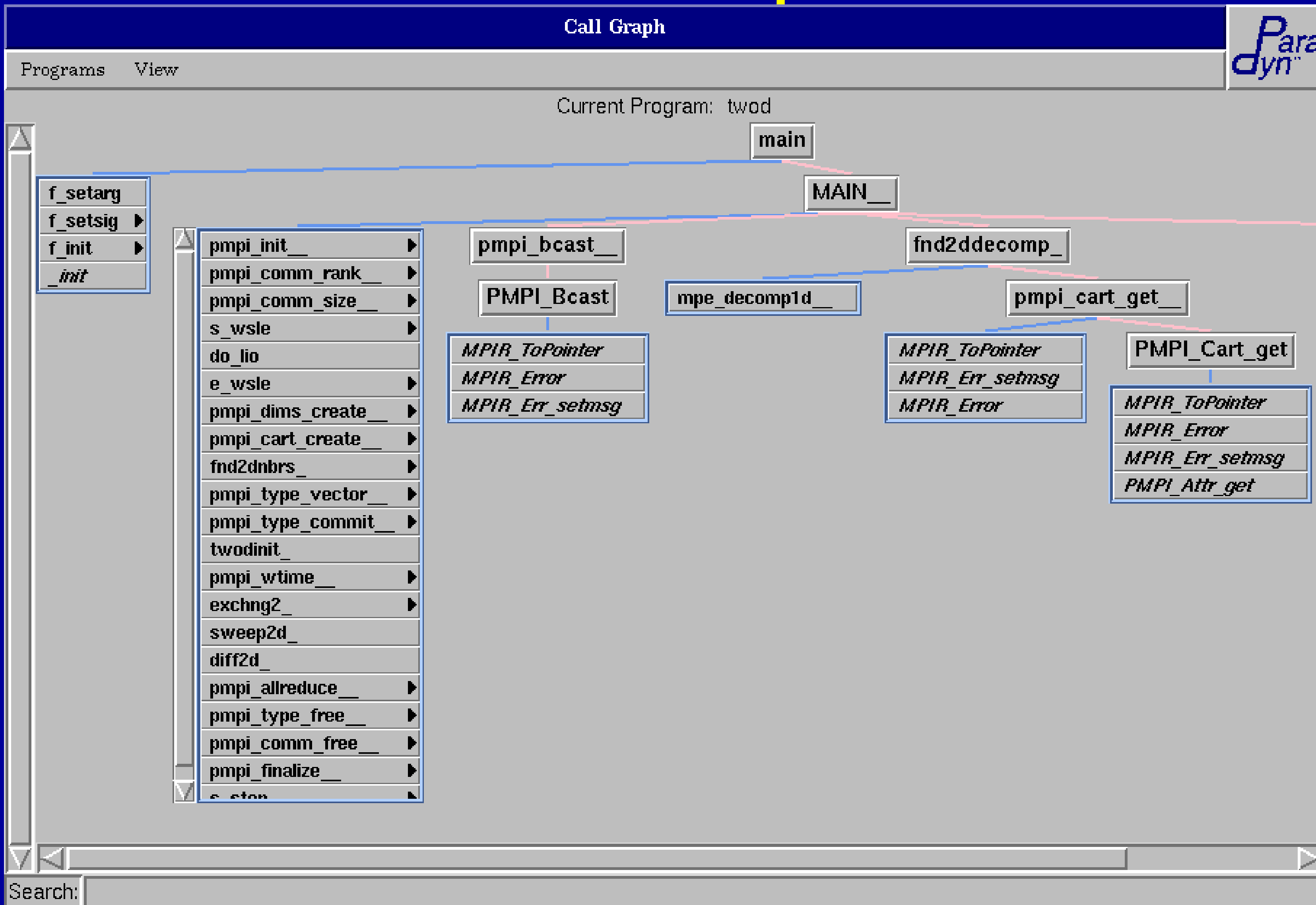
  Total sync blocking time < 25% of exec time

The "Why" Axis: A Hierarchy of Bottlenecks

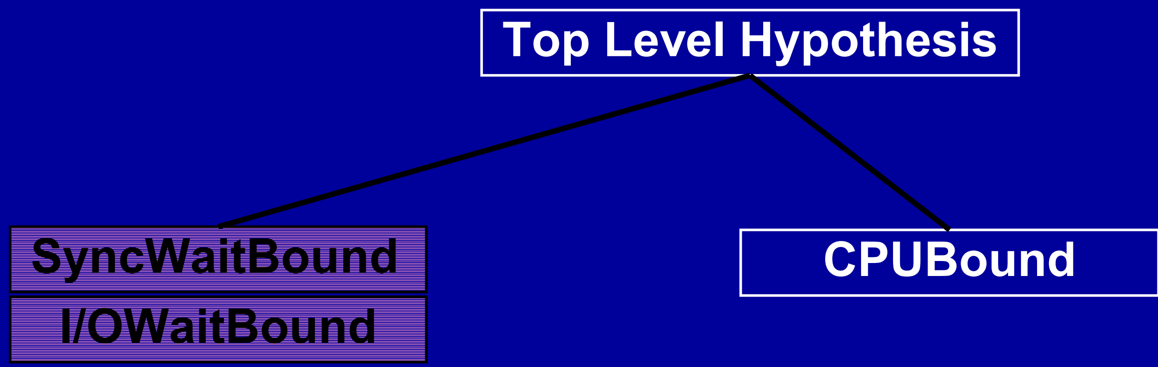



Selections
Navigate
Abstraction
Whole Program
Code
Machine
SyncObject
decomp.f
diff2d.f
dolio.c
endfile.c
err.c
exchng2.f
f2cext.c
fmt.c
fmtlib.c
getarg_.c
ld-linux.so.2
libc.so.6
libdyninstRT.so.1
libgcc2.c
libm.so.6
lread.c
lwrite.c
main.c
open.c
rdfmt.c
rsfe.c
s_stop.c
fndnbr2d.f
fnd2ddecomp_
fnd2dnbrs_
c08.cs.wisc.edu
c09.cs.wisc.edu
c10.cs.wisc.edu
c11.cs.wisc.edu
c12.cs.wisc.edu
c07.cs.wisc.edu
twod{20917}
Barrier
Semaphore
SpinLock
Message
130
135
91
134
-1
0
1
Search:

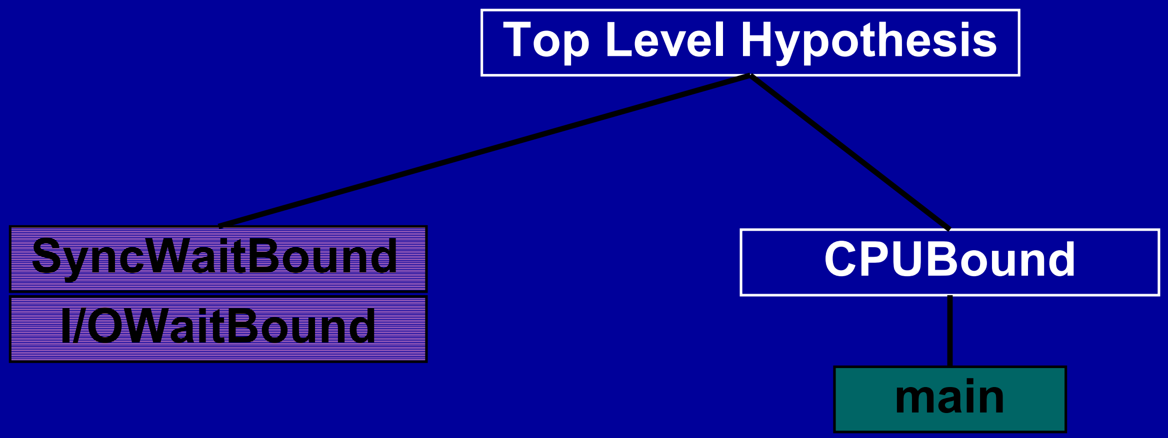
Call Graph


Call Graph
Programs
View
Current Program: twod
main
MAIN__
f_setarg
f_setsig
f_init
_init
pmpi_init__
pmpi_comm_rank__
pmpi_comm_size__
s_wsle
do_lio
e_wsle
pmpi_dims_create__
pmpi_cart_create__
fnd2dnbrs_
pmpi_type_vector__
pmpi_type_commit__
twodinit_
pmpi_wtime__
exchng2_
sweep2d_
diff2d_
pmpi_allreduce__
pmpi_type_free__
pmpi_comm_free__
pmpi_finalize__
pmpi_bcast__
PMPI_Bcast
MPIR_ToPointer
MPIR_Error
MPIR_Err_setmsg
mpe_decomp1d__
fnd2ddecomp_
pmpi_cart_get__
MPIR_ToPointer
MPIR_Err_setmsg
MPIR_Error
PMPI_Cart_get
MPIR_ToPointer
MPIR_Error
MPIR_Err_setmsg
PMPI_Attr_get
Search:

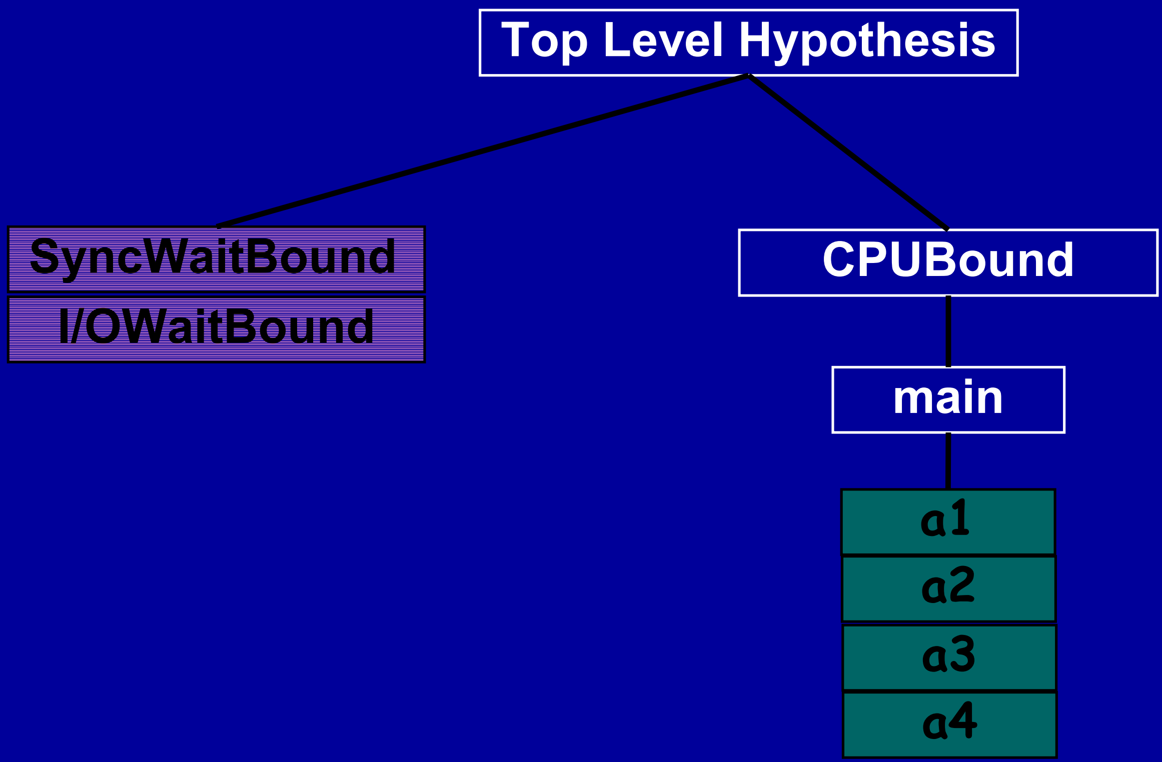
Call Graph Based PC Example



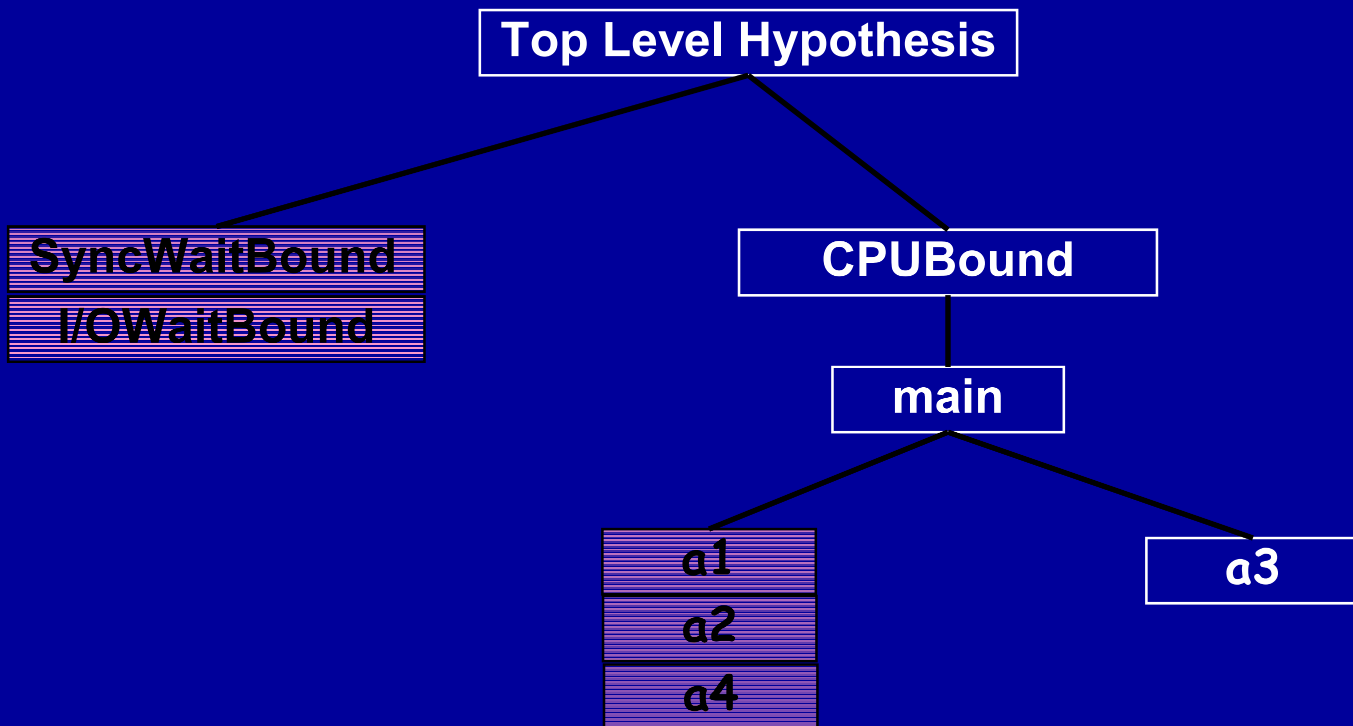
Call Graph Based PC Example



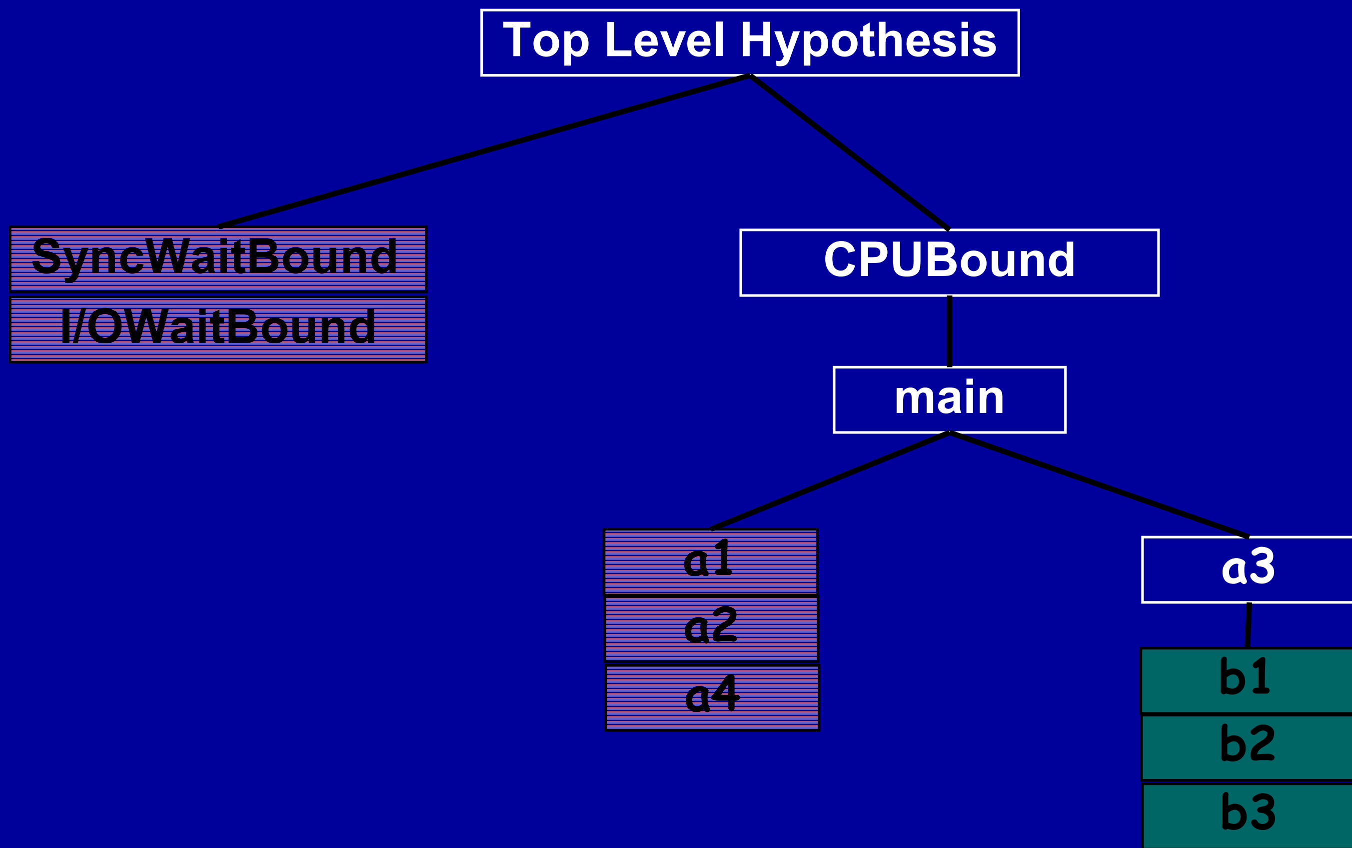
Call Graph Based PC Example



Call Graph Based PC Example



Call Graph Based PC Example



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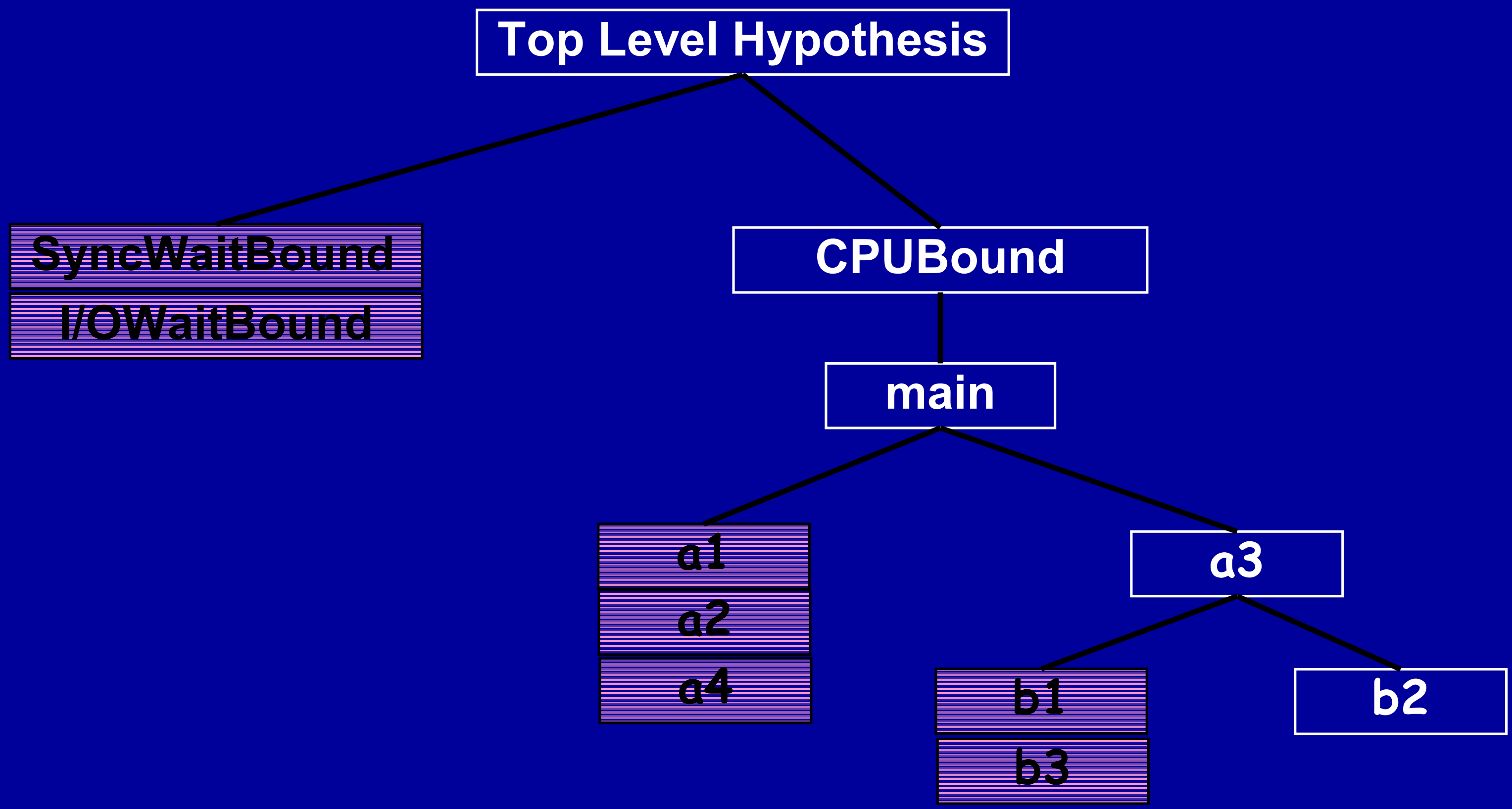
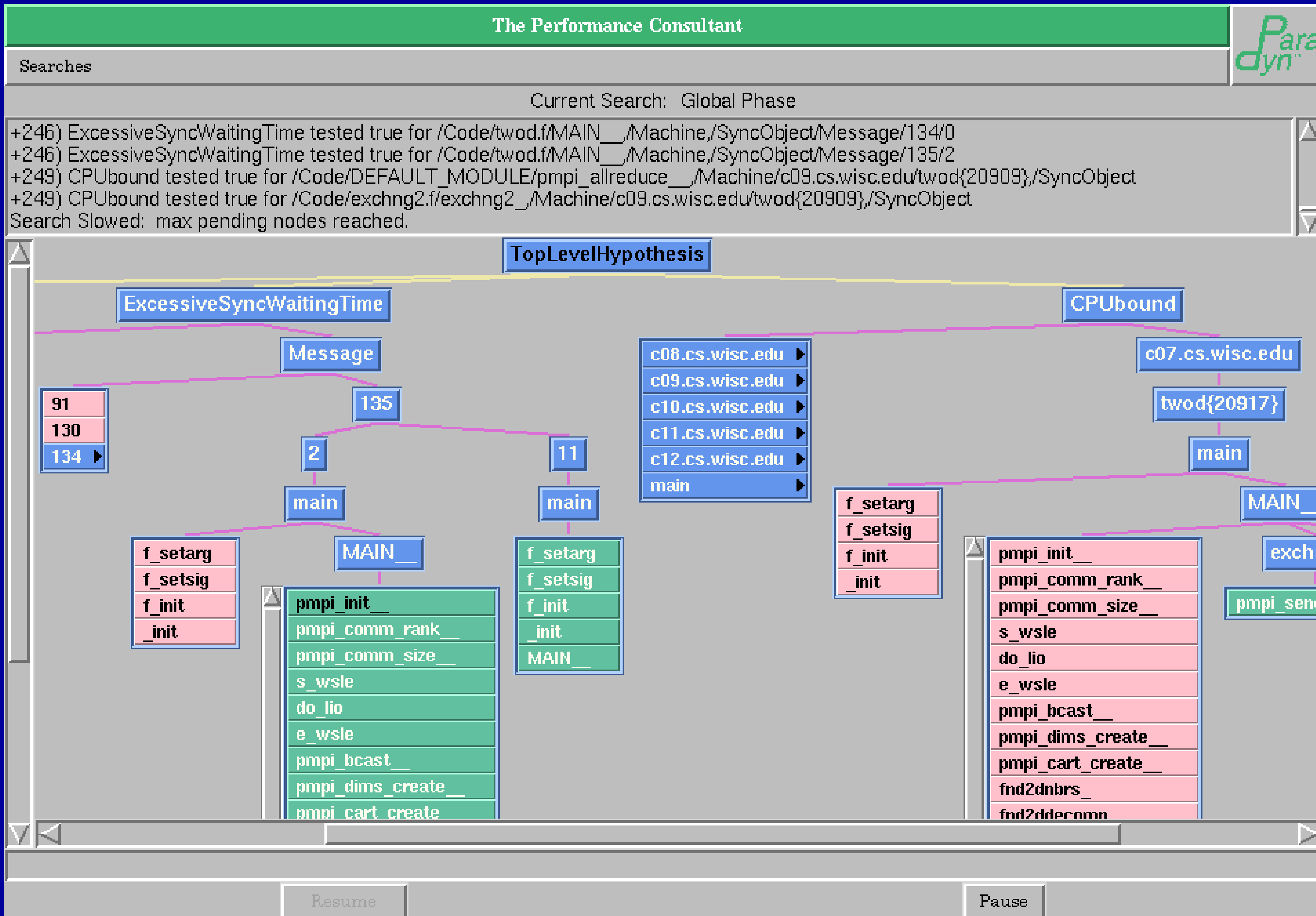


Performance Consultant (SHG)



Call Graph Construction

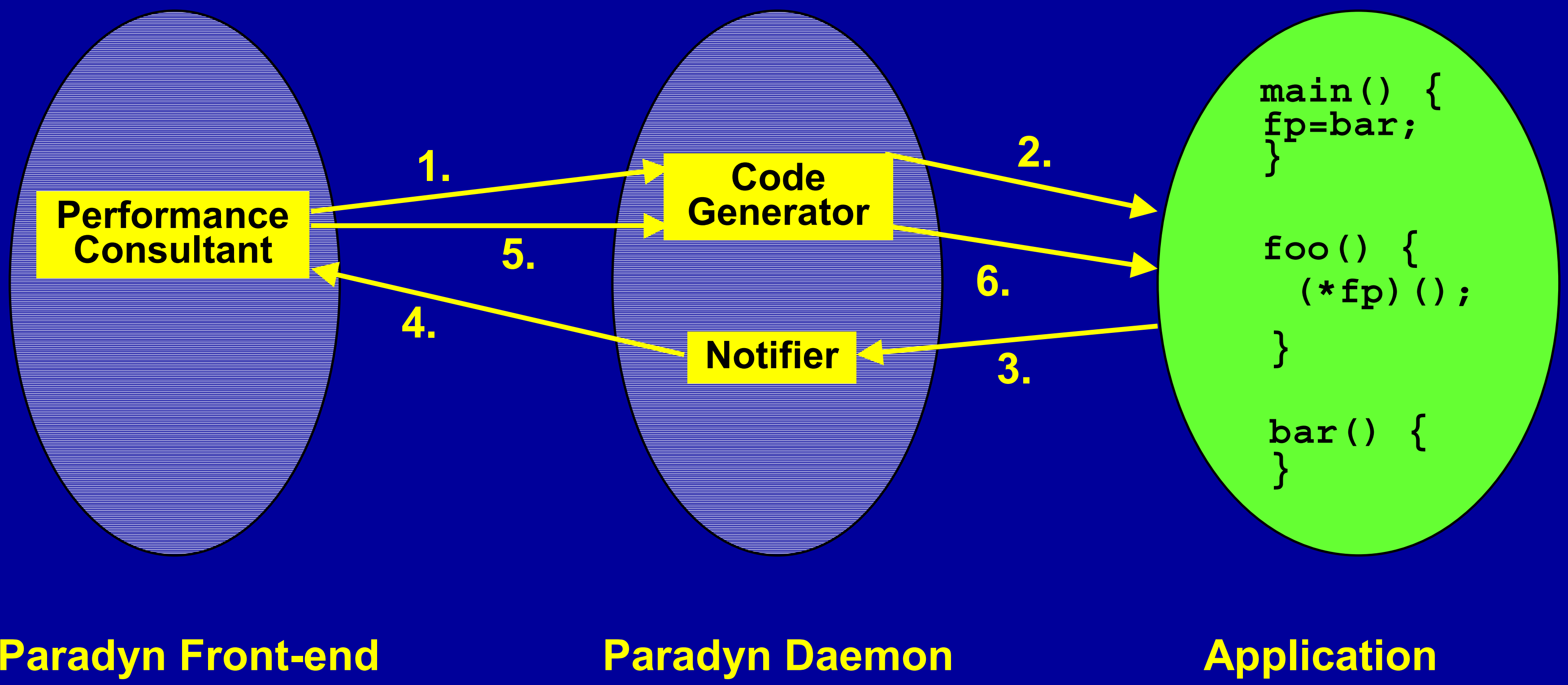
- Problem: targets of calls using function pointers and virtual functions are not statically determinable.
- Unknown callees in static call graph may cause blind spots in new PC search
- We resolve dynamic callee addresses at run time
- Strategy:
  - Build static call graph at program start
  - Fill in dynamic call graph on demand.

Dynamic Call Sites

- Characterized by keeping the address of a callee in a register or memory location
- New type of instrumentation necessary to determine callee
- Examples:

Instruction Set	Call Instruction
MIPS	`jalr $t9`
X86	`call [%edi]`

Call Site Instrumentation: Chain of Events



Controlling Instrumentation Cost

"What is the overhead of instrumentation?"

translates to:

"How many hypotheses do we evaluate at once?"

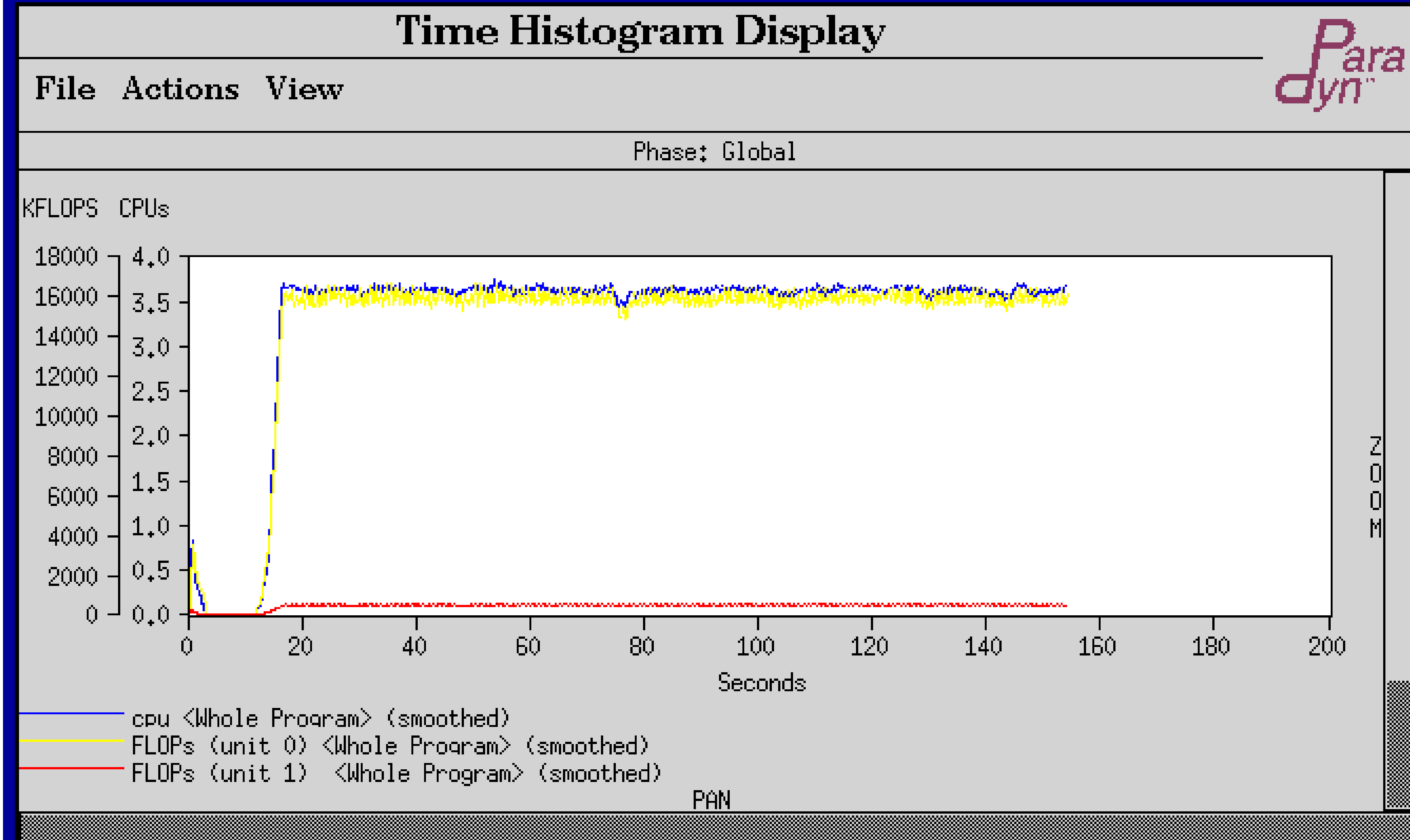
Predicted Cost:

- Known primitive cost
- Estimate frequency
- User-defined threshold

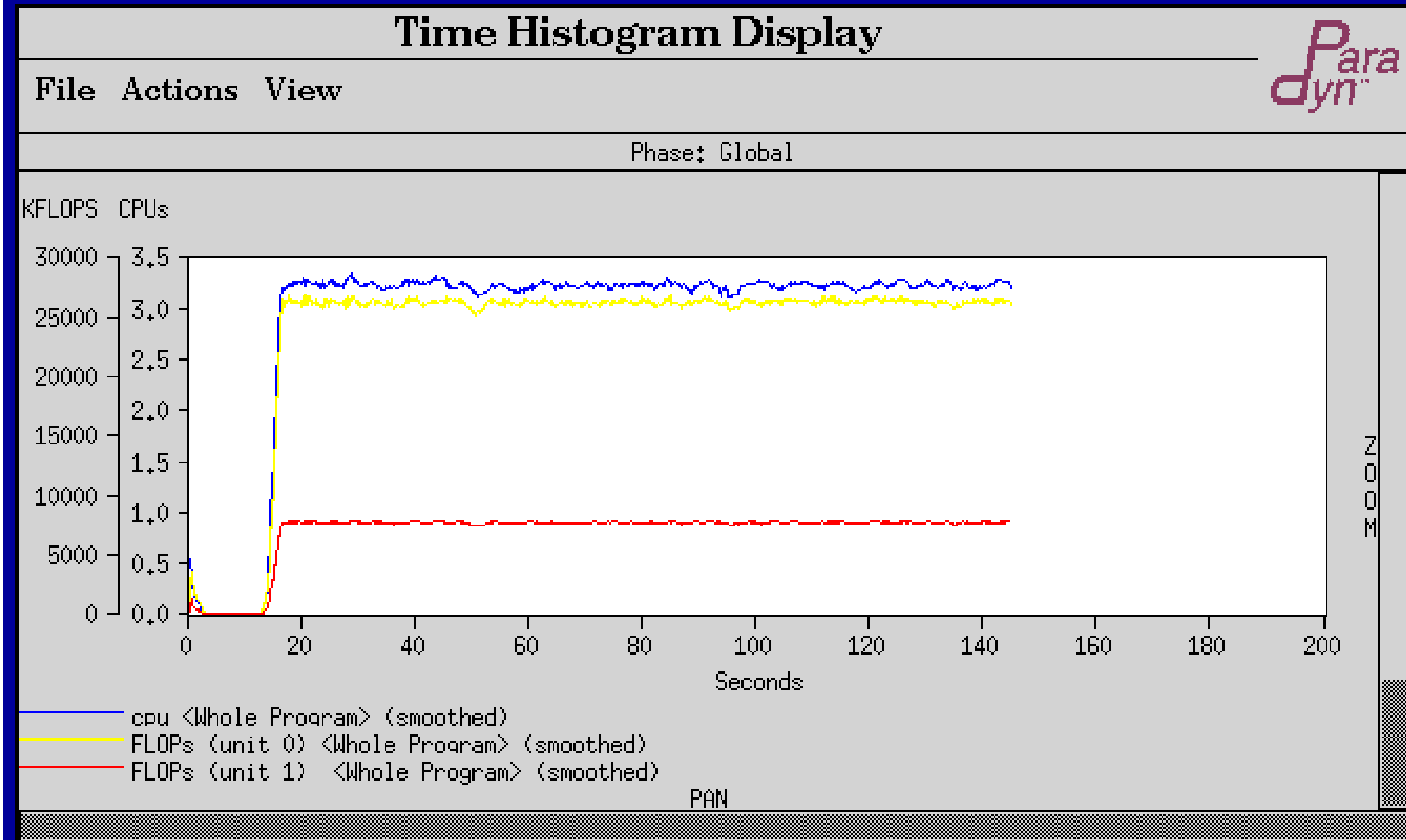
Observed Cost:

- Calculates actual cost
- Meta-instrumentation
- Reports to Performance Consultant

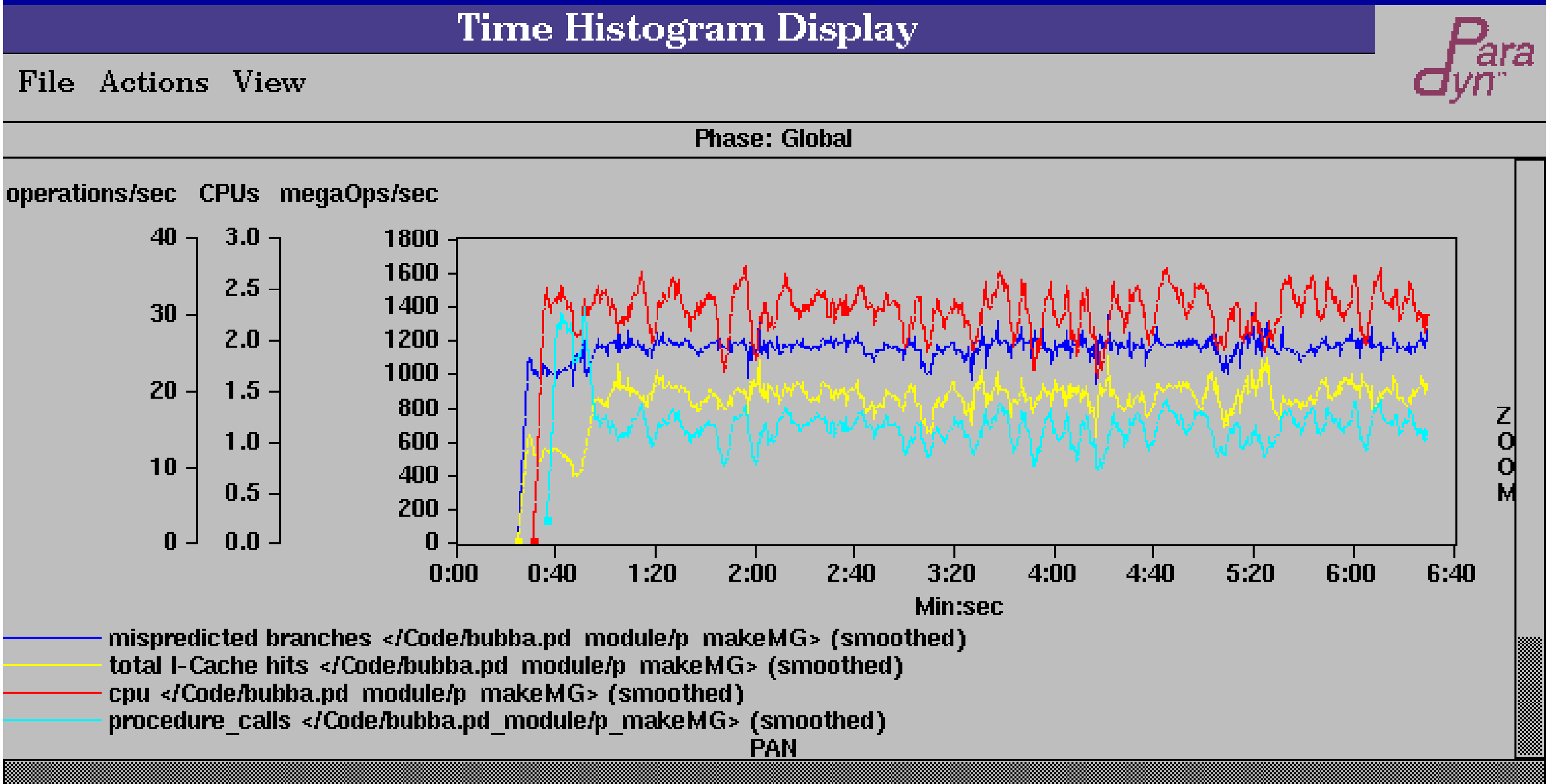
SP2 Hardware Perf Counters (gcc2.6.3)



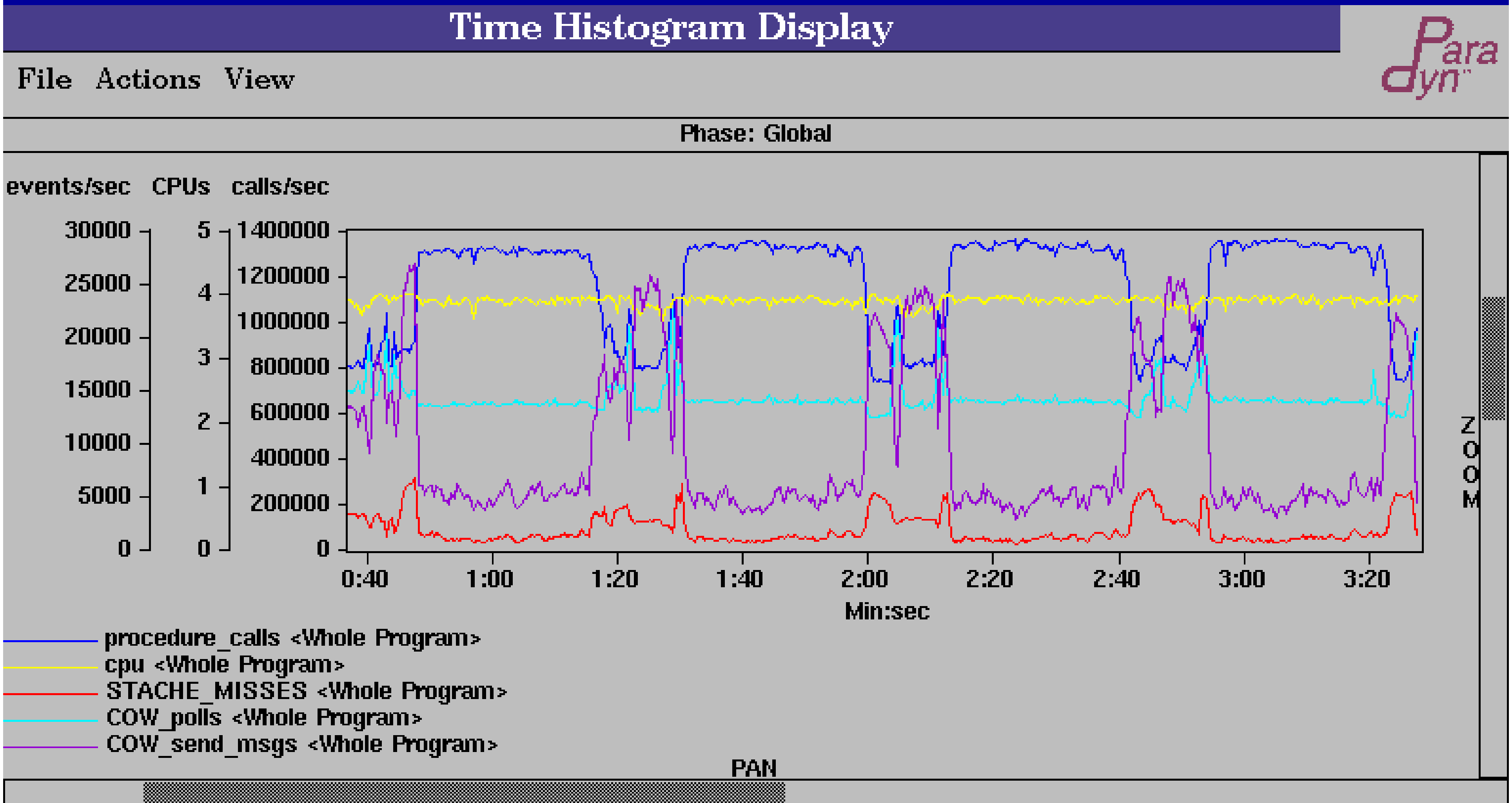
SP2 Hardware Perf Counters (IBM xlc)



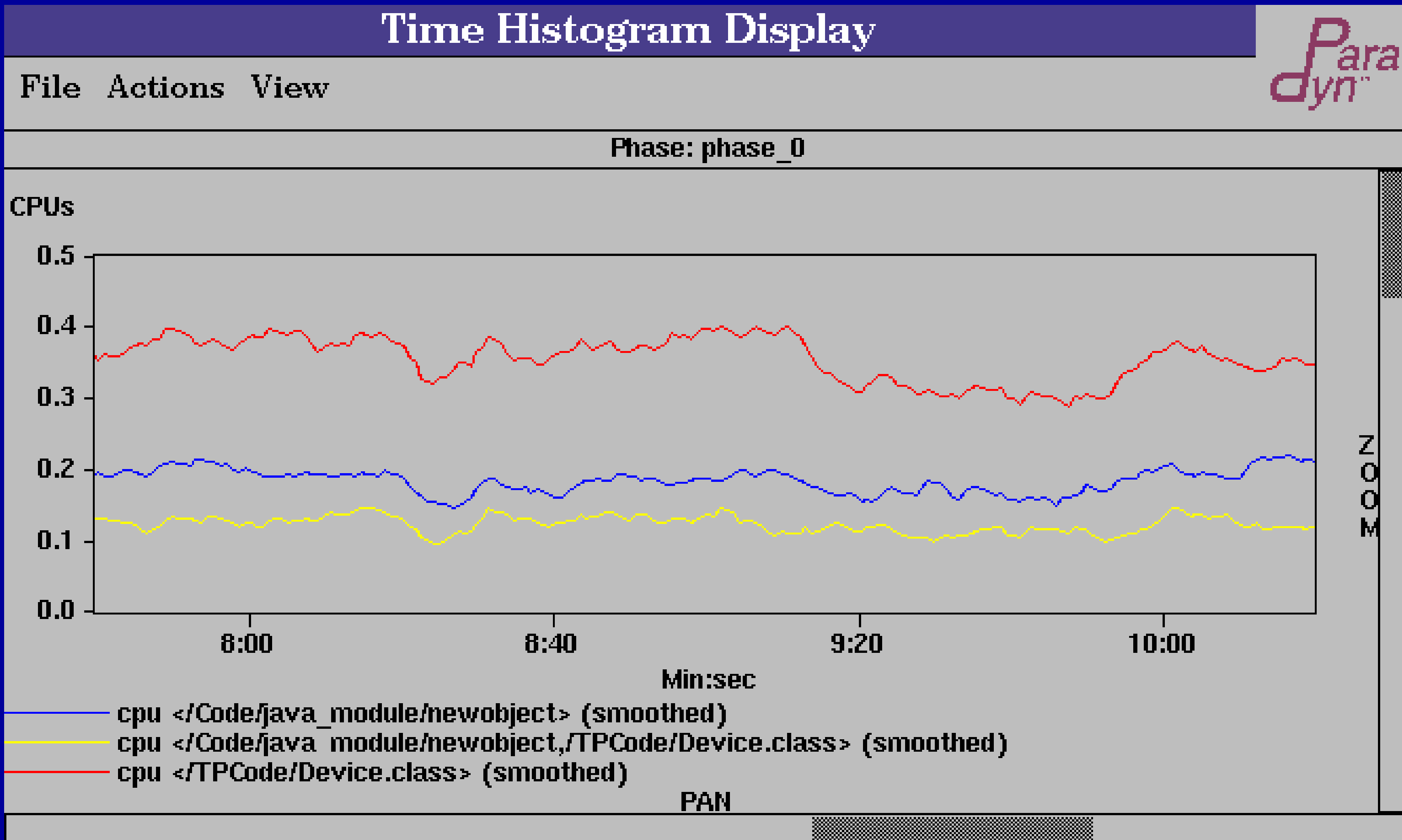
UltraSPARC Hardware Perf Counters



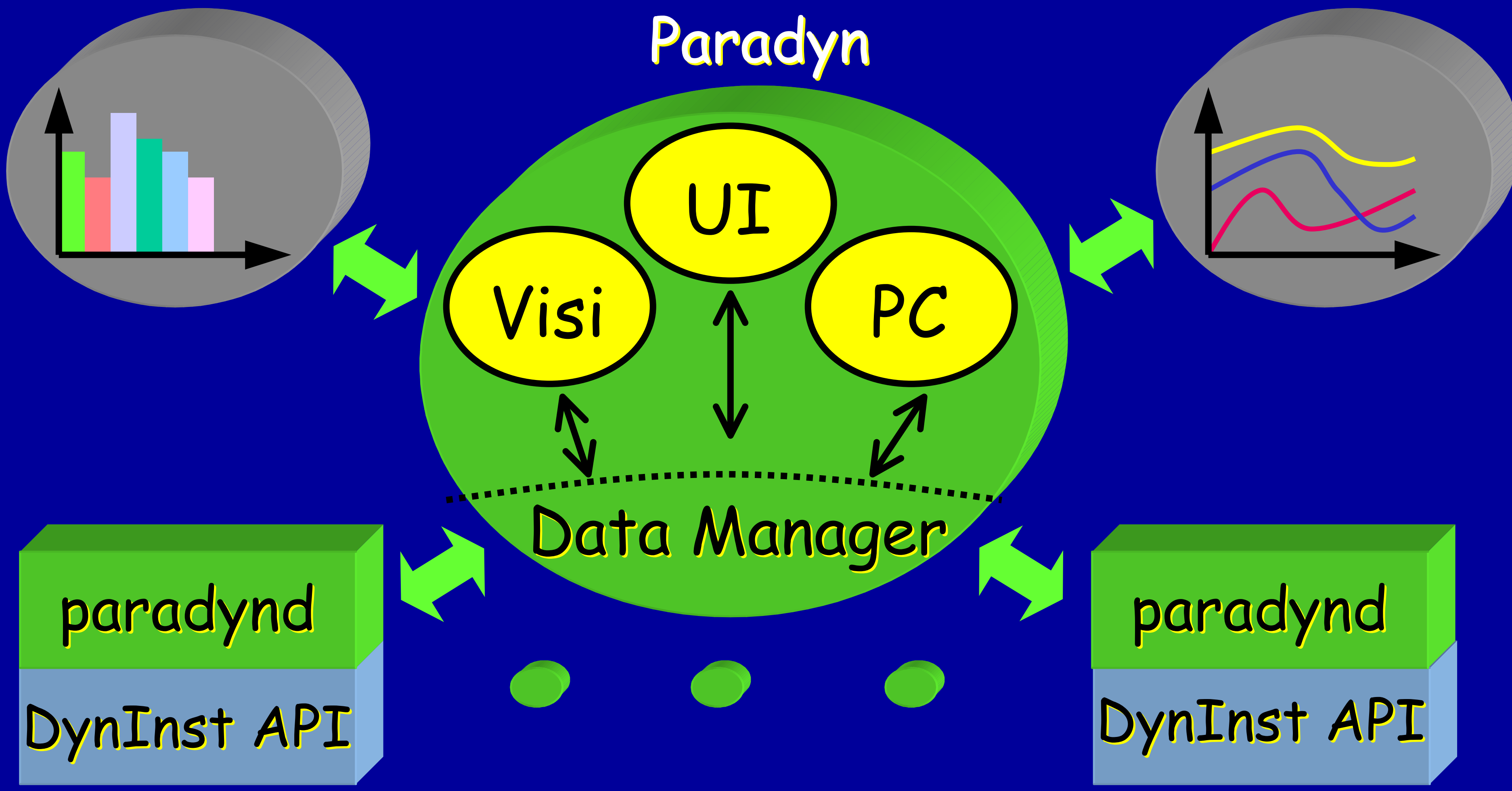
Paradyn Running on Blizzard/Cow (Barnes)



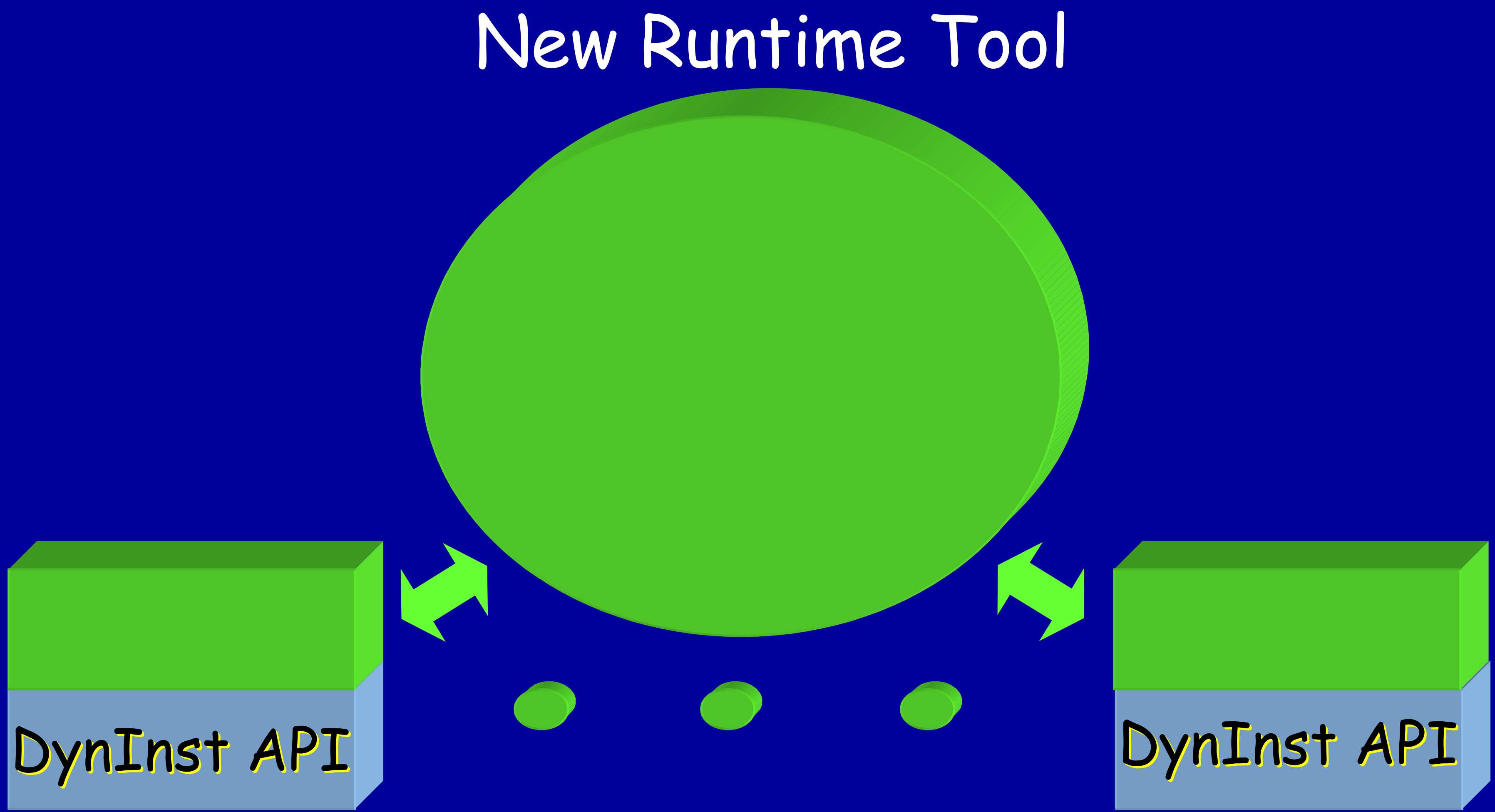
Java Application and VM Profiling



DynInst API: A Common Substrate



DynInst API: A Common Substrate



How to Get a Copy of Paradyn:

Release 3.0 (beta)

- Documentation: Installation Guide, Tutorial, Users Guide, Visi Programmers Guide, Libthread Programmers Guide, Developers Guide, MDL Programmers Guide.
- Free for research use.
- Runs on Solaris (SPARC & x86), NT (x86), Irix, AIX/SP2, Linux (x86), DEC Unix.

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

paradyn@cs.wisc.edu

MDL Example: Define Instrumentation Points

```
resource list pvm_sync_ops is procedure
  {
   items {"pvm_send", "pvm_recv"};
   flavor {pvm}
   library true:
}
```

MDL Example: Basic Metric Defn (Sync Wait)

```
metric P_syncWait {
  name "PVM SyncWait";
  units Seconds; unitStyle normalized;
  aggregateOperator agv;
  flavor {pvm}

  constraint functionConstraint;
  constraint moduleConstraint;
  constraint msgTagConstraint;
```

```
metric P_syncWait {
  base is wallTimer {
    foreach func in pvm_sync_ops{
    append preInsn func.entry
     constrained
     (*
       startWallTimer(p_syncWait);
    *)
    prepend postInsn func.entry
     constrained
     (*
    stopWallTimer(p_syncWait)
    *)
  }
}
```

```
constraint functionConstraint
  /Code/Module is counter {
   append preInsn $constraint.entry
      (* funcConstraint = 1; *)
   prepend postInsn $constraint.exit
      (* funcConstraint = 0; *)
   foreach callsite in $constraint.calls {
      append preInsn callsite
         (* funcConstraint = 0; *)
      prepend postInsn callsite
         (* funcConstraint = 1; *)
   }
}
```

```
constraint msgTagConstraint
  /SyncObject/MsgTag is counter {
   foreach func in pvm_sync_ops {
      append preInsn func.entry
       constrained
         (* if ($arg[1] == $constraint)
              msgTagConstraint = 1;
         *)
      prepend postInsn callsite
         (* msgTagConstraint = 0; *)
   }
}
```